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V. S. Ramachandran

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PERCEPTUAL DEVELOPMENT

Laura A. Thompson
New Mexico State University

Dominic W. Massaro
University of California at Santa Cruz

Glossary

Differentiation The active search for features of the environment that remain stable in a constantly changing world.

Distal stimulation Information about objects and events in the world which is incompletely specified by proximal stimulation.

Habituation The gradual waning of a response through repetitive stimulation. Dishabituation is a return to the original level of attentive responding.

Proximal stimulation The stimulation as it impinges on sensory receptors (e.g., the image produced in the visual system by a pattern of light).

HUMAN PERCEPTION involves the active pick-up and coordination of sensory information via sensory channels such as vision, hearing, and touch, in order to understand, act on, and react to the world around us. Perceptual abilities are present even before birth and show rapid development during early infancy. More gradual improvements in perceptual understanding occur during childhood. Recent research findings on infant perceptual abilities are abundant and have broad implications for the nativist/empiricist debate. In the present article, selected research findings are set in the context of different approaches to the question of "What develops?" in perception.

I. THEORETICAL APPROACHES AND LEVELS OF ANALYSIS

A. Theoretical Approaches

1. Ecological Perception Approach

In the field of perceptual development, data are gathered and findings are interpreted within a particular theoretical perspective. Researchers are often forced to adopt a perspective before beginning their studies, because the selection of both stimuli and methodologies depends on which theoretical perspective is adopted. One of the reasons perceptual development is so interesting then, is that, lying beneath the surface of any "wow!-look-what-that-tiny-baby-can-do" finding is at least one controversial topic concerning the origin and nature of human thought. In current research, this tension is perhaps most apparent between those studying infant perception using the psychophysical approach, and those using the ecological approach. [*See* ECOLOGICAL PSYCHOLOGY.]

To the ecological perceptionist, the newborn infant's natural environment offers her plenty of opportunities for active, exploratory perception of complex stimuli which are important for her survival and for her normal development as a human being. There is an assumed richness of structure to the infant's perceptual world, a structure that is either inborn or discovered when there is a purpose to this discovery. Most important to the infant's survival are human beings, who, in their caregiving activities, present stimulation in many perceptual dimensions simultaneously, by cuddling infants close, communicating with their voices and facial expressions, and giving them tasty nourishment. Human voices, faces, and movements are examples of especially meaningful patterns of perceptually complex configurational information. Research has shown that newborns seek out and favor these patterns over patterns which are not inherently human-like.

One of the more controversial aspects of the ecological approach regards the level of perceptual representation which is innately given and accessible to infants. J. J. Gibson's premise was that people perceive information about objects and events (distal stimulation) directly, without accessing the stimulation initially given to the cortex from the receptor systems (proximal stimulation). Thus, *affordances,* or meanings of objects and events, are not constructed out of the more sensory elements of experience. The relevant question developmentalists must ask is, how does the distal perceptual experience of objects and events develop? How do infants learn to differentiate those relations among stimulus features that remain stable across many different situations from those that are not constant? Alternatively, perception can be construed as a matter of activating internal objects and events that are innately determined through adaptive change in human evolution.

2. Psychophysical Approach

The psychophysicist's approach to understanding perceptual development is to begin by precisely measuring and manipulating the primitive elements composing objects and events, such as the wavelength or the intensity of sounds or light. Often, stimulation is presented to the infant in a manner that is highly artificial and unlike the version of stimulation presented by the real world. However, some researchers adopt this reductionist approach because of its potential for uncovering more parsimonious explanations for behavior. The psychophysical approach sometimes identifies simple stimulus variables contained within more complex stimuli which alone can be used by the infant perceptual system. With a focus on the minimal stimulation required for detection, localization, discrimination, or identification, much is revealed about the infant's impressive perceptual abilities under optimal circumstances. [*See* PSYCHOPHYSICS.]

3. Piagetian Approach

Jean Piaget's contributions to the field of perceptual development bear some resemblance to his influential theory of cognitive development. To Piaget, the young infant perceived fleeting images that did not extend across time and space. He claimed that there were many characteristics of infant and toddler intelligence that prevented them from perceiving the world as adults know it. First, he thought that the ability to represent (hold an image in the mind when an object is not present) did not emerge until late in the second year of life. Second, infants could only perceive these passive perceptions as they related to their perspective, that is, egocentrically. Third, perceptions and actions were independent processes, and gradually became coordinated. He also believed that vision, hearing, and touch began as independent perceptual experiences. After taking a long time to construct representations based on single modalities, Piaget thought that infants must learn to reconstruct their world to unify their previously separate perceptual experiences. And fourth, Piaget believed that perception was dependent on the cognitive abilities available to the child. For example, when a child matured enough to make perceptual comparisons by attending first to one stimulus dimension, and then another, perceptions could be "corrected" to be more like the adult form. Only gradually would children learn about object constancies, or be free of the deceptive influence of certain stimulus dimensions responsible for some visual illusions. [*See* COGNITIVE DEVELOPMENT.]

4. Information Processing Approach

The human anatomy that accomplishes perception is composed of living biological materials. The flow of information from the receptor surfaces through the nervous system is electrochemical, its structural and functional characteristics a culmination of tens of thousands of years of our species' biological adaptation to the ever-changing characteristics of the world. On the other hand, computer circuitry and the conductance of information from input to output or storage is electrical, not biological and not chemical. Yet, the analogy of the human as a computer-like system forms a productive approach to understanding perception and its development. Human perception is assumed to begin with the activity of taking in physical energy from the environment and subsequently translating the internalized input into an abstract code, that is, into objects and events we experience. People are like computers in that they are both fast symbol manipulation systems capable of operating at many levels in parallel.

Central to this approach is the distinction between information and information processing. *Information* is the code that is stored in long-term memory and it is also the code being accessed "on-line," that is prior to, and at the moment of, perceptual experience. Developmental change can occur in the representational code itself, due to neuroanatomical maturation, and also as a consequence of learning. *Information processing* is a descriptive analysis of what happens to the information as it flows through the perceptual and cognitive system. Developmental change can occur along several dimensions of information processing. One ubiquitous change involves the speed of information flow. As children mature, their faster information transmission rates allow for faster detection and recognition. Second, as children mature, they acquire knowledge. A third processing factor is apparent in developmental change in the efficiency of the selective attention mechanisms. Fourth, change occurs in the way information is segmented during perception. This factor is best understood using the example of learning to segment the stream of sounds in a second language. At first, the speech seems a continuous stream of unfamiliar sounds, and only after much intensive struggle are we able to parse the stream into meaningful words and phrases. Fifth, during the earliest moments of on-line processing, codes are transformed and integrated. These integration processes can undergo developmental change. Finally, there is developmental change in the strategies that are available to the child in directing attention to information that will ultimately result in veridical perceptual representations.

B. Multiple Levels of Analysis

1. Computational Theory Level

In 1982, David Marr outlined three levels of scientific understanding of information processing systems. At the highest level, the level of computational theory, scientific inquiry is focused on the problems needed to be solved by perceptual systems. Questions can be phrased in terms of needs, goals, and tasks. What does a person need to perceive to survive and, by surviving, what genetic codes and their behavioral manifestations are passed on to the next generation? What immediate goals is the individual attempting to fulfill by performing mental transformations on representations? How can information and information processing be better understood by looking at the physical laws of nature constraining the structural characteristics and behavior of objects and events humans perceive? The ecological perceptionist approach is aimed at undestanding perception at this level.

2. Representation and Algorithm Level

Marr recognized that the information-processing approach derives an understanding of perception at the level of representation and algorithm. The main questions asked about perception are, as Marr states, "How can this computational theory be implemented? In particular, what is the representation for the input and output, and what is the algorithm for the transformation?" Many different types of representations and many different algorithms often tie for first place in the competition for the best theoretical explanation. Some theoreticians argue that there is as yet no justifiable method for determining the most accurate description of representations nor the algorithms relating sensory inputs to more abstract representational codes. The ecological perceptionist approach to studying infant perceptual development, with its nonconstructivist claims, seems to deny this level. However, the more gradual changes occurring through perceptual learning beyond infancy are viewed within the representational and algorithmic level of inquiry.

3. Hardware Implementation Level

In human vision, the eye, retinal ganglion cells, lateral geniculate neurons, and the neurons in the occipital lobe of the cortex together constitute most of the hardware of the visual system. Scientific inquiry at this level is focused on understanding their physiological and anatomical features. Development at this level can be shown to influence perception in infancy. However, as Marr warns us, ". . . trying to understand perception by studying only neurons is like trying to understand bird flight by studying only feathers: It just cannot be done. In order to understand bird flight, we have to understand aerodynamics; only then do the structure of features and the different shapes of birds' wings make sense." Thus, the most complete understanding of perceptual developmental change and stability is attained through consideration of factors affecting human information-processing systems at all three levels of scientific inquiry.

II. DOMAINS OF PERCEPTUAL PROCESSING IN INFANCY

A. Visual Perception

1. Perceptual Guidance System

Imagine for a moment that you had survived a horrible accident, yet were left completely paralyzed. Your legs could no longer transport you, your arms could no longer reach, your hands could no longer hold, your neck could no longer change your visual or auditory perspective. Without the ability to move, you would have minimal control over the stimulation available to your perceptual system. You would still have attentional control in that you could choose to "tune in" and out as you desire, but you would be at the mercy of the environment in offering you continual perceptual stimulation. This example illustrates the importance of action in perception. There is a dynamic interplay between perception and action such that they are entirely dependent on each other. For instance, muscle and joint movements are controlled by optical flow patterns interpreted by our perceptual systems which, in turn, guide action. Growth and development of the human system for action thus greatly affects our perceptual experiences.

Bennett Bertenthal recently proposed that infants are born with two distinct perceptual systems; one functions as a self-guidance system, the other functions to acquire and represent information about objects and events. To use shorthand, they can be referred to as the "where" and the "what" systems, respectively. Bertenthal claims that the two systems can be distinguished by their different courses of maturation and development. The what and where systems are also distinguishable by three processing differences. First, unlike the what system, the where system does not access fixed representational codes for objects. It does not need to look backward, because its purpose is to control bodily movements in the here-and-now, and to gather information so that movements can be planned ahead. Second, codes are accessed in both systems; however, the nature of the representational code is different. The what system uses representations that have been stored in a rather permanent, immutable form. Conversely, the where system uses representations that are continuously altered during the process of self-guidance and control. The third difference relates to the role of awareness. The control of perceptually guided action can often be attained without any conscious awareness, such as when you run along a desert path unconsciously leaping over rocks and dodging thorny bushes because you have your mind on last night's movie. However, conscious attention to the details of objects and events is a necessary component of perception for later successful discrimination or recognition (e.g., "Was that a rattle on the end of that snake's tail?").

There is much research evidence supporting the existence of a rudimentary perceptual guidance system in newborn infants, a system that is at first dependent on reflexive movements for looking, turning the head, sucking, and grasping. As Piaget so carefully demonstrated, these initially reflexive actions become more finely tuned, and the reflexes become coupled with greater accuracy and intentionality as the infant matures. However, Piaget's claim that perception and action are independent and uncoordinated in infancy does not appear to be correct. At birth, for example, infants orient in the general direction of a sound. Newborns track moving objects and even attempt to reach for objects that are moving slowly. Undeniably, the perceptual guidance system undergoes considerable tuning in the early months of life. Tracking is performed with greater ease as infants learn to stabilize the head. Between 8 and 24 weeks of age, there is dramatic improvement in the ability to detect the direction that a sound is coming from, and to orient to the sound source. Within their first 6 months, they will be engaging their adult caregivers in "conversation" by taking turns in a babbling, cooing, "do-se-do," a perceptually guided language game with two players who want to have fun.

The link between visual perception and action in infancy is clearly demonstrated using an apparatus called the "moving room." An infant sits on the nonmoving floor of the apparatus while the walls and ceiling move in a way that the visual information would appear to move if he were actually falling. Many studies have shown that infants make compensatory postural movements of the head and trunk in response to this simulated visual flow information.

Development of locomotor ability affects the frame of reference used by infants in coding the locations of objects. Prior to crawling, an infant uses a spatial frame of reference which is centered on his own body. That is, the positions of objects are marked in relationship to where he is lying or sitting. While this method of spatial referencing may be adequate for the prelocomotor infant whose relevant world is contained within his nearby radius, he learns that it is not a reliable method once he is able to change his position in the environment on his own. For mobile infants, a nonegocentric (landmark) method of coding ensures that he can find the locations of objects when the spatial relationship between himself and the object have changed positions since he first encoded its location. Bertenthal tested two groups of infants who were of the same age, but some could crawl and some had not yet begun to crawl. An object was placed under one of two containers on a table, located on either the infant's right or left side. Then, the infant was moved 180°, to the opposite side of the table. They found that infants who had learned to crawl were much more likely to search for the object under the correct container than noncrawling infants. [*See* MOTOR DEVELOPMENT.]

Research has shown that infant action can also be directed by proprioceptive information, since glowing and sounding objects are successfully touched in the dark. Blind babies have been found to use echolocation in navigating around a room. Thus, vision is not the only perceptual modality that infants can use in guiding their actions. However, in the sunlit environment where we usually find ourselves, our visual system is the most dependable source of information for getting us to where we are going. An infant does not see the world exactly as we see it, but her perceptual exploratory system is matched to the demands of her environment. [*See* VISUAL PERCEPTION.]

2. Visual Object Recognition

Research conducted in the last two decades has revealed a number of immaturities in the newborn infant oculomotor system that together conspire to make it difficult for them to fixate on objects. Pupil dilation, the adjustment power of the lens, and muscular coordination of the eyes when fixating on objects at different distances all improve within the first few months after birth. Using sophisticated methods of testing, such as the corneal reflection method, three types of eye movements have been documented in infants by the age of 2 months: (a) infants make saccadic eyemovements toward a stationary target, but they usually undershoot it, (b) infants track a slowly moving object but they have difficulty keeping up with it, and (c) infants sometimes show an ability to make stabilizing eye movements, that is, they alternately use smooth and rapid eye movements when looking at something that interests them. Three additional maturational changes occur in the neuroanatomical system for vision. Retinal cells migrate along the receptor surface, potentially altering the mapping of spatial codes represented by the brain. The cone photopigments in the retina responsible for perceiving short (blue) wavelengths of light may not be fully developed until 3 months (although the other two photopigments are present at birth). Finally, as neuronal axons develop myelin sheaths during infancy, the speed of neural transmission becomes markedly faster. Thus, newborns develop rapidly at the level of hardware implementation.

Newborn infants cannot name the letters on the eyechart, but if they could, their acuity of between 20/200 and 20/600 would indicate the need for very thick lenses. In the first half year of life there is a substantial increase in spatial resolution, measured by the infant's ability to detect smaller and smaller black and white rings in a bullseye pattern. At birth, their contrast sensitivity, the ability to detect differences in brightness intensity between adjacent black and white rings, is approximately 1/10th of that measured in adults. These findings imply that great amounts of contrast in visual patterns are needed for the visual information to reach "decision centers" in the visual cortex. It is not coincidental that the types of patterns newborns fixate on are patterns with angles, edges, and high contrast.

The "externality effect" is an interesting and robust finding in newborn infants. Infants are shown a simple pattern, such as an outline of a square with a smaller square inside it. They are shown the pattern long enough to become habituated to it, in other words, to get bored with it. Habituation is indicated when, for example, sucking slows down to a slow and steady rate. When the inside square of the pattern is changed, 1-month-old infants do not dishabituate to the pattern unless the pattern moves. Four-month-old infants do notice a change in the internal elements of the pattern, even when the pattern is stationary. The newborn infant's predisposition to focus on high contrast areas of a two-dimensional picture, combined with the finding that he does not notice internal elements of a display unless the elements move, can help to explain why he seems to focus on the hairline of his caregiver's face and does not seem to make eye contact until the person holding him speaks.

Human faces have a special place in the visual world of an infant. At birth, infants will track moving schematic illustrations of faces further than faces with the same features in mixed-up positions (nose where the mouth should be, etc.). At 3 months, they show a preference for looking at nonmoving face patterns over "scrambled" face patterns. At this age, they can discriminate familiar faces from faces they have never seen before. Three months later, they are capable of recognizing faces from a different angle of orientation than their initial view of the picture. Also at 6 months, infants can classify photos by gender, and they even look longer at photos of faces that have been rated as attractive by adults, compared to unattractive faces. Across their first half year of life, increasingly realistic presentations of facial stimuli are required to capture and maintain their attention. [*See* FACE RECOGNITION.]

The environment of humans is a constantly changing one. As the sun rises and sets, the intensity of light reaching the eye changes. As people and objects move around us and as we move around them, their retinal images change size and shape. Yet, adults translate these varying forms of proximal stimulation into stable distal perceptions. This stable perception is called *constancy*. Do young infants have color, shape, and size constancy? There is some evidence that shape constancy exists in newborn infants. After habituating to a square, for example, 6-day-old infants dishabituate to a trapezoid, but not to a square that is rotated 90° from its original orientation along the frontal plane. Shape constancy does not hold for objects rotated in depth, however. Color and size constancy do not emerge until approximately 4 months of age. In one experimental test of size constancy, infants first habituated to a large mannequin head positioned 60 cm from their eyes. Then, they were tested in two different conditions to see if they would dishabituate. In one condition, the same large mannequin head was shown 30 cm from their eyes, which would produce a much larger retinal image (and would appear to an adult as the same object now closer). In the other condition, a smaller version of the mannequin was presented at the distance of 30 cm, so that the retinal image was the same as the mannequin at the 60 cm distance. Infants dishabituated to the smaller of the two mannequins, but not to the original mannequin brought closer, which shows that they have size constancy.

Information about depth is available from three sources, and is used by the infant at different points in her development. One source is kinetic information. Kinetic depth cues exist because velocities of objects change as they change location in depth and as the body changes location in space. Kinetic depth cues are used by 3-month-old infants. Infants will make eyeblink and startle responses when objects in space appear to loom toward them. Interestingly, they do not make these avoidance responses for the reversed form of this kinetic information, called "zooming" stimuli. A second source, available about 1 month later, is retinal disparity. Objects that are close to us create two separate retinal projections that are fused into a single, three-dimensional representation of the world. Infants adjust their reach to grab for the nearer of two objects when they are able to use both eyes. Binocular cues to depth are not always needed for depth perception, however. Six-month-old infants will avoid the deep side of a "visual cliff" when they are wearing an eye patch over one eye. In this case, infants use a third source, pictorial depth cues. Pictorial depth cues are the cues that artists use to create the impression of depth on a two-dimensional surface. They include texture gradients (objects far away have finer-grained textures than nearer objects), interposition (objects farther away are occluded by nearer objects), linear perspective (painting a trapezoid shape "up" the canvas to give the impression of a road projecting into depth), and shading. By the age of about 6 months, she can use all three sources of depth cues to help prevent her from falling off the bed, down the stairway, or even into the Grand Canyon. [*See* DEPTH PERCEPTION.]

Pictorial cues also provide information about the boundaries of objects; however, these cues would not be very useful to us if we had never learned to associate them with objects. Picture a small baby who is looking at the trunk of a tree. On the tree trunk is a very still moth. We know that moths have wings, they tend to be flat and their coloring usually camouflages them against the tree trunk. If an adult looked at the exact location on the tree, he might spot the moth but the baby would not, that is, not until the moth flies away. The 5-month-old infant knows that gaps between surfaces usually imply that those surfaces form the boundaries of different objects. If the surfaces of two objects touch, however, even if they are composed of very different colors and textures, they will perceive the two objects as one. Clever experiments have shown that young infants will reach for the closer of two objects if they are separated by a gap, although if the surfaces are touching, they reach for the further surface if it looks more "graspable."

Common motion of object surfaces is a dependable cue that parts belong to a whole, even if segments of the whole are occluded by the surfaces of other objects. Elizabeth Spelke and her colleagues tested 4-month-old infants in an experiment where they were shown a rod directly behind a rectangular block, the rod's surfaces protruding above and below it. When the rod parts touched the block and when they moved in the same direction and rate with each other and with the block, infants handled the rod and block as if they were one object. When the upper and lower parts of the rod moved in synchrony but the block remained stationary, they behaved as though the rod and block were distinct, by reaching for only one of them. When the upper and lower parts of the rod moved in different directions, they treated them as separate objects. A recent and related experiment showed that 3-month-old infants looked longer at a conically shaped object whose top half broke apart from the bottom and rose into the air, compared to when the entire object rose. [*See* Visual Motion Perception.]

These findings and many similar ones led Spelke to the conclusion that young infants' perceptions of objects are guided by two processing constraints. The principle of cohesion is an understanding that *surfaces lie on a single object if and only if they are connected.* The principle of contact also helps them identify objects because they understand that *surfaces move together if and only if they are in contact.* A new area of research involves an attempt to determine if the perception of object motion is guided by a set of constraints based on the laws of kinematic geometry. The physical laws of nature governing object motion have not changed across human evolution; therefore, the visual system *may* be setup such that, at birth, the infant does not have to learn to predict object motion.

People form a special class of objects in motion. An extensive series of studies performed by Bertenthal and a colleague, Jeannine Pinto, shows that infants discriminate human walking (biological) motion from nonbiological motion. Their method for testing is to present two types of visual displays of points of light to the infant. Figure 1 illustrates the two types of displays shown to infants. In the canonical condition, the motion of the lights corresponds to the way they would move if they were attached to a walking person's head and joints, such as the knee and elbow. In a separate condition, the temporal patterning of the lights is phase-shifted so that the movement no longer could have been produced by a human walker. Three- and five-month old infants discriminate canonical from phase-shifted displays, and demonstrate a preference for the canonical displays. A salient difference between 3 and 5 month olds implicates the role of learning. Three month olds discriminate the two types of displays even if they are presented upside down, whereas 5 month olds do not. Perhaps in a period of 2 months, the older infants have learned to represent the abstract global structure of a human form in motion.

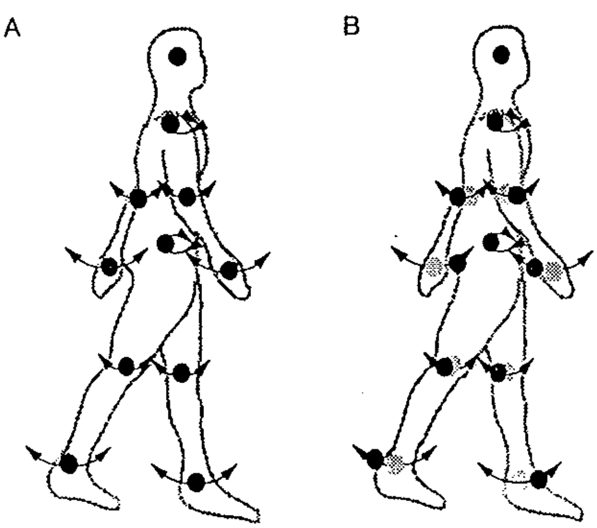

FIGURE 1 Point-light displays of a human walker in (A) canonical and (B) phase-shifted conditions (gray circles are canonical positions in phase-shifted displays).

In sum, there are several processing constraints that infants use to guide their interpretation of higher-order perceptual structure. These constraints may be innate, but if not innate, they are acquired by the first half year of life. Object representations are formed through learning, and as such are defined with reference to the past.

B. Auditory Perception

At 25 weeks past conception, brain wave activity occurs in the human fetus in response to sounds. In the 28th week of fetal development, the fetus will clamp its eyelids tightly in response to a 110 dB sound. At birth, anatomical development of the ear is complete, and infants with normal hearing can detect sounds at most of the frequencies that adults are sensitive to. In fact, newborns are actually slightly more sensitive than adults in their detection of the higher range of frequencies given in human speech (speech extends between approximately 50 and 8000 Hz). Newborns' threshold for detection of a sound is only 10–20 dB higher than the adult detection threshold, which is about the amount of decrement we experience when we have a cold with fluid in our ears. Infants can respond to acoustic differences in loudness, pitch, duration, and timing at birth, and these abilities improve with age. For example, adults can discriminate pitch changes on the order of 1% whereas the 5- to 8-month-old infant requires 2% pitch change to notice a difference. Also present at birth is the ability to locate the general direction where a sound is coming from. However, the localization response disappears at approximately 3 months, emerging again at 4 to 5 months. This nonmonotonic developmental pattern implies the existence of an initial reflexive mechanism which later becomes an exploratory mechanism as subcortical activation becomes linked to cortical functioning in the fourth month of life. [*See* EARS AND HEARING.]

It is easy to overlook one very important environmental context for learning, yet some recent provocative studies suggest that speech-based learning begins at the source—in the womb. This possibility is apparent in the preferences infants show at birth, preferences that could only exist if the stimuli were familiar to the infant. Newborn infants will go to some trouble to listen to their mothers' voices. In one experiment, infants learned that their rate of sucking on a nipple activated a tape recorder. Infants "played" their mothers voice more often than a strange female's voice. Using French and Russian languages, newborns were found to prefer the prosodic components (stress, rhythm, timing) of the language spoken by their mothers compared to the nonnative language. Even more remarkably, newborn infants can distinguish between two different Dr. Seuss stories, a task that is challenging to some adults. Twice a day, mothers in their last trimester of pregnancy read passages from *The Cat in the Hat* to their babies. This prenatal exposure enabled the infants to extract from the passages an overall story melody, and it was on this basis that they discriminated the familiar from the unfamiliar story passage when they were just 2 days old.

Equipped with excellent auditory resolution and a capacity for learning specific sound patterns, infants are quickly assimilated into the language game. Each language has a unique set of speech segments that differ from one another in subtle ways. These differences allow the segments to be discriminated from one another. Infants are capable of distinguishing these distinctions from all languages at the age of 6 months. However, adults have trouble distinguishing segments of a new language that they are learning. One classic example is the difficulty that native Japanese speakers have with the segments /r/ and /l/. On the other hand, 6-month-old Japanese infants have no trouble making this discrimination. An early conclusion from this research was that learning a spoken language involved a *loss* in the ability to discriminate nonnative contrasts. However, additional research revealed that adults could discriminate nonnative contrasts to some extent, and that they were capable of learning the new contrasts to a high degree of accuracy. This research, carried out by Janet Werker, David Pisoni, and others, prompted investigators to think about other explanations for why perceivers better distinguish contrasts in their own language relative to other nonnative languages. These new hypotheses included explanatory concepts such as attention, perceptual tuning, and cognitive mediation.

Although the exact mechanism cannot be specified at this time, it is clear that perceivers become tuned to the important distinctions of their language. One way to think about this is in terms of the psychophysical approach. The infant's auditory system (and visual system) makes available a set of primitive sound qualities during language processing. These qualities necessarily become associated with different meanings. With extensive experience, the infant learns which sensory qualities are important in signifying specific meanings. Given that meaning is where the action is in the language game, the child learns to attend to those qualities that are significant in his or her language. This process can be interpreted within the ecological approach by the infant learning to differentiate those sensory properties and their relationships that are consistently associated with meaningful distinctions. As monolinguals, we learn the distinctions unique to our language. Confronted with another language, we must learn anew the distinctions important in that language because they will necessarily differ from our native language. Insights into the exact nature of learning to perceive speech will be facilitated by the information-processing approach because it can specify the memory representations and psychological processes that occur.

C. Intermodal Perception

Distinct physical forms of energy are efficiently used by the separate sensory systems; likewise, the brain has separate areas for processing and storing the information made available by the separate modalities. However, the "divide and conquer" design does not capture the essence of most human perceptual experience. Fortunately, nature, in its infinite wisdom, endowed infants with a way to put back together what the sensory modalities take apart.

The capacity for intermodal representation in infancy was long debated by developmental psychologists, including Piaget, who believed in the gradual coordination of separate modality-independent perceptions. However, in the last two decades, the results of many informative studies reveal that Piaget's interpretation was an underestimation of infant perceptual abilities. In one study, 1-month-old infants suckled on a pacifier with either a nubby or a smooth surface. Shortly after this tactile exploration period, they were shown pictures of the two pacifiers. Infants looked longer at the pacifier that they had suckled, showing that they could match object properties specified visually and tactually. Four-month-old infants will look longer at a video image of an event that looks like it should be making the noise they are hearing. In one experiment, they were presented two different films, side-by-side, on screens in front of them. The sound source was directly in the middle of the two screens. A kangaroo on puppet strings jumped into the air and hit the ground on one side, and a donkey did the same on the other, but the two animals moved at different rates. The sound (a thump or a gong) was synchronous with the impact of one of the animals. Infants looked longer at the video image that matched the tempo of the sound that was playing through the central speaker. Further experimentation revealed this preference even when the sound occurred in synchrony with the moment that the animal reached its highest point and began to fall. Thus, any abrupt change in the direction of the object's movement was sufficient for the infant to connect sight and sound.

Infants also coordinate sights and sounds when the objects to be coordinated between modalities are faces and voices. Infants prefer to look at a picture of a female over a picture of a male when a female voice is playing, and vice versa. If they hear one of their own parent's voices, but look at snapshots of both parents simultaneously, they look longer at the face whose voice it is they are hearing. They also detect the correspondence between the visual and auditory modes of conveying emotion at least by the age of 6 months. Adult strangers appeared on side-by-side films talking in either a "happy" or an "angry" manner. The sound track, coming as before through a centrally located speaker, was from only one of the films. By now, it is easy to predict the findings: Infants looked for longer periods of time at the film consistent with the emotive content of the monologue they were hearing.

The previous experiments are convincing in their demonstration of a general intermodal perceptual ability in infancy, but they do not inform as to how finely tuned the ability is. Patricia Kuhl and Andrew Meltzoff have conducted an extensive series of studies on 4- and 5-month-old infants, which clearly show that infants detect auditory and visual correspondences in speech. In their experiments, infants sat in a seat facing two screens. A speaker presented speech sounds directly in front of them and between the two screens. An infrared camera filmed them from above. The film showed an adult repeatedly making the vowel sounds /i/ (as in *peep*), or /a/ (as in *pop*). Infants looked longer at the matching visual speech display. The experiment was carefully controlled so that there could not have been temporal characteristics in the sound stimuli that were associated with the phonemic contrasts. In this study, infants were engaging in *lip-reading*. They recognized that /i/ sounds are made with retracted lips and that /a/ sounds come from open mouths. Kuhl and Meltzoff discovered another important aspect of the intermodal organization of speech, specifically, the infant's capacity for vocal imitation. When infants heard pure tones that were vowel-like, but were not speech, they gurgled, squealed, and grunted. In contrast, when they heard /i/ and /a/, they produced speech sounds. Phonetically trained listeners found that infant productions matched the presentations of the different vowels. Relating speech sounds with the visual articulatory movements necessary to produce them is an early and impressive human language achievement. The infant's tendency to speak when spoken to will entice her caregiver to provide ample spoken language input, and will also help to maintain their communicative bond.

III. PERCEPTUAL DEVELOPMENT BEYOND INFANCY

Oddly enough, relative to the voluminous literature on infant perceptual development, there is comparatively little research in childhood populations above the age of 2. Certainly one factor that can account for this differential emphasis is theoretical focus. Those interested in the question of what perceptual capacities are innate simply must conduct their investigations with infant populations. However, as the remainder of the chapter will show, perceptual growth continues during childhood and across the lifespan.

One of the themes that has emerged in recent research is that children and adults use similar perceptual mechanisms, but they process information at different rates. One experiment of our own illustrates this point. We employed a visual search task which had previously been used to test a theory of attention in adult populations. The theory, proposed by Anne Triesman, states that recognition of objects during visual search is accomplished in two stages. In the first stage, primitive elements, or features, of objects are accessed in parallel across the visual field. In the second stage, features are fused using a "spotlight" of attention into the wholistic percepts that we are aware of seeing. The first stage is accomplished automatically, without demanding cognitive resources. When searching for a target that has a different feature from the rest of the objects in the visual field (feature search), the target "pops out" immediately, no matter how many objects are present. The second stage is resource-demanding, and is evident in a different pattern of data. Specifically, the amount of time it takes people to find targets should be a linearly increasing function with display size (conjunctive search). Figure 2 shows the search data for 5-year-old children and young adults. Since children in our experiment showed the pattern of results predicted by the theory, we concluded that children and adults used the same processes of object recognition during visual search. However, children were different from adults in that they conjoined features more slowly in the second stage of processing. Many studies comparing children and adults show that children become faster processors of information as they develop into adolescence.

We have also studied adult–child similarities and differences in pattern recognition processes used to understand the perception of speech by ear and by eye. The youngest age group we have tested was 4 years of age and the oldest group were individuals in their 70s. The fundamental processes involved in understanding visible speech (articulatory movements of the face and mouth) and auditory speech appear to be the same across age groups. That is, features of the auditory and visual stimuli are first evaluated, and then integrated in a process of matching the percept with a representation held in long-term memory. In a final stage of understanding, a decision is made as to the best category for the auditory–visual speech event, in comparison to all possible relevant alternative categories. However, there were significant differences in the informational value of auditory and visible speech as a function of age. The adults discriminated the auditory and speech categories better than children. Furthermore, children did not lip-read as well as adults. This factor can explain why the influence of visible speech in auditory–visual speech understanding was diminished in children compared to adults. Results from several of our own studies lead us to the conclusion that the prototype descriptions of the distinguishing characteristics of speech increase in resolution during childhood.

If there is one guiding principle that can be used to conceptualize perceptual development across the lifespan, it is differentiation. According to the ecological perceptionists, human perception is guided by a search for order and invariance in a highly fluctuating environment. It is a lifelong nonexistential search for meaning. Sometimes, our search ends almost instantaneously. For example, you might be searching for a face in a crowd and pass right over it, but when your friend next to you says, "Over

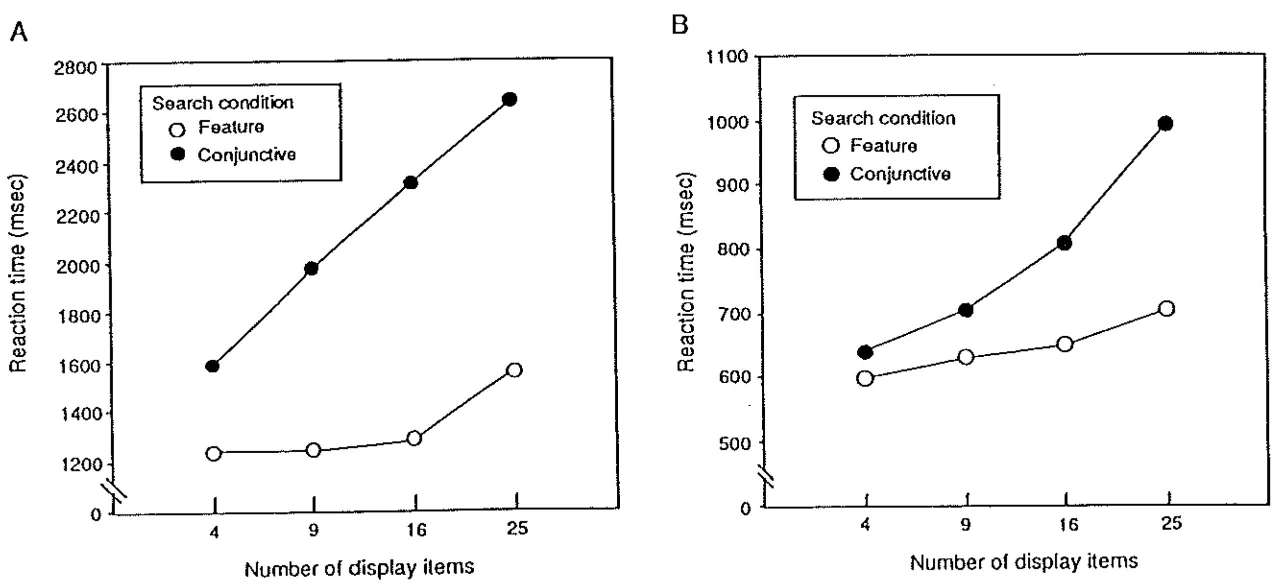

FIGURE 2 (A) Children's and (B) adult's mean reaction times for feature and conjunctive search conditions.

there, the one with the red glasses!" the face pops out at you, and you can no longer see that mirage of faces without seeing the one you were looking for. Or, the search for meaning can be long and frustrating, like when you learn to understand the words of a new language. Research shows that young children have difficulty finding simple forms which are embedded in larger pictures, while older children easily find much more complicated forms within embedded figures. Thus, much of perceptual development can be described as a constant process of learning what to look or to listen for. During learning, representations are formed that aid us in subsequent similar perceptual experiences.

In summary, the equipment in our perceptual system is up and running at birth, and functions superbly by the age of 4 months. Perceptual development beyond infancy involves five basic phenomenon. First, representations are built at the level of sensory primitives and at the level where they are bundled into the "wholes" that define the objects and sounds we are aware of seeing and hearing. Second, these representations increase in resolution with experience. Third, although not specifically addressed in this article, the ability to selectively attend, to focus on the relevant and filter out the irrelevant, does improve with age. Fourth, children become generally faster at processing information, so that objects are detected and recognized with less time across development. And finally, with experience we accumulate knowledge, which is perhaps our best source for constructing meaning from the multiple and rich sensory experiences we actively seek from our world.

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