The Integrated Development of Sensory Organization

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• Sensory integration • Intersensory redundancy

SENSORY INTEGRATION AND ORGANIZATION

Most objects and events present a complex mix of visual, auditory, tactile, and olfactory stimulation to the senses. How do young infants determine which patterns of sensory stimulation belong together and which ones are unrelated? For much of the twentieth century, most developmental scientists assumed that infants must gradually learn to coordinate and integrate information obtained by the separate sensory systems.[1–3] From this view, information had to be integrated across the separate senses through a gradual process of association for infants to perceive unified objects and events. This integration was thought to occur by the infant interacting with objects, experiencing concurrent feedback from different senses, and associating, assimilating, or calibrating one sense to another. For example, the pioneering developmental psychologist Jean Piaget[3,4] proposed that it was not until well into the first half year after birth that vision and touch begin to be integrated. Through acting on objects, tactile feedback was thought to gradually endow the 2-dimensional visual image of an object with 3 dimensionality. The attainment of perceptual abilities such as size and shape constancy, visually guided reaching, and object permanence were thought by Piaget and his colleagues[5] to be slow to emerge and to depend on the gradual development of sensory integration. Before this integration, the visual world of the infant was thought to consist of images shrinking, expanding, changing shape, and disappearing and then reappearing. Until the gradual achievement of sensory integration, infants were thought to perceive unrelated patterns of visual, acoustic, or tactile stimulation, expressed by the well-known description of the world of the newborn infant by William James as a "blooming, buzzing confusion."

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Infant-based research performed over the last several decades has seriously challenged this traditional view of early sensory organization and perceptual development. It is now known that the senses function in concert even in very early infancy and that young brains are organized to use the information they derive from the various sensory systems to enhance the likelihood that objects and events will be detected rapidly, identified correctly, and responded to appropriately, even during very early development.[6] Infants are sensitive to audiovisual synchrony from birth. For example, even newborns can match visual with auditory information[7] and orient visually toward a sound.[8] By 4 months of age, infants presented with 2 superimposed films and an audio track that corresponds to only one of the films will attend to the film that is in synchrony with the sound track.[9] Such abilities are likely based on young infants' sensitivity to relatively low levels of intersensory relations, including intensity and temporal synchrony.[10,11]

Evidence obtained from neurophysiologic research over the last decade indicates that the brain is remarkably skilled at integrating input from the different sensory systems to maximize the information available for perception and action.[6,12–14] Further, the ability to integrate information from different senses is not limited to any particular brain structure. Multisensory integration has been found in neurons at many locations in the nervous system, including subcortical areas such as the superior colliculus, early cortical areas such as the primary visual and auditory cortices, and higher cortical levels such as the superior temporal sulcus and intraparietal areas.[13,15–17] Available evidence from human brain imaging studies also indicate that cortical pathways once thought to be sensory specific can be modulated by signals from other sensory modalities.[18–22]

This more integrated view of sensory organization can be traced in part to the ground-breaking work of the perceptual psychologists James J. Gibson[23,24] and Eleanor Gibson.[25] In a sharp break from the traditional association views of perceptual development described earlier, the Gibsons recognized that the existence of different forms of sensory stimulation was not a problem for the perception of unitary events but instead provided an important basis for it. They argued that all senses should be considered as a perceptual system that interacts and works together to pick up invariant aspects of stimulation. One important type of invariant information is amodal information that is common across the senses. Amodal information is not specific to a particular sensory modality but can be conveyed redundantly across multiple senses. For example, the rhythm or tempo of a ball bouncing can be conveyed visually or acoustically and is completely redundant across the 2 senses. One can detect the same rhythm and tempo by watching the ball's motion or by listening to its impact sounds. The sight and sound of hands clapping likewise share temporal synchrony, a common tempo of action, and a common rhythm.

It is known from developmental research conducted over the past 30 years, inspired in large part by the Gibsons' innovative approach to perception, that young infants are adept perceivers of amodal information.[10,26–28] Infants readily detect the temporal aspects of stimulation, such as synchrony, rhythm, tempo, and prosody, that unite visual and acoustic stimulation from objects and events, as well as spatial colocation of objects and their sound sources and changes in intensity across the senses during the first 6 months after birth.[29,30] Such demonstrations of infants' detection of amodal information seriously question the notion that young perceivers have to learn to coordinate and somehow put together separate and distinct sources of information. By detecting higher-order amodal information common to more than one sense modality, even relatively naive perceivers can explore a unitary multimodal event in a coordinated manner. The major task of perceptual development then becomes to