Development Across the Life-Span: The Case of Intersensory Perception

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As we all know, adults are exquisitely skilled at selectively attending to specific features or aspects of objects and events, picking out information that is relevant to their needs, goals, and interests, and ignoring irrelevant stimulation. For example, we easily pick out a friend in a crowd, follow the flow of action in a ball game, and attend to the voice of the speaker at a cocktail party in the context of competing conversations. We long ago learned to pick out human speech from non-speech sounds and parse continuous speech into meaningful words by ignoring variations across speakers, accents, and intonation. Similarly, we have learned to parse the visual array into coherent objects and surfaces despite variation due to lighting and shadow and interruption of surfaces due to occlusion. The foundations of these remarkable skills, easily taken for granted by experienced perceivers, develop across infancy as a result of ongoing experience with objects and events. This rapid perceptual development depends on improving attentional allocation and economy of information pick up for relevant aspects of the environment.

In this light, the newborn infant faces a significant developmental challenge following birth - how to become increasingly economical and efficient at attending to multimodal stimulation that is unitary (coherent across the senses and originating from a single event) and relevant to their needs and actions, while ignoring stimulation that is less relevant. This is a challenging task, as the environment provides far more stimulation from multiple objects and events than can be attended at any given time. The infant must learn to attend to variations in incoming stimulation that are meaningful, relevant, and coherent (e.g., coordinated changes in the face and voice of a single speaker amidst unrelated changes in other objects and people) and ignore other variations that are relatively meaningless (differences in lighting and shadow across cohesive objects, variations in speaker voice or intonation across the same phoneme). What factors determine which information is selected and attended to by infants and which information is typically ignored during early development?

A large body of research has indicated that the detection of amodal information such as temporal synchrony, rhythm, tempo, and intensity is a cornerstone of early perceptual development (Bahrick & Lickliter, 2002, Lewkowicz, 2000; Lewkowicz & Lickliter, 1994). *Amodal information* is information that is not specific to a particular sense modality. Rather, it is information that can be conveyed redundantly across multiple senses, including fundamental aspects of stimulation such as time, space, and intensity. The finding that infants are adept at perceiving amodal information is consistent with J.J. Gibson's (1966, 1979) ecological view of perception, which proposed that the different forms of stimulation available to the senses are not a problem for perception, but rather provide an important basis for perceiving unitary objects and events such as a person speaking or a ball bouncing. Gibson proposed that our senses work together as a unified perceptual system. For example, by attending to and perceiving amodal information, there is no need to learn to integrate stimulation across the senses in order to perceive unified objects and events, as proposed by constructivist accounts of early perceptual and cognitive development (e.g., Piaget, 1952, 1954). Perceiving amodal relations, combined with an increasing sensitivity to the statistical regularities of the environment, effectively ensures that young inexperienced perceivers preferentially attend to unified multimodal events, such as people speaking, dogs barking, or keys jingling.

Temporal synchrony is the most fundamental type of amodal information. Temporal synchrony refers to the simultaneous co-occurrence of stimulation across the senses (for example, audio-visual) with respect to onset, offset, and duration of sensory patterning. It is a higher-order, global amodal property, in that it can be detected only by abstracting information across different sense modalities (e.g., audible and visual changes) over time. Thus, it is inherently relational and abstract. Further, temporal synchrony facilitates the detection of nested amodal properties such as rhythm, tempo, and duration across the senses (Bahrick, 2001; Lewkowicz, 2000). Temporal synchrony has been proposed as the "glue" that effectively binds stimulation across the senses (Bahrick & Pickens, 1994; Bahrick & Lickliter, 2002; Lewkowicz, 2000). For example, by attending to audiovisual synchrony, the sounds and sights of a single person speaking will be perceived together as a unified event. Detecting this synchronous information can prevent the accidental association of unrelated but concurrent sensory stimulation, such as nearby conversations.

It is clear that infants quickly establish efficient patterns for selectively attending to relevant and coherent aspects of the environment, and these patterns become increasingly efficient with experience, eventually evolving into the expert patterns of adult selective attention. A central issue for developmental science is to uncover what principles govern this process. Lorraine Bahrick and I have proposed and provided empirical support from animal and human infants for the intersensory redundancy hypothesis (IRH), a framework based on four general principles that we think guide this developmental process (Bahrick & Lickliter, 2000, 2002; Lickliter & Bahrick, 2004). These principles, which I will briefly review in my talk, are all an outcome of young infants' sensitivity to and use of intersensory redundancy to guide attentional allocation, perceptual processing, and learning and memory during the first months of postnatal life.

Intersensory redundancy is provided by an event when the same amodal information (rhythm, tempo, intensity changes) is simultaneously available and temporally synchronized across two or more sense modalities. For example, when the rhythm and tempo of speech can be perceived by looking and by listening, the rhythm and tempo are redundantly specified. Most naturalistic, multimodal events provide intersensory redundancy for multiple properties (e.g., tempo, rhythm, duration, intensity). By definition, only amodal properties (as opposed to modality specific properties) can be redundantly specified across the senses. Typically, a given event (such as a person speaking) also provides non-redundant modality specific information, such as the appearance of the face, the color of clothing, and the specific acoustic qualities of the voice. Infant-based research consistently indicates that redundancy across the senses promotes attention to redundantly specified properties of objects and events at the expense of other non-redundantly specified stimulus properties, particularly in early development when attentional resources are most limited (Bahrick & Lickliter, 2002; Bahrick, et al., 2010). Studies of infant affect discrimination, face discrimination, numerical discrimination, sequence detection, and abstract rule learning have all shown that intersensory redundancy facilitates earlier detection of the information of interest when compared to non-redundant unimodal exposure to the same information. This pattern is referred to as *intersensory facilitation*. With additional experience, attention can be extended to less salient, non-redundantly specified properties. Factors such as complexity, familiarity, the length of exploratory time, and the level of expertise of the perceiver can affect the speed of progression through this salience hierarchy.

Although the IRH was originally proposed as a framework for describing the early development of attention and intermodal perception, recent evidence suggests that the principles of the IRH can apply across the life-span, particularly under conditions where attentional resources are limited (for example, for difficult or demanding tasks or high cognitive load). These contextual factors appear to play a key role in whether and to what extent we observe this possible developmental homology and I plan to focus on the importance of context in my talk.

Early development is a period during which task demands are typically high. Infants are relatively naïve perceivers of objects and events, and therefore perceptual processing of most objects and events is likely rather difficult and effortful. Consequently, the effects of intersensory redundancy should be most pronounced in early development. However, because perceptual learning and differentiation occur across the lifespan, intersensory facilitation should also be evident-in later development when task demands are high. Children and adults continue to develop expertise across the life-span, acquiring new information and learning to perceive finer distinctions such as learning a new language, playing a new musical instrument, or becoming skilled at identifying birds, dinosaurs, or airplanes. In early stages of learning, expertise is low in relation to task difficulty, and consequently task demands are high. The intersensory redundancy hypothesis predicts that when task demands are high, and attention therefore progresses more slowly along the salience hierarchy, children and even adults should experience intersensory facilitation. Thus, when learning new material that challenges their skill level, intersensory redundancy should promote selective attention, perceptual processing, and learning in older perceivers. Similarly, when cognitive load is high and attentional resources are taxed, such as under conditions of divided attention ("multi-tasking") or under conditions that require greater self-regulation, executive function, or higher effort, intersensory facilitation should also be apparent in older perceivers.

Research findings from studies of adult perception (Kaplan & Berman, 2010; Lavie, 1995, 2005) are consistent with this view. Further, studies with older infants and children across a variety of domains, including motor and cognitive development, indicate that under conditions of higher task difficulty and cognitive load, performance often reverts to that of earlier stages of development (Adolph & Berger, 2005; Berger, 2004; Corbetta & Bojczyk, 2002). We have recently provided data that indicate intersensory facilitation in adults under conditions of high task difficulty (Bahrick, et al. 2009). In our study, we manipulated task difficulty and found that adults demonstrate enhanced processing and discrimination of the amodal property of tempo in the context of redundant audio-visual stimulation as compared with unimodal visual stimulation. Research with adults has also demonstrated that bimodal cues capture spatial attention more effectively than unimodal cues under conditions of perceptual load (Santangelo, Ho, & Spence, 2008; Santangelo & Spence, 2007), again suggesting that multisensory information plays a key role in directing attention in demanding events or situations across the life-span. If our recent findings of intersensory facilitation in adults hold up across additional studies, we should be able to better answer whether and to what extent the use of intersensory redundancy during infancy is homologous with the use of intersensory redundancy in adulthood.

Importantly for our discussions of developmental homology, evidence accumulated over several decades of infancy research indicate that selective attention is initially more stimulus-driven during early development and with experience becomes increasingly endogenous and modulated by top down processes, including the individual's goals, plans, and expectations (Colombo, 2001; Johnson, Posner, & Rothbart, 1991; Ruff & Rothbart, 1996). Thus, for experienced perceivers prior knowledge, categories, goals, plans, and expectations typically guide selective attention and information pick-up (Chase & Simon, 1973; Neisser, 1976; Schank & Ableson, 1977). Given these significant differences in the deployment of attention between infants and adults, they may not share the same structural basis. To begin to address this issue, we need to better understand how attentional and perceptual skills are organized across ontogeny, how they become better coordinated, and how they function in the real-time behavior of the individual.

It seems to me that a key issue in assessing developmental homology will be understanding how a phenomenon (for example, intersensory facilitation) comes about from the coordination of existing skills and processes *and* how things change and how they stay the same over the course of the life-span. This will require a developmental point of view.

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