predict, for instance, the sound that a red object would make if dropped or struck.

The third principle is that the detection of amodal relations guides and constrains perceptual learning about arbitrary relations. For example, if infants detect the synchrony between a person's face and voice they are likely to learn the unique (arbitrary) pitch and sound of the voice and associate it with that person. However, if there is no amodal information, as when a face is seen and a voice heard, but if the two are not synchonized, then the association will not be learned.

These principles act both as powerful constraints on, and guides to, learning. The young infant has an enormous amount to learn, and it would be a complex and chaotic world if infants associated all arbitrary pairing of sights and sounds, and other intermodal combinations, and clearly they do not. As Bahrick concludes, "selective attention to global, amodal, relations in the first months of life can provide a means of organizing, guiding, and constraining perceptual experience in a way that ultimately leads to the intermodal knowledge of the adult perceiver."

Increasing Specificity in the Development of Intermodal Perception

Lorraine E. Bahrick

Increasing Specificity in the Development of Intermodal Perception

The infant is born into a world of objects and events that present a vast array of information to all the senses. Research now clearly demonstrates that young infants are adept perceivers of this multimodal stimulation (for a review, see Lewkowicz and Lickliter, 1994). They are able to perceive coherent, unitary multimodal events, even in the first months of life. For example, 2- to 5-month-olds are able to perceive a relationship between a person's face and their voice on the basis of temporal synchrony and shared rhythm between the movements of their mouth and the timing of their speech (Dodd, 1979; Lewkowicz, 1996a; Walker-Andrews, 1986) as well as between the shape of the lips and the corresponding vowel sound (Kuhl and Meltzoff, 1982, 1984). By 5- to 7-months, infants can match faces and voices on the basis of the age and gender of speaker (Bahrick et al., 1998; Walker-Andrews et al., 1991) as well as affective expression (Caron et al., 1988; Walker, 1982; Walker-Andrews, 1986, Walker-Andrews and Lennon, 1991). Young infants are also able to recognize information specifying the self by detecting amodal invariant relations. They can match their own body motion, experienced proprioceptively, with a visual display of the motion, on the basis of shared temporal and spatial information (Bahrick and Watson, 1985; Bahrick 1995; Rochat 1995; Rochat and Morgan, 1995; Schmuckler, 1996). For example, when 5-month-old infants view a live video display of their own legs moving, alongside that of another infant's legs, they can discriminate the two and prefer to watch the novel display of the other infant. Young infants are also able to detect the visually and acoustically specified substance and composition of an object striking a surface, as well as the synchrony, rhythm and tempo of impacts common across the senses (Bahrick, 1983, 1987, 1988, 1992; Bahrick and Lickliter, submitted; Lewkowicz, 1996b; Spelke, 1979). With no prior knowledge to guide selectivity, infants are able to make sense of this multimodal array and perceive intermodal relations across a wide range of natural events. However, we currently know little about how and in what developmental sequence, infants detect these intermodal relations. In this chapter, I present evidence that this process of perceptual development is set in motion and guided by the detection of amodal invariant relations and occurs in order of increasing specificity.

Amodal Information and the Principle of Increasing Specificity

Amodal information is information that is not specific to a particular sense modality, but is completely redundant across two or more senses (see Bahrick and Pickens, 1994; Gibson, 1969). For example, the sights and sounds of hands clapping share a synchrony relation, a common tempo of action and a common rhythm. The same rhythm and tempo can be picked up visually or acoustically. According to Gibson (1969), infants come into the world with a unified perceptual system, equipped to abstract amodal relations. Detection of amodal relations focuses attention on meaningful, unitary multimodal events and, at the same time buffers against learning inappropriate relations (Bahrick, 1992, 1994; Bahrick and Pickens, 1994). For example, if the infant detects temporal synchrony, shared rhythm and tempo between the sounds of a person's voice and the sight of their moving face, the infant will necessarily be focusing on a unitary event; the person talking. During that time, the infant would not attend to sights that are unrelated to the audible voice such as the nearby movements of colorful objects or the activities of other people.

Objects and events have hierarchically organized properties. Some properties are nested within others. Gibson (1969) has proposed a

principle of *increasing specificity* suggesting that global, abstract relations are detected developmentally prior to more specific, nested relations. I have applied and tested this principle in the domain of intermodal learning about audible and visible events. In this chapter, I present evidence from several series of studies that illustrate this principle. Together, these studies reveal three basic principles about how perception becomes increasingly more specific with development. First, they demonstrate that global amodal relations, such as temporal synchrony, are detected developmentally prior to nested amodal relations (in this case, information specifying object composition). Second, research from several domains demonstrates that amodal relations are detected developmentally prior to arbitrary relations. Third, evidence suggests that detection of amodal relations guides and constrains perceptual learning about arbitrary relations.

For the purpose of this research, audio-visual relations were defined as having different levels of specificity:

1 Amodal *temporal synchrony* between the sights and sounds of an object hitting a surface was defined as the most global level. Synchrony specifies the unity of audible and visible stimulation.
2 Amodal *temporal microstructure* is a more specific and embedded kind of audio-visual relation that characterizes the nature of each synchronous impact. There is a temporal structure common to the type of sound and type of motion that can tell us about the object's substance, its composition, weight, size, or number. In the case of object composition, a single object striking a surface produces a single, abrupt impact sound with a single, abrupt change in visual trajectory. In contrast, a compound object (composed of many smaller elements) produces a more prolonged sound with a more gradual onset and a correspondingly gradual change in visual trajectory. This internal temporal structure is common across vision and audition and specifies the object's composition.
3 Modality-specific or *arbitrary* audio-visual relations (such as the relation between the pitch of a sound and the color of the object) were defined as the most specific level. Arbitrary audio-visual relations are context specific and not united by common information common across the different sense modalities.

Global Amodal Relations are Detected Developmentally Prior to Nested Amodal Relations

One series of studies (Bahrick, 1996; Bahrick, submitted) explored the developmental progression of infants' sensitivity to global, amodal synchrony versus nested, composition relations. Would infants detect temporal synchrony developmentally prior to amodal information for object composition, consistent with an increasing specificity view?

Four pairs of events were created to illustrate the synchrony and embedded composition relations (see figure 6.1). They each depicted an object striking a surface in an erratic temporal pattern. One member of each pair was a large, single object, which produced a single, discrete impact sound, and the other was a similar looking compound object (comprised of many smaller elements), which produced a more prolonged, complex impact sound. There were two categories of objects, plastic fruit and metal hardware. The plastic objects were abruptly hit against the two wooden surfaces by an unseen hand from behind. The metal objects were suspended from a string and abruptly dropped against the wooden surface. Pairs of objects within the same category differed from one another in terms of color and shape (e.g., pears versus tomatoes), but were comprised of the same substance (plastic or metal) and were moved in the same manner.

Infants were habituated, in an infant controlled procedure (see Bahrick, 1992, 1994; Horowitz et al., 1972), to a single and a compound event in an alternating sequence from one of the two pairs of metal objects. Each event was accompanied by its natural synchronized sounds. After infants met the habituation criterion (a 50% decrement in looking on two successive trials with respect to the infant's initial interest level), they received two test trials depicting either a change in synchrony or a change in composition relations. For the synchrony change test, each visual event was presented out of synchrony with its soundtrack. Thus, the only change from habituation to test, was the synchrony relation between the films and soundtracks. For the composition change test, the wrong sounds were played in synchrony with the object's motions. That is, the motions of the single object were synchronized with the sounds of the compound object and the motions of the compound object were synchronized with the sounds of the single object. Thus, the only change from habituation to test was the

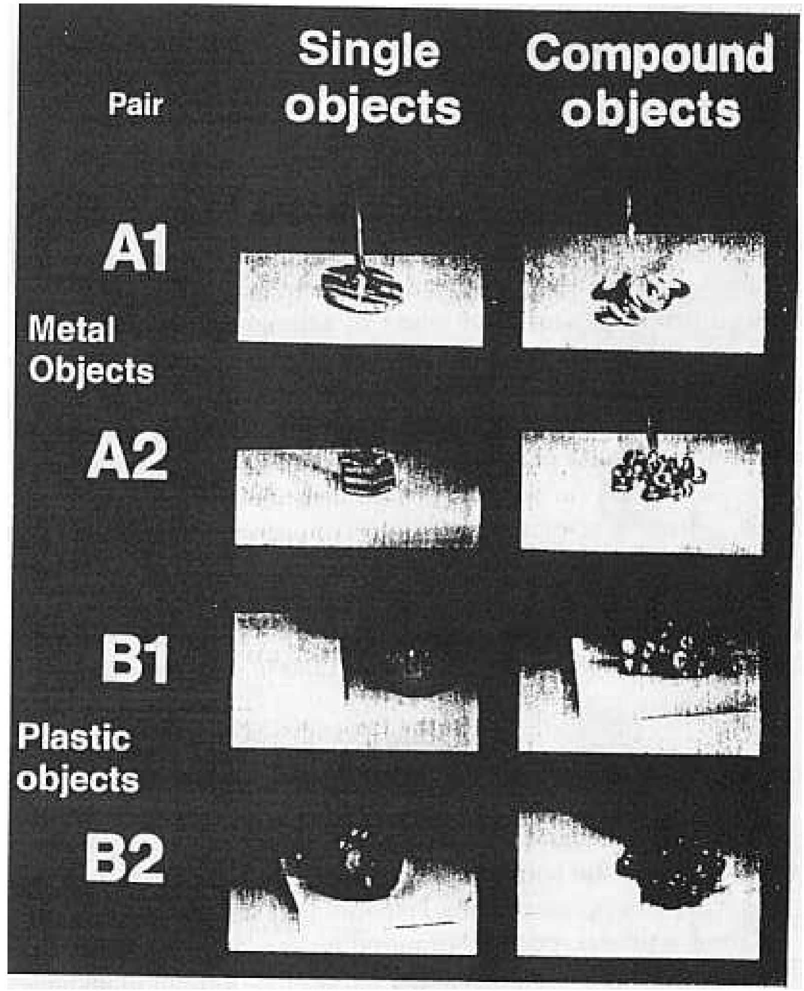

Figure 6.1 Photograph of the stimulus events (from Bahrick, 1992)

pairing of the objects and sounds. Visual recovery to the change in relationship between the objects and sounds was measured for each type of test.

Ninety six infants were tested, 48 at 11-weeks, 28 at 7-weeks, and 20 at 4-weeks of age. Half the infants in each age group participated in the synchrony change condition and half in the composition change.

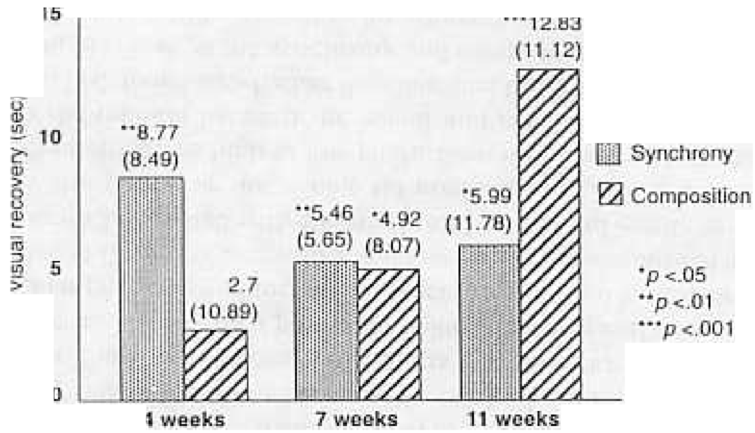

Figure 6.2 Visual recovery to the change in temporal synchrony and temporal microstructure specifying object composition a 4-, 7-, and 11-weeks of age (from Bahrick, submitted)

Results (depicted in figure 6.2) demonstrated significant visual recovery to the change in temporal synchrony at all ages, according to single sample *t*-tests. However, visual recovery to the change in composition relations was significant only at the two older ages, and not at 4-weeks of age. In fact, at 11-weeks of age, recovery to the change in composition was significantly greater than recovery to the change in synchrony ($p < .05$). A trend analysis also revealed a significant linear increase in sensitivity to composition information across age ($p = .01$), but no change in sensitivity to synchrony across age. Thus, these results indicate that by 4-weeks, sensitivity to synchrony was already present and it remained fairly stable across age. And by 7-weeks, sensitivity to object composition emerged, and increased dramatically, so that at 11-weeks it was more salient than synchrony. Further, a control study demonstrated that 3 to 4-week-olds were in fact able to discriminate both the visual and acoustic changes specifying object composition (see figure 6.3). That is, within each pair of events, they could discriminate between the single and compound moving objects, and they could discriminate between the single and compound impact sounds. Thus, even by 3-weeks of age, infants were able to discriminate unimodal information for object composition, but they did not relate this information across modalities before the age of 7-weeks.

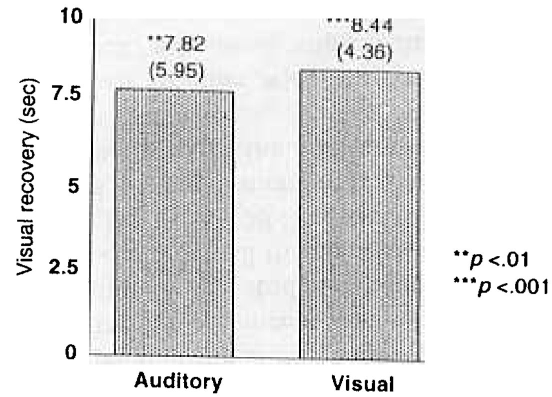

Figure 6.3 Visual recovery to the change in visual versus acoustic information specifying a single versus a compound event at 3–4 weeks of age (from Bahrick, submitted)

These findings reveal evidence of infants' sensitivity to amodal synchrony and composition information at much younger ages than previously thought. More importantly, they demonstrate a changing sensitivity to amodal information across age, consistent with the principle of increasing specificity. Infants detect global amodal relations prior to nested amodal relations. This pattern is adaptive. By first detecting temporal synchrony, infants can focus on unitary events and further differentiation will be appropriately constrained. The initial focus on global, synchrony relations creates a natural buffer against processing unrelated streams of visual and acoustic stimulation. By ensuring that attention is first focused on audible and visible stimulation that belongs together, further processing of multimodal events can proceed in an economical and veridical way.

Amodal Relations are Detected Developmentally Prior to Arbitrary Relations

Multimodal events make a variety of intermodal relations available. Some are amodal and redundant across the senses, such as synchrony, rhythm, tempo, and information specifying object composition. Other information is modality-specific and arbitrarily related across the senses. For example, the relation between the unique sound of a person's voice and the sight of their face or hair style is arbitrary; so is the relation between the color or shape of a moving object and the pitch of its impact sound; or the appearance of an object and the verbal label we give it. Although amodal relations can be directly perceived, arbitrary relations must be learned. Although amodal relations are context-free, arbitrary relations may vary from one context or event to another. Thus, arbitrary relations are considered the most specific type of relation because they are context specific whereas amodal relations are not. For example, in the case of amodal relations, a compound sound always goes with a compound object and a single sound is always produced by a single object. The sights of an erratic rhythm always specify the sounds of an erratic rhythm. However, arbitrary pairings can vary from one context or event to another. A dull, low-pitched sound only sometimes goes with a yellow, round object; a happy, lilting voice only sometimes goes with mommy's face. Because of this, it would be maladaptive for infants to learn arbitrary relations that vary from one context to the next, prior to learning about amodal relations that can be appropriately generalized across contexts. Thus, another way of evaluating the principle of increasing specificity is to ask whether infants would detect amodal relations developmentally prior to detecting arbitrary audio-visual relations.

In one study (Bahrick, 1992), I explored this issue by assessing infants' sensitivity to the amodal synchrony and composition relations in the metal and plastic events (see figure 6.1), as well as to an arbitrary, modality-specific relation provided by the same events. The arbitrary relation was one between the pitch of an impact sound and the color/shape of the object. All objects that impact a surface can be characterized as having a particular color and shape and a sound of a particular pitch. An auditory signal processor was used to raise or lower the pitch of the object's natural impact sounds. Three-month-old infants were again habituated with the single and compound events as before (either the plastic or metal objects) producing natural synchronous sounds of either the high or low pitch. Then they received test trials in which the relation between the visual and acoustic information was mismatched, to assess whether they detected the change from habituation. Infants received the synchrony and composition change tests just like in the prior study, as well as an arbitrary change test. In the arbitrary change test, infants received trials where the object with the high-pitched sound now was synchronized with the low-pitched impact

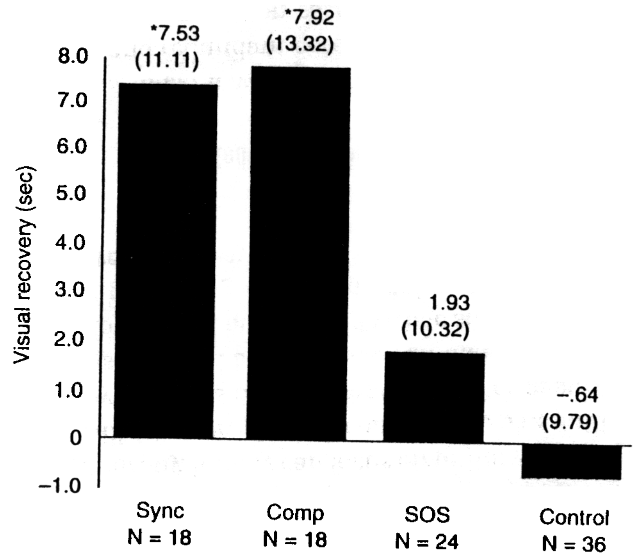

Figure 6.4 Mean visual recovery to a change in synchrony (Sync), composition (Comp), and pitch-color/shape (SOS; specific object-sound) relations, as compared with no-change controls (from Bahrick, 1992) (*$p \leq .01$ with respect to controls)

sound, and vice versa. Results are depicted in figure 6.4. They demonstrated that infants showed significant visual recovery to the change in both synchrony and composition relations, but not to the change in the relation between the pitch of the impact sound and the color/shape of the object, relative to the performance of control subjects who received no changes. Two further control studies demonstrated that 3-month-olds could, in fact, discriminate all the color/shape and pitch changes used. A further study (Bahrick, 1994) extending the test for arbitrary relations to infants of 5- and 7-months demonstrated that only the 7-month-olds were able to detect the arbitrary color/shape-pitch relations used.

These findings, taken together with the studies described earlier (Bahrick, 1996; Bahrick, submitted), suggest that prior to 3-months, infants were already sensitive to the amodal relations, but they were not able to detect the arbitrary pitch color/shape relations until much later. This suggests there may be a developmental lag between the detection

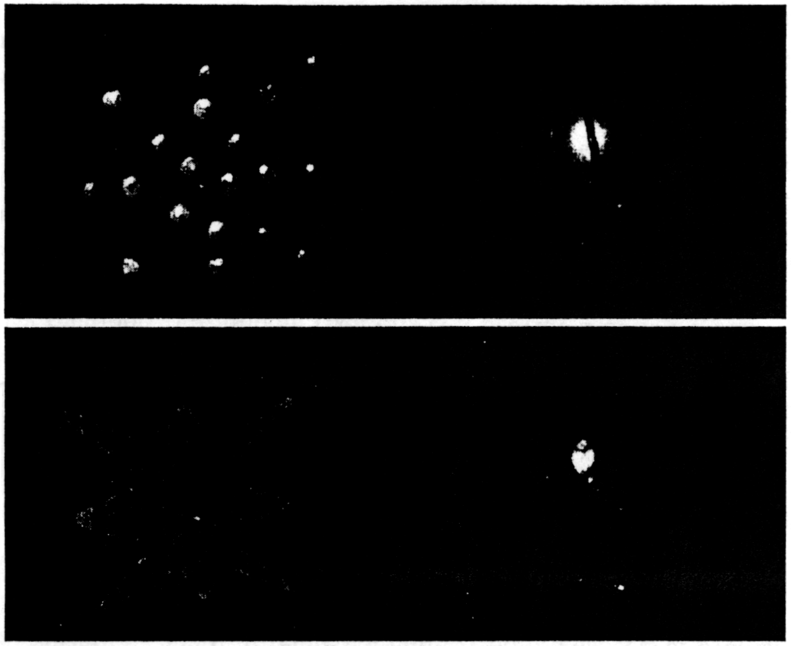

Figure 6.5 Three-dimensional objects presented for visual-tactual exploration (from Hernandez-Reif and Bahrick, submitted)

of amodal and arbitrary relations from a given set of events. It appears that the detection of amodal relations developmentally precedes and constrains detection of arbitrary relations in a given domain.

Converging evidence for this developmental lag comes from another set of studies we conducted in the area of visual-tactual perception of objects (Hernandez-Reif and Bahrick, submitted). Amodal information for object shape was detected by infants of 4- and 6-months of age. However, only the 6-month-olds were able to detect the arbitrary relation between the haptically experienced shape of the object and its color and pattern. Infants were given two objects, one at a time, to explore visually (above a bib) and haptically (below a bib) during familiarization trials (see figure 6.5). Each object had a distinctive color and pattern. Then infants received test trials where the two objects were displayed visually, side by side, while they haptically explored one of the objects at a time below the bib. Results (see figure 6.6) indicated

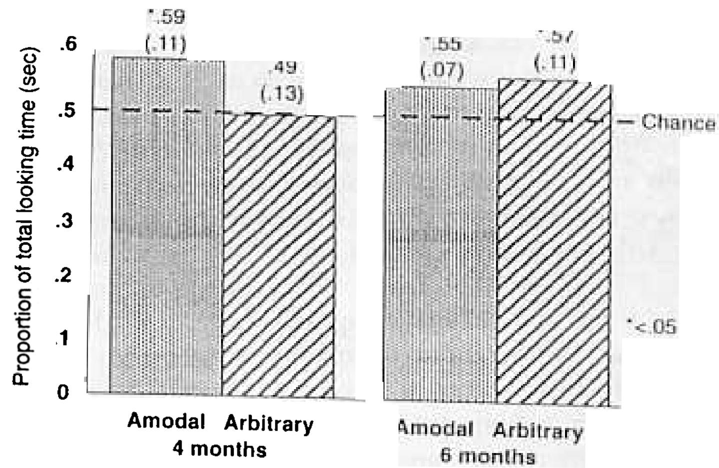

Figure 6.6 Proportion of total looking time to the visual display that matched the object in the infant's hand (from Hernandez-Reif and Bahrick, submitted) (*$p \leq .05$)

that infants at both 4- and 6-months looked significantly more to the object that matched the shape of the one in their hands, demonstrating matching on the basis of amodal information for shape across vision and touch. In contrast, when infants were given test trials assessing matching on the basis of the arbitrary relation between the color and pattern of the object and its haptically experienced shape, only the 6-month-olds, but not the 4-month-olds showed matching. That is, when two flat posterboards displaying the distinctive color/patterns were displayed side by side (see figure 6.7) while infants haptically explored the three-dimensional object under the bib, only the 6-month-olds looked more to the color/pattern that matched the object in their hands. The younger infants showed no evidence of detecting the arbitrary relation between the haptically experienced shape and the visually given color-pattern.

These findings converge with those on audio-visual event perception and demonstrate a developmental lag between the detection of amodal and arbitrary relations across the senses. This developmental lag is likely to be adaptive in promoting the development of veridical object and event perception. By detecting amodal relations first, infants can develop intermodal knowledge about persistent properties of object and events

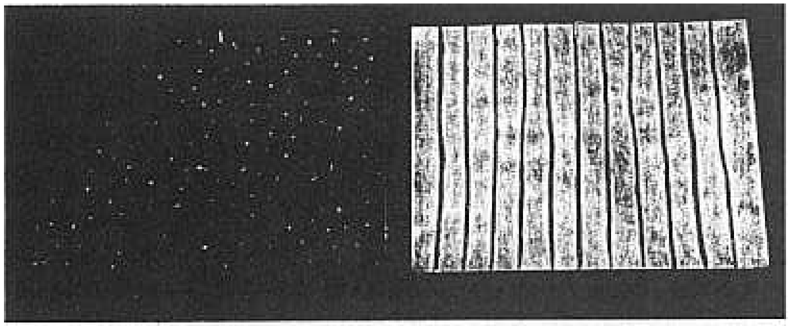

Figure 6.7 Two-dimensional displays of color and pattern information (from Hernandez-Reif and Bahrick, submitted)

prior to acquiring knowledge about more idiosyncratic, arbitrary relations that often vary from one context or event to another. By first detecting amodal relations, infants will avoid making inappropriate generalizations about unrelated or context-bound aspects of events.

Detection of Amodal Relations Guides and Constrains Learning about Arbitrary Relations

Evidence from at least two sets of studies (Gogate and Bahrick, 1998; Hernandez-Reif and Bahrick, submitted) suggests that detection of amodal relations not only developmentally precedes detection of arbitrary relations, but amodal relations can provide a basis for detecting and learning about arbitrary relations as well. In the series of studies on visual-tactual matching described above (Hernandez-Reif and Bahrick, submitted), another experiment was conducted exploring the basis for the 6-month-olds' ability to match the tactually experienced shape with the arbitrarily paired color/pattern information. It asked if amodal information for shape were eliminated during the familiarization trials, would infants no longer be able to match on the basis of the arbitrary shape-color/pattern relations during the test trials. Thus, instead of receiving an identical three-dimensional object of a particular shape above the bib for visual inspection and below the bib for haptic exploration, infants haptically explored the three-dimensional object below

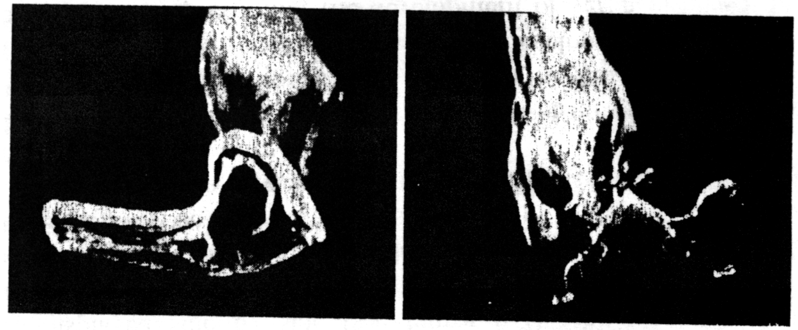

Figure 6.8 Objects used in the study of speech sound-object relations (from Gogate and Bahrick, 1998)

the bib while viewing the flat two-dimensional posterboard displaying the distinctive color/pattern above the bib. In this way the visual information for three-dimensional shape was eliminated during the familiarization trials, while still presenting the color/pattern information. Test trials were identical to those described earlier with the flat posterboards. Results indicated that 6-month-olds no longer showed matching of the haptically experienced shape and the color/pattern during the test trials. These findings suggest that the common shape information provided to touch and sight during familiarization was necessary for successful performance in the arbitrary matching task. Six-month-old infants apparently related the object's color/pattern with its shape by first detecting the shape common to the two modalities. Thus, detection of amodal shape information must have guided learning about arbitrary shape-color/pattern relations.

A recent set of studies on the perceptual precursors to language learning (Gogate and Bahrick, 1998) also suggests that detection of amodal relations provides a basis for detecting and learning about arbitrary relations. Seven-month-old infants were taught arbitrary relations between two verbal labels ("a" versus "i") and two distinctive looking objects under one of three conditions during a habituation procedure. In one condition (the amodal condition) there was synchrony relating the motions of the objects with the timing of the speech sounds (like showing and naming the object simultaneously; see figure 6.8). In a second condition the objects were moved out of synchrony with the

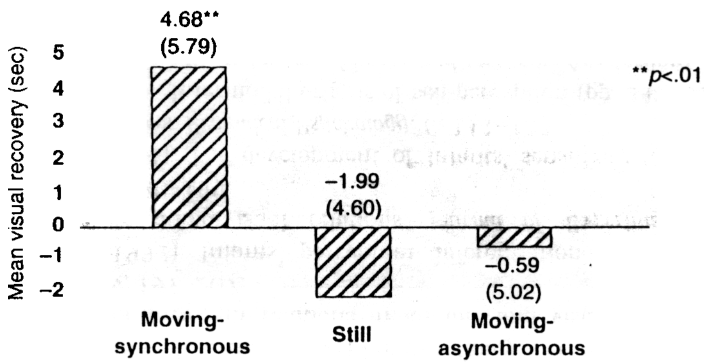

Figure 6.9 Mean visual recovery to the change in vowel-object relations in the moving-synchronous, still, and moving-asynchronous conditions (from Gogate and Bahrick, 1998) (**$p < .01$)

speech sounds, and in the third condition, the objects were still while the speech sounds were presented. Each object was presented along with its corresponding vowel sound, in an alternating sequence, until the infant was habituated. Then infants received test trials where the relationship between the sound and the object was switched. Visual recovery reflected detection of the change in object-sound relations. Results (figure 6.9) demonstrated significant visual recovery to the change in object-sound relations only in the amodal condition where temporal synchrony united the motions of the objects with the speech sounds. Infants showed no evidence of learning to relate the speech sounds and objects when there was asynchrony, or when the objects were still. These findings suggest that arbitrary associations between speech sounds and objects are best learned on the basis of amodal synchrony at first. Prior research had failed to demonstrate learning of arbitrary speech sound-object relations in infants so young, presumably because multimodal synchrony was not present. As infants mature and learn that sounds can stand for objects, synchrony is apparently no longer necessary for learning new object-sound relations. In fact, further research (Gogate et al., submitted) has demonstrated that mothers use synchrony to teach their young infants new names for objects, but the use of synchrony decreases as the infants become older and more lexically competent. Thus, the mother's use of temporal synchrony parallels the infant's

changing reliance on it. These finding converge with those in the area of visual-tactual perception to demonstrate how detection of amodal information can guide and constrain detection of arbitrary relations across the senses.

Conclusions

In this chapter, I have reviewed evidence from a number of studies supporting three developmental principles that show how perception becomes increasingly more specific with development. Infants appear to detect intersensory relations in a particular order developmentally. When multimodal events make both amodal and arbitrary relations available, as is typical in the natural environment, infants first differentiate global amodal synchrony relations. Later, developmentally, they differentiate nested amodal relations such as information specifying object composition. Finally, they detect the arbitrary relations between aspects of the object's visual appearance and its sound or touch. There appears to be a developmental lag between the detection of global amodal, nested amodal, and arbitrary relations within a given domain or set of events.

How might this lag develop? Amodal relations appear to be perceptually more salient to infants because they create redundancy across the senses (see Bahrick and Lickliter, submitted). Amodal properties convey the same information to two senses simultaneously. Redundant stimulation captures infant attention at first, and becomes "foreground" while other, non-redundant properties become "background". Thus, when stimulation is multimodal, the attentional salience of intersensory redundancy can lead to a processing priority for amodal relations. This processing priority is illustrated in a recent study. Bahrick and Lickliter (submitted) showed 5-month-old infants films of a hammer tapping out one of two distinctive rhythms. Results demonstrated that infants could distinguish between the two rhythms when they were presented bimodally (visually and acoustically), but not when they were presented in either modality alone. Further, the advantage of bimodal audio-visual stimulation over unimodal stimulation was only evident when the films and soundtracks were temporally synchronous and not when they were presented asynchronously. Apparently, the attentional salience of amodal information presented redundantly across two senses creates a processing advantage and in turn creates a developmental lag between detection of properties that are bimodally specified and those that are not. Thus, the developmental lag between detection of amodal and arbitrary intersensory relations is result of the attentional salience of redundant stimulation. This developmental lag is adaptive because it fosters infant learning of consistencies and regularities across the senses that are context independent. It fosters appropriate generalization and minimizes learning of inappropriate, context bound relations. Thus, detection of amodal relations can guide and constrain learning of nested amodal and arbitrary relations.

Together, the findings reported here provide converging evidence for the principle of increasing specificity. Through perceptual experience, infants come to differentiate increasingly more specific levels of stimulation, from global synchrony, to nested amodal relations, to modality-specific arbitrary, associations. Detection of each level constrains and guides further perceptual selectivity. In this way, selective attention to global, amodal, relations in the first months of life can provide a means of organizing, guiding, and constraining perceptual experience in a way that ultimately leads to the intermodal knowledge of the adult perceiver.

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SEVEN

Social Perception

Introduction

Have you ever noticed how disconcerting it is when someone looks over your shoulder while you are talking to them? When you look at a sea of faces, either live or in pictures, do you notice how the ones looking in your direction tend to stand out from the group? As adults, we are exceptionally sensitive to eye-contact, particularly during face-to-face conversations when eye-contact helps us determine that the message is meant for us. Well, the same thing seems to be true for very young infants.

This paper in part II, by Symons, Hains and Muir, bridges infancy research in perceptual (part II) and social (part IV) development. Social perception concerns the perception of people (and other living things) as opposed to objects. Symons et al. examine how sensitive young infants are to one social cue, adult eye-direction. There are several important differences between this selection and others in part II that should be noted. First, a certain degree of stimulus control (the use of standard pictures, or recorded sounds, that can be precisely described and used in any laboratory to replicate and extend the work) is sacrificed. Symons et al. tested infants using a more natural context designed to engage their "social perception system." The procedure is based on the discovery that when adults engage infants as young as 3-months of age in brief (1–2 minute) face-to-face interactions, the infants appear to respond in a "reciprocal" manner. Of course these young infants do not actually talk, but they do look and smile at the adult, move their arms and legs, and sometimes vocalize during the interaction, even when the infants and adults are looking at each other on TV monitors (like using a videophone).

The trick is to introduce (instruct) infants to the task by first engaging them in a normal face-to-face interaction for 1–2 minutes. Next, the adult's behavior is altered for 1–2 minutes, followed by another normal