Reprinted from: A. Diamond (Ed.), *Annals of the New York Academy of Sciences: Vol. 608. The development and neural bases of higher cognitive functions* (pp. 1-31). New York, NY: New York Academy of Sciences.

Towards a Developmental Cognitive Science

The Implications of Cross-Modal Matching and Imitation for the Development of Representation and Memory in Infancy[a]

ANDREW N. MELTZOFF

Department of Psychology
University of Washington
Seattle, Washington 98195

This book concerns higher cognitive functioning, and at the outset one might inquire whether there can be any "higher cognitive" functioning in a young human infant—an organism without language and with a brain quite different from a normal adult. The question is intriguing, because there are often sharp dissociations in infants' performance depending upon whether a question is posed to them in one way versus another. Consider two problems of memory. Faced with object-hiding tasks, young infants act as though "out of sight is out of mind." However, if these same infants are presented with an imitation-from-memory task, they clearly demonstrate that out-of-sight information is *not* out of mind, for they imitate the perceptually absent events, even after lengthy delays, with facility. Why should infant "memory" seem so fragile in one case and not the other? What does this tell us about the nature of the infants' representational code? These puzzles are addressed in this chapter.

One aim is to show that research on early cognition has relevance for theories in the neuro- and cognitive sciences. Recent work on the nature of memory, especially the work suggesting there may be multiple memory systems (Sherry & Schacter, 1987; Squire, 1987; Tulving, 1983, 1985; see Schacter, this volume), has had a strong impact on developmentalists. As I will show, several new phenomena in infant memory may now, in their turn, cycle back and interest theorists who do not traditionally investigate infant behavior and development. More generally, it will be shown that there is a body of data pertaining to what might be called "*developmental* cognitive sciences." This enterprise concerns, among other things, the origins and nature of the young child's representational system and the respects in which it does and does not change during the first few years of life. In this chapter I will focus on studies concerning imitation from memory, cross-modal coordination, and speech perception in infancy. The results suggest that infants have very different sorts of memory and representational capacities than was traditionally believed.

By investigating early imitation, we can probe the perceptual–cognitive capacities of very young infants well before the onset of language. Successful imitation

[a] A grant from the National Institute of Health (HD-22514) supported the writing of this chapter.

necessitates that infants perceive an adult's act, translate the perceived act into analogous acts of their own, and execute a motor plan. In short, infant imitation raises classic issues in perception, motor organization, and cross-modal integration. Discussed here are studies of early imitation, including the most recent experiments using newborns only hours after birth. The results reveal a primitive capacity for imitation, with direct implications for theories about cognition and the coordination of perception and action.

Imitation involves cross-modal functioning, and this leads to the issue of whether there are modality-specific stores or some capacity for "multimodal" representations in the preverbal child. Piaget postulated a newborn state in which there are uncoordinated "heterogeneous spaces"—one for the visual modality, another for audition, a third for touch, and so on. As viewed through the Piagetian lens, a major achievement of early infant development was becoming able to recognize equivalences between information picked up from separate sensory systems—to learn the correspondences between information picked up by eye, by ear, and by hand. Several studies of cross-modal matching are discussed, including the tactual–visual matching of objects and auditory–visual matching for speech sounds. The results of these new studies indicate that psychological development cannot be characterized as having an early stage in which infants are limited to registering basic sense data in the form of modality-specific retinal images or raw acoustic energy. Some of the cross-modal coordination that we used to think took place later in infancy is present at birth or achieved quite early. It is as if the senses already "speak a common language" and perception and action are closely hooked even from the earliest phases of postnatal growth.

Despite the rich beginnings, infants have some profound cognitive deficits as compared to slightly older children. This chapter considers one of these, the apparent *in*ability of young infants to act on the basis of representations of "hypothetical" events. It is argued that although young infants can represent actual states of affairs from the past, there nonetheless is a profound deficit, before about 18 months of age, in representing what "might be" or deducing what "must have been." Data will be reviewed supporting the notion that there is a fairly abrupt, regular, and ontogenetically late shift to this level of functioning. The basis for this psychological shift remains a mystery.

In sum, this chapter marshals data from the study of intact human infants to address questions about cross-modal functioning, imitation, and types of early memory and representation, and it illustrates how the new results from infant laboratories are of relevance to those working in the cognitive and neuro-sciences.

IMITATION AND CROSS-MODAL MAPPING

The imitation of facial movements poses a special psychological problem. Although infants can see such acts, they cannot see their own mouths. If the infants are young enough, they will have never seen their own faces in a mirror. At what age can they bridge the gap between the seen and the unseen? Piaget (1962) argued that facial imitation was a landmark achievement that emerged at about 1 year of age. He argued that infants needed particular types of experience to accomplish it—mirror experience or tactual experiences reaching out to comparing the mother's mouth and their own. These experiences led infants to coordinate their own unseen face with the visible face of others.

Given this context, Meltzoff and Moore's (1977) report that human neonates between 12 and 21 days old could imitate certain facial actions came as a surprise to developmentalists. Two studies were conducted, the first of which examined four different body actions: lip protrusion, mouth opening, tongue protrusion, and sequential finger movement (see FIG 1). The gestures were carefully chosen to evaluate the specificity of the imitative response. The specificity of the behavior was

FIGURE 1. Photographs of 2- to 3-week-old infants imitating facial gestures presented to them by an adult experimenter. (From Meltzoff & Moore, 1977; reprinted with permission.)

demonstrated because infants responded differentially to two different movements of the same body part (mouth opening vs. lip protrusion) and also responded differentially if two different body parts produced the same general movement (lip protrusion vs. tongue protrusion). This suggested that infants were matching particular *acts,* not just activating a certain region of their body (lips) or generally reproducing a vector in space with many body parts (general "protrusions").

Study 2 investigated whether young infants were restricted to some sort of reflexive shadowing of human actions but could not store the display and imitate after delays or intervening motor tasks. In this study, a pacifier was put in infants' mouths as they watched the display; infants could observe the adult, but could not duplicate the gestures on-line. At the end of the stimulus-presentation period, the experimenter assumed a passive-face pose and only then removed the pacifier. Infants were then given a 150-sec period in which to respond, during which the adult maintained this passive face regardless of the infant's response. The response periods were videotaped and the segments were subsequently scored in a random order by an observer who was kept uninformed as to the gesture shown to the infant in any given segment.

The pacifier technique was effective in disrupting imitation when the target was perceptually present. Infants' sucking reflex took precedence over any tendency to imitate. They did not open their mouths and let the pacifier drop out during the mouth display; nor did they push the pacifier away with their tongues during the tongue display (Meltzoff & Moore, 1977, 1983a). Even with this pacifier technique, the infants were found to imitate the two displays.

Although these findings were originally considered surprising and controversial (for reviews see Meltzoff & Moore, 1983a; Meltzoff & Kuhl, 1989), the findings of early imitation have now been replicated and extended in well over a dozen different studies in eight independent laboratories, both in this country and cross-culturally—in Nepal, France, Switzerland, and Sweden (Abravanel & Sigafoos, 1984; Field, Goldstein, Vaga-Lahr & Porter, 1986; Field *et al.,* 1983; Field, Woodson, Greenberg & Cohen, 1982; Fontaine, 1984; Heimann, 1989; Heimann & Schaller, 1985; Heimann, Nelson & Schaller, 1989; Jacobson, 1979; Kaitz, Meschulach-Sarfaty, Auerbach, & Eidelman, 1988; Reissland, 1988; Vinter, 1986). In short, the basic phenomenon reported by Meltzoff and Moore has now been documented by independent investigators, in different settings, using a variety of different procedures. Attention has now shifted from debates about the existence of early behavioral matching to a search for the mechanisms underlying this precocious perceptual–motor coordination.

An Innate Basis of Early Facial Imitation

One possibility was that the 3-week-old subjects in our original studies might have learned to mimic during the nonverbal "dialogues" that occur during face-to-face interactions with caretakers. If early imitation depends upon such learned contingencies, then newborn infants in the first hours of postnatal life should fail at these tasks. A test was designed involving 40 newborns with a mean age of 32 hours (Meltzoff & Moore, 1983b). The youngest subject was only 42 *minutes* old at the time of test.

The infants were tested in a laboratory located within a newborn nursery in a large Seattle hospital. Infants acted as their own controls, and each was presented with both a mouth-opening and a tongue-protrusion gesture in a repeated-measures design, counterbalanced for order. Two 4-min test periods were used, one for each type of display. Within each 4-min block the experimenter alternately demonstrated the gesture for 20 sec, then assumed the passive-face pose for 20 sec, and so on. At the end of this first 4-min period, the experimenter simply switched gestures. The entire experiment was time-locked, and there were no breaks or pauses during the test.

The experiment was videotaped and subsequently scored by an observer who was blind to the modeled behavior. The results supported the hypothesis of imitation. Infants responded with significantly more mouth openings in response to the adult mouth-opening display than to the adult tongue-protrusion display. Similarly, there were more tongue protrusions in response to the adult tongue-protrusion display than to the adult mouth-opening display. Statistical tests were also conducted to assess the correlation between imitative performance and hours since birth. No correlation was found.

The question arises as to whether oral matching is privileged, or whether early imitation is based on a more general proclivity for visual–motor mapping. In the next study we assessed the newborns' ability to imitate an adult head movement (Meltzoff & Moore, 1989). Production of controlled head movements are not beyond the motor abilities of newborns, if their heads are well supported. A group of 40 newborns with a mean age of 40.6 hours old was tested.

For the purposes of determining the underlying mechanism, it is necessary to evaluate whether infant "tracking" responses might be mediating the mimicry of the head-movement gesture. Might infants make head movements of their own as they visually track the adult's moving head, in a sense being perceptually tethered to the adult's movements? This account would predict that infants would make head movements during the stimulus display (when the adult's head was moving), but would cease when there was no movement in the perceptual field, no moving stimulus to "drag" along the infant's head.

The data were first analyzed isolating the responses obtained during the adult gesture periods alone (the 20-sec periods in which the gesture was performed); and, as expected, infants significantly matched the adult during these periods. Analyzed next was the data from the passive-face periods alone. During these 20-sec periods there were no adult movements to follow visually, only a stationary face to fixate. The results showed that the infants matched the adult's gesture, even though there was no movement to track at the time.

Finally, it was investigated whether infants might be continuing a response into the passive-face period that they had begun in the presence of the model. This was addressed by determining whether infants successfully imitated head movements during a passive-face period even if they had made no previous head movements during the adult's display. For this analysis, infant head-movement responses had to meet two criteria: (a) they had to occur during a passive-face period, and (b) the infant could not have already produced any head movement during the adult gesture period. The first criterion assured that the infant was not presently tracking the adult (because the adult was physically stationary during the passive-face intervals). The second criterion assured that the infant had not yet performed such a tracking head movement in a previous gesture period (and therefore could not merely be continuing or repeating it). The results supported the results of imitation. Infants produced more head movements to the adult head-movement display than to the tongue-protrusion display even under these restrictive conditions, which indicates that tracking is not a *necessary* condition for eliciting this matching response. (Tracking may, of course, be sufficient for eliciting head movements.)

The hypothesis we offered to account for early imitation is that it is accomplished through a process of active intermodal mapping (AIM) (Meltzoff, 1985a; Meltzoff &

Moore, 1977, 1983a, 1983b). The crux of the AIM hypothesis is that neonates can, at some level of processing, apprehend the equivalence between body transformations they see and body transformations of their own that they "feel" themselves make. The adult's gesture would truly act as a model against which infants would compare their responses (Meltzoff, 1990).

EARLY TACTILE–VISUAL COORDINATION

One way of probing the foregoing viewpoint is to conduct converging experiments—for example, testing whether young infants exhibit skills other than imitation that also rely on the ability to appreciate and use intermodal equivalences. An experiment was therefore conducted to evaluate cross-modal matching in 1-month-old infants (for reviews of cross-modal work with older infants, see, Rose, this volume; Butterworth, 1981a; Rose & Ruff, 1987; Spelke, 1987).

To evaluate early cross-modal functioning, Meltzoff & Borton (1979) modified the standard visual paired comparison technique used for assessing recognition memory in infants (Fagan, 1970, also this volume). Such tests begin with a brief familiarization period during which the infant is allowed to look at a stimulus. Next, the infant is shown a pair of stimuli, one matching the original stimulus, the other novel. If infants show differential visual fixation to the familiar versus novel stimulus, this is taken as evidence for visual discrimination and recognition memory. Our experiment followed the same logic and general experimental procedure, except the infants were not allowed to *look* at the initial stimulus. Instead, they were given the object to explore tactually during the familiarization period. The tactual object was then removed and the infants given the paired-comparison visual test.[b]

In pilot studies we attempted putting objects in infants' hands during the tactual

[b] In most studies of visual recognition memory, infants of about 5–6 months old fixate longer on the novel pattern (Fagan, this volume). However, the basic logic of the test paradigm holds whether the infants prefer novelty or familiarity. If there are no experimental artifacts, then any deviation from the 50% chance level (whether in one direction or another) during test indicates that the infant's experience during the familiarization phase is influencing the preference during test; it indexes some sort of memory or retention phenomenon. Interestingly, the direction of infant preference, novelty versus familiarity, appears to depend on a host of factors, rather than being "naturally fixed" to the novel stimulus. Ten years ago I (Meltzoff & Borton, 1979, Table 1; Meltzoff, 1981) described four factors that appeared to interact to determine the direction of infant preference: (a) age (developmental level) of the subject, (b) familiarization time, (c) perceptual modalities used in familiarization and test periods, and (d) the complexity of the stimuli. These factors seem to operate such that holding familiarization time and all other things constant, older infants will tend to prefer novelty relatively more than younger ones; presumably this is because older infants process the information faster and identical amounts of absolute study time are not *psychologically* identical. On the other hand, same aged infants may be shifted from a familiarity to a novelty preference by lengthening the study time (habituating the infant on the familiarization stimulus is an extreme version of this approach). One modality (e.g., vision) may be a quicker mode of extracting particular stimulus information (shape) than another (e.g., touch). The overarching idea is that the direction of preference reflects the degree of encoding of the familiarization stimulus and the match between the stored representation of the familiarization stimulus and the test stimuli (*cf.,* Meltzoff, 1981; Hunter, Ames & Koopman, 1983; Rose, Gottfried, Melloy-Carminar & Bridger, 1982; Wagner & Sakovits, 1986).

familiarization period. This procedure had to be abandoned, however, because neonates tended to grasp the objects rigidly rather than to explore them actively. Gibson's (1962, 1966) work with adults had already shown that cross-modal matching was particularly difficult, even for adults, if the subject is not allowed to actively explore the familiarization stimulus. Next, we tried putting the objects in their mouths. This proved successful—the neonates actively explored them with their lips and tongues.

Pacifiers were modified so that mouth-sized geometric shapes could be mounted on them (see FIG. 2). The tactual shapes used in the test were a small sphere and a sphere-with-nubs. Visual objects of the same shapes were constructed out of orange styrofoam for the infants to examine in the subsequent paired comparison visual test. The experiment evaluated the extent to which the infants systematically fixated the shape they had previously felt.

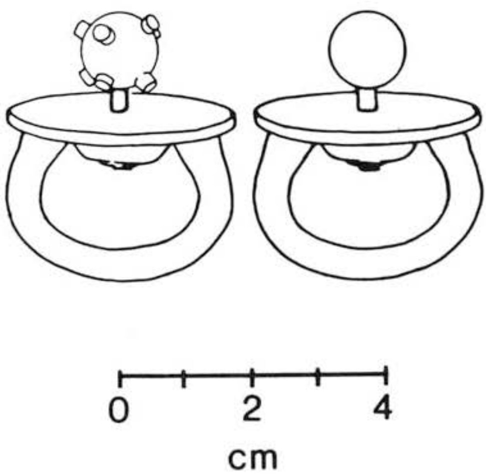

FIGURE 2. Shapes used to assess tactual-visual matching. (From Meltzoff & Borton, 1979; used with permission.)

Two studies were conducted using infants about 1 month old (mean age = 29.4 days). Both experiments commenced with a 90-sec tactual familiarization period during which the infants orally explored either the sphere or the sphere-with-nubs. The tactual object was then carefully removed without the infant seeing it, and the infant presented with the visual choice.

Of the 32 infants tested in the first experiment, 24 fixated the shape matching the tactual object longer than the non-matching shape ($p < 0.01$). The mean percent of total fixation time directed to the matching shape was 71.8%, as compared with the chance level of 50% ($p < 0.01$). Several other recent studies corroborate the findings. Using different stimuli, Gibson and Walker (1984) reported positive effects in a cross-modal task with 1-month-old human infants using oral exploration. The neonatal cross-modal effect was also replicated and extended by Pêcheux, Lepecq, and Salzarulo (1988). In an intramodal discrimination task, Rochat (1983) confirmed that infants in the first month succeeded on shape discrimination tasks when differently shaped nipples were inserted in their mouths. Streri (1987) and Streri and Spelke (1988) reported positive effects for a manual–visual test in 2- to 3-month-old and 4-month-old infants, respectively. Gunderson (1983) borrowed the cross-modal stimuli from our lab, pacifiers and all, and replicated Meltzoff and Bortons' results in a study using infant pigtail monkeys under 1 month of age.

The inference that can be drawn from all this work with infants under 6 months of age is that some primitive ability to detect correspondences between touch and vision is basic to the perceptual system of human infants, possibly even of certain nonhuman primates, without need for a protracted learning process.

CROSS-MODAL SPEECH PERCEPTION: A RECOGNITION TASK

One question that immediately arises concerns the generality of the cross-modal effects: Is there a privileged relation between the visual and tactual/motor systems, or is there evidence for cross-modal relations in other modalities as well? Another question concerns the basis of early cross-modal effects: What is the "invariant" that is recognized across modalities? The domain of speech perception provides an exceptionally rich arena in which to pursue such questions. It is clear, for example, that adults can recognize speech by eye, as they do when they lip-read. Visual information about speech is taken into account when faces are presented to listeners (Green & Kuhl, 1989; Massaro & Cohen, 1983; McGurk & MacDonald, 1976). At what age does speech attain a multimodal character?

Kuhl and Meltzoff (1982) presented 4-month-old infants with a lip-reading problem. The major goal was to test whether young infants could recognize the correspondence between the visual and auditory manifestations of a speech act. We tested whether infants recognized that an /a/ vowel sound (as in "pop") corresponded to one articulatory gesture and that an /i/ sound (as in "peep") corresponded to another articulatory gesture. The infants were placed within a three-sided enclosure (see FIG. 3). A film of two faces articulating the vowels was projected onto the front wall of the enclosure. One face was articulating the /a/ vowel, and the other the /i/ vowel. The two faces were life-sized and in color. The faces were filmed and edited so that they would articulate in perfect temporal synchrony with one another. The vowel sounds were presented from a loudspeaker placed midway between the two faces.

Thirty-two 4-month-old infants served as subjects. The test was initiated with two sequential 10-sec periods in which each visual face was presented without sound. The infant's attention was then brought back to the midline by flashing a small light between the faces. Then, one soundtrack (/a/ or /i/) was activated and the films of the two faces were allowed to play for a 2-min test period.

If infants could detect correspondence between auditory speech and visual speech, they should look longer at the face that produced movements appropriate to the sound they heard. The hypothesis was supported. Of the total fixation time, 73.6% was devoted to the face that matched the soundtrack, which is significantly greater than the 50% chance level ($t[31] = 4.67, p < 0.001$). An independent team of investigators has also reported a cross-modal matching effect for speech in 5- to 6-

month-olds using consonant-vowel-consonant-vowel (CVCV) disyllables such as "mama" versus "lulu" (MacKain, Studdert-Kennedy, Spieker & Stern, 1983).

Towards Specifying the Basis of Cross-Modal Speech Perception

What is the psychological basis for these face–voice matches? Suppose in our experiment that the auditorially presented /a/ vowels happened to be longer in duration than the /i/ vowels, and the /a/ articulatory acts were similarly longer. If this were the case, infants could have succeeded on the task by using purely temporal information (e.g., the longer sound would have emanated from the longer visual movement). Nothing about the infants' representation of *speech* per se need be involved. This concern is real enough because infants' ability to recognize temporal patterns cross-modally has been demonstrated (Dodd, 1979; Spelke, 1979, 1987).

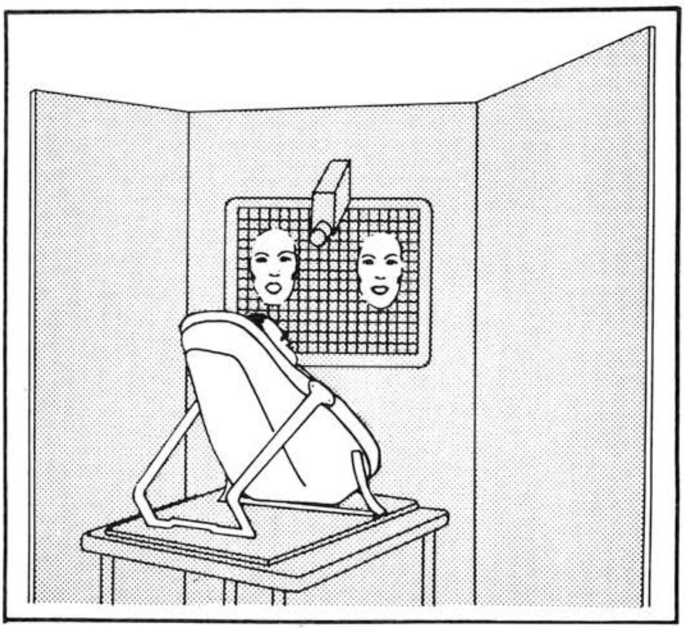

FIGURE 3. Experimental arrangement used to test cross-modal speech perception in infants. (From Kuhl & Meltzoff, 1982. Used with permission.)

To test this possible basis for our speech effect, the /a/ and /i/ vowels were altered to remove the spectral information that distinguished the sets of vowels (their formant frequencies) while leaving the temporal and amplitude aspects of the signal intact (Kuhl & Meltzoff, 1984). In a sense, we stripped away the "vowelness" of the signals and left all the other temporal parameters of the sound the same. If infants were succeeding on our task by using purely temporal patterns to link the auditory and visual events, then they should still succeed on this task. Using computer analysis techniques, both the time-intensity curves (the amplitude envelopes) and the precise durations were extracted from each of the vowels used in the original experiment. Then pure-tone stimuli were computer-synthesized that precisely matched these temporal parameters. These stimuli were synthesized with a frequency of 200 Hz (the average value of the talker's fundamental frequency). The altered stimuli were used with another group of 32 infants of the same age as the original sample. The test procedure was identical to that of Study 1. The results fell to chance. It was not that the infants were inattentive to the faces in the presence of these altered stimuli. Infants spent an average of 93.1% of the test time staring at one or the other of the articulatory gestures, which did not differ from that spent in Study 1 (90.3%). However, the direction of their visual fixations were not driven by these altered auditory signals. Of the 32 infants, only 17 looked longer at the "matched" face.

The results show that spectral (formant frequency) information is critical to the detection of the face–voice correspondences in our experiments. In essence, infants can link up a particular vowel quality and the sight of the articulatory movements that naturally correspond to that sound. Work in our laboratory is now being directed at isolating the more precise spectral information that is supporting the cross-modal effect. This research involves systematically taking apart the speech signal—for example, presenting infants with signals that one by one isolate certain "distinctive features" of the vowels. The aim of this line of work is to isolate the necessary and sufficient aspect of the auditory signal that allows the infant to link it to the moving faces. Some progress has been made in this regard (Kuhl & Meltzoff, 1984, 1988)—a venture that Gibsonian theorists would call specifying the intermodal invariant. Regardless of the outcome of this research, the current findings suggest that the registration of speech signals is not solely the province of acoustic analyzers. It may be fruitful, as well as more ecologically valid, to think of speech as a multimodal event (Kuhl & Meltzoff, 1988). Speech can be perceived by eye as well as by ear[c]; there is a multimodal representation of speech even in "prelinguistic" infants who are too young to speak, and this may facilitate their eventual mastery of language.

VOCAL IMITATION: A PRODUCTION TASK

The foregoing task probed the infant's knowledge of auditory–articulatory links in a *perception* task. A far more important skill, and a deeply related one, is the link between audition and articulation in *production*. Human infants acquire the vocal repertoire of their particular culture by hearing and mimicking it. Even before the children's first words emerge, they will have adopted the particular accent or tone of their native language (e.g., de Boysson-Bardies, Sagart & Durand, 1984).

This species-typical proclivity for vocal learning is not widespread in the animal kingdom (Kuhl, 1988). We share this ability with avian species who learn their full conspecific song only if they are exposed to it during a critical period early in life (Marler, 1974; Nottebohm, 1975). The evidence shows that early auditory experience is also critical to the development of the vocal repertoire in humans. Early rearing in

[c] For possibly related work at the neural level concerning auditory–visual interactions in nonhuman animals, see Meredith & Stein (1983, 1985) and Stein & Meredith, this volume.

a particular language environment puts a long-lasting mark on one's speech patterns. Chomsky—not renowned for his emphasis on experience—has pointed to the role of early auditory exposure in the development of phonetics. He cites his own current Philadelphian accent, despite not living there for over 25 years, as a good instance of the long-lasting mark of early environment on the development of speech (Rieber, 1983).

When in development do humans begin mimicking the speech patterns they hear; when do they begin vocal imitation? The cross-modal speech studies provided a laboratory setting in which to study this issue. The stimuli were totally controlled, both visually and auditorially. There were no human interactions with the infant during the test, and the infants were seen in one visit with the test lasting approximately 2 min; thus there was no chance for the adult to shape the infant during the session.

Imitation of Speech Sounds in Early Infancy

Kuhl and I analyzed the vocalizations of the 64 infants who participated in the /a-i/ studies, as well as the vocalizations of infants in the ongoing studies using non-speech (pure tone) signals. The results demonstrated a clear superiority of human speech in eliciting infant vocalizations, even though the non-speech sounds were acoustically equated in loudness, duration, and temporal envelope to human speech sounds (Kuhl & Meltzoff, 1988, and in press). This informed us about the stimulus characteristics effective in eliciting infant speech. It also provided suggestive evidence that young infants responded differently to animate (in this case, human speech signals) versus closely matched inanimate signals (temporally matched sounds from a nonhuman source). It is relevant to social–developmental theory that this distinction may be made in the auditory domain at this early age (Carey, 1985; Gelman & Spelke, 1981), and also that infants respond to human sounds by vocalizing ("talking back?") to them more than to the inanimate one.

Rich though they are, these data did not provide firm evidence that infants' productions actually duplicated or were organized around what they heard. The infants' productions were, therefore, analyzed to determine the degree to which they conformed to the speech presented (Kuhl & Meltzoff, in press). Two approaches were taken—speech analysis by computer and perceptual scoring by a trained phonetician.

The phonetician listened to each infant's productions and judged whether they were more "/i/-like" or "/a/-like." Infants at this age do not typically produce perfect /i/ vowels due to anatomical restrictions on their vocal tracts. They can, however, produce other high front vowels such as /I/ or /ɛ/ (as in pip and pep, respectively). Similarly, a perfect /a/ is difficult for 4-month-olds, but similar central vowels, such as /æ/ and /ʌ/ (as in pap and pup) are elicitable. Thus, the judgment made by the observer was a forced-choice one concerning whether the infant's vocalizations were more /a/-like or more /i/-like. The results showed that infants produced /a/-like vowels when listening to /a/ and /i/-like vowels when listening to /i/, allowing the judges to predict with 90% accuracy the vowel heard by the infant from the vocalization the infant produced ($p < 0.01$).

The second type of scoring involved speech analysis by computer and was guided by distinctive feature theory (Jakobson, Fant & Halle, 1952). The formant frequencies of /i/ are spread widely apart (exhibiting the distinctive feature "diffuse"), while the formants for /a/ are close together in frequency (exhibiting the distinctive feature "compact"). The first and second formant frequencies were extracted from each infant vocalization, and the values of the diffuse-compact feature were calculated using the formulae devised by Fant (1973). The data showed that infants hearing /i/ produced vocalizations that were significantly more diffuse. Similarly, infants hearing /a/ produced sounds that were significantly more compact (Kuhl & Meltzoff, in press). Thus young infants demonstrate a capacity for vocal imitation.

LONG-TERM MEMORY, REPRESENTATION, AND THE CONTROL OF ACTION IN 1- TO 2-YEAR-OLD CHILDREN

Imitation can only play a limited role in development if it is severely constrained in terms of the types of acts imitated or the temporal interval that can be spanned. For imitation to be of true functional significance in infant psychology, infants must imitate object-related actions as well as the simple body movements and vocalizations discussed in the foregoing sections. Infants must also be able to imitate an event that they may have seen only once, perhaps hours or days earlier. At what age do we find imitation from memory after significant delays?

Meltzoff (1988a) conducted a study of deferred imitation in a large sample of 9-month-olds: 60 were tested immediately and 60 after a 24-hour delay. Three different target actions, each involving a different object, were shown to the infants. In the experimental condition, infants were shown all three actions on day 1 and then were presented with the objects either immediately (immediate imitation group) or after a 24-hour delay interval (deferred imitation group). During the response period the infants' behavior was videotaped; it was subsequently scored by observers, who were blind to the treatment group, to determine how many of the target actions had been produced. Three types of control groups were used to evaluate the chance likelihood that the target acts would be produced spontaneously in the absence of modeling. The control infants were subjected to the same general procedure as infants in the imitation conditions, except that they did not see the target actions modeled.

In the "baseline" control condition, the infants were simply presented the objects with no adult demonstration; this assessed the spontaneous likelihood of the target acts. In the "adult-touching" condition the adult touched each object during the stimulus-presentation period, but did not demonstrate the target acts themselves. This controlled for the possibility that infants might be induced into producing the target behavior if they simply saw the adult approach and touch each object even if the exact target action was not modeled. The third control, the "adult-manipulation" condition, mimicked the imitation condition even more closely; the experimenter actively played with the objects during the display period (just as in the imitation condition) but refrained from demonstrating the particular target acts under test.

A Condition (4) $\times$ Delay (2) ANOVA showed a main effect for condition ($p < 0.001$). A follow-up Newman–Keuls test showed that infants produced more target behaviors in the imitation condition than in each of the controls (all p's < 0.05) and that the level of responding in the control conditions did not differ among themselves. There was no main effect for delay, and no Condition × Delay interaction, indicating that the imitation effect was not dampened after the 24-hour delay. At the level of individual subjects, the most striking examples of intentional imitation came from those subjects who duplicated all three of the behaviors they were shown. In the imitation condition 20% of the infants retained and accurately imitated all three of the displays. None of the 72 control infants did so, documenting that this is an otherwise improbable event in spontaneous play with these objects ($p < 0.0001$).

The next study both increased the retention interval and broadened the range of acts that has been investigated (Meltzoff, 1988b). We used a retention interval of 1 week and investigated whether infants could keep in mind a wide variety of actions, including a novel action. Imitation serves the function of providing "no trial" learning in our species precisely because it allows the direct pick-up of novel behaviors from the observation of others. The ability to imitate novel acts after a delay would be of great adaptive significance for an infant.

Six different actions on different objects were shown to 14-month-old infants on day 1. One object was a small wooden box with a translucent orange plastic panel for a top surface. The novel act demonstrated was for the experimenter to bend forward and bang the panel with the top of his forehead. The design of the experiment was similar to that just described (in which the performance of an imitation group was compared both to baseline and to adult-manipulation controls).

TABLE 1. Number of Subjects Producing Different Numbers of Target Acts as a Function of Test Condition

	Number of Target Acts						
Test Condition	0	1	2	3	4	5	6
Baseline control	3	4	4	1	0	0	0
Adult-manipulation control	2	4	4	0	2	0	0
Imitation	0	1	0	6	3	2	0

An ANOVA on the number of target acts produced as a function of treatment showed that infants produced significantly more target actions in the imitation condition than in the control conditions, $p < 0.05$ (TABLE 1). Eleven of the 12 subjects in the imitation condition duplicated three or more target behaviors, whereas only 3 of the 24 control subjects did so ($p < 0.0001$). What is most striking is the aptitude these young infants exhibited for duplicating the novel act. Fully 66% of the infants in the imitation condition produced this behavior as compared to none in the control conditions ($p < 0.0001$).

Infants' Use of Symbolic Models to Guide Real-World Action and the Role of Similarity between the Model and the Self

In all the research discussed in the foregoing sections, an adult served as the model. In such cases the infants are directly mimicking with their own bodies acts that were seen in 3-D space with a minimum of differences between the stimulus (the adult's actions) and the response (the imitative act). It is also of interest whether infants can perform deferred imitation when there is "distancing" (Werner & Kaplan, 1963) or a symbolic relation (Potter, 1979) between the stimulus and response, that is, when the initial display is not in the identical format as the subsequent matching response. Television presents a miniature, two-dimensional depiction of actions in three-dimensional space. Will infants readily pick up information depicted in this type of 2-D representation and incorporate it into their own behavior?

Meltzoff (1988c) tested imitation from TV models in subjects at two ages, 14 and 24 months, under conditions of immediate and deferred (24-hour delay) imitation. In the deferred imitation condition, infants were exposed to a TV display of an adult manipulating a novel toy in a particular way, but were not presented with the real toy until they returned to the lab after a 24-hour delay. Note that the "real" object was not in the infant's perceptual field during the televised display, and thus the infant did not have the opportunity of looking back and forth between the TV depiction and the real object.

Infants did not treat the TV as real; they did not reach for the object in the TV, and they smiled at the person on TV less than in the live situation. Nonetheless, infants as young as 14 months old used this type of miniature model as a guide for their real-world actions. Infants' imitation from a TV display (a display that they did not confuse with a real person) provides a glimpse into the very earliest phases of their ability to use "models" of reality to guide their actions—an issue of significance in adult cognitive psychology, and the focus in a series of elegant studies by DeLoache (1987, 1989, in press).

There are, of course, important differences between the imitation-from-TV task and those devised by cognitive developmentalists such as DeLoache. The TV display used in our studies of infants has a fairly iconic link to the world it depicts (though some theorists emphasize the symbolic/representational aspects of pictures [e.g., Goodman, 1968] more than others [Gibson, 1979]). Nonetheless, it is of interest that preverbal infants can succeed using this iconic depiction of reality as a guide for their own subsequent actions, especially in view of DeLoache's (1987) data that 2.5-year-old children uniformly fail on a related task in which they must use a small-scale model as a "map" to guide their behavior in a full-sized environment. Specifically, the children in her study were shown an object being hidden in a scale model and asked to find an analogous object in a corresponding location in a large environment. The imitation-from-TV task would seem to be a lower-order task than the use of such small-scale "maps," because imitation involves recreating an action, whereas the DeLoache task involves projecting a spatial relation between particular objects from one domain (in the scale-model space) to another. It would now seem profitable to investigate whether preverbal infants in the imitation task could succeed if the information were depicted by scale-model dolls or represented in a series of stick-figure drawings.

Adults and older children often learn actions with special facility within situations in which the model is perceived to be "like me." Hanna and Meltzoff (1989, 1990) conducted a series of studies testing peer imitation among infants. Specifically, we wanted to see what would happen if infant "experts" (infants who had already learned to produce a series of specific target actions) demonstrated particular target actions to "infant novices" (who had no previous training). In the 1989 experiment, the novice 14-month-old infants were allowed to watch the expert 14-month-old infants manipulate the objects, but were not allowed to handle the toys during this peer modeling. A 5-minute delay period ensued before the observers were re-presented with the test objects. In the peer imitation group, 80% of the infants who watched the peer modeling produced 3 or more of the 5 targets modeled, as opposed to only 1 of 20 control infants ($p < 0.0001$). Similar results have been found in a follow-up study using a 48-hour delay and a change of context (infants were shown the display by a peer in the lab and given the recall test at home) (Hanna & Meltzoff, 1990). The striking level of success in these peer-modeling studies raises the (somewhat counterintuitive) possibility that in some cases infants may actually learn better from observing their peers than from the pedagogical forays of parents. Perhaps the actions of peers are in some sense perceived of as more "like me," and therefore the projection from observed action to performed action is facilitated (Bower, 1982, 1989; Meltzoff, 1990).

SIX ASPECTS OF INFANT COGNITION IN SEARCH OF ADULT CORRELATES AND NEURAL UNDERPINNINGS

Six principal findings can be culled from the foregoing sections that concern cognition in infancy. The implications of these findings for recent work in neuro- and cognitive psychology will be considered in subsequent sections.

(1) *Long-term memory.* The results on deferred imitation demonstrate that at least by 9 months of age infants have long-term memory for briefly displayed events (Meltzoff, 1988a). Infants were not allowed to learn the response through motor practice because they were not allowed to touch the toys during the demonstration. Yet, they imitated the model after the 24-hour delay.

(2) *Memory for a novel action.* Is infant imitation from memory limited to acts that are already well-practiced and familiar? Meltzoff (1988b) presented 14-month-old infants with a series of actions, including a completely novel one that had a zero probability of occurrence in the absence of modeling. The results demonstrated deferred imitation. Evidently, infants can acquire a new response from a brief observation and no motor practice and can reproduce it after a significant delay interval—in this case, a delay interval of 1 week.

(3) *Cross-modal memory.* Meltzoff and Borton (1979) showed that 1-month-olds could perform simple cross-modal matches for shape (or texture) information. The design required sequential, not simultaneous, matching. Infants were given the shapes to feel in their mouths; the shapes were then removed, and only then were the visual shapes presented for the cross-modal recognition test. A good deal of work supports the notion that infants in the first 6 months of life can perform cross-modal matches; this particular experiment is of interest because of the age of the subjects (1 month old), and the fact that a sequential matching task was used.

(4) *The multimodal representation of speech in infants.* Kuhl and Meltzoff (1982) presented 4-month-old infants with a lip-reading task. Infants detected the cross-modal match between speech as picked up by eye and ear. Further experiments

showed that this was not due to cross-modal timing information (e.g., the length of time the sound was on and the lips were moving). The results fell to chance when the auditory signal was altered so as to preserve timing information, but to delete the spectral information necessary for identifying the vowel. Kuhl and Meltzoff (1988, also in press) also found that 4-month-olds imitate speech sounds. There seems to be a special bond between the audition and articulation of speech in young infants, regardless of whether the articulatory act is picked up by eye (cross-modal speech effect) or is self-generated (vocal imitation). For young infants, speech appears to be represented in a non-modality-specific form, which elsewhere led us to talk about "supramodal speech units" (Kuhl & Meltzoff, 1984, 1988).

(5) *Facial imitation in newborns: Coordination of perception and action.* A series of studies showed that infants have a proclivity to reproduce elementary body acts that they see. This is an innate ability in the sense that we have demonstrated facial imitation in infants as young as 42 minutes old at the time of test. Imitation of facial gestures implies that infants have some capacity to equate their own unseen behaviors with gestures they see others perform. A common representational code may unite the perception and production of basic human acts.

(6) *Hints of a very early capacity to act from memory.* Are neonates constrained to direct mimicry in which the matching motor response is triggered concurrently with the perception of the adult's action? In this case, early imitation would reveal an intertwining of the perceptual and motor systems, but would not implicate a memory component. Two experiments suggest that imitation goes beyond immediate perception and taps early memory and representation.

(a) Meltzoff & Moore (1977) used a pacifier to block immediate, on-line imitation. The pacifier was put in the infant's mouth while the target action was demonstrated. Infants tended to suck on the pacifier, thus engaging in competing motor activity during the display (Meltzoff & Moore, 1977, 1983a). The adult then stopped the display and only then removed the pacifier. Even after the pacifier was removed, there was no evidence for an immediate bursting forth of the response, as if the response was fragilely retained in the motor system (on the tip of the infant's tongue, as it were). Infants frowned at the adult's now passive face, and often after a considerable pause, began to imitate during the 2.5-min period that followed (Meltzoff, 1981; Meltzoff & Moore, 1983a). There was also evidence that they corrected their response over successive efforts, despite the fact that they could not re-access the target display visually.

(b) Meltzoff & Moore (1989) designed a newborn study in which there was an alternation between a demonstration period and a passive-face pose. The data were analyzed to check whether the imitation occurred solely during the demonstration period and then dropped to chance when the target display was no longer perceptually present. In other words, was "out of sight" functionally equivalent to "out of mind" for the neonate? The results showed imitation even during the passive-face periods. Moreover, a microanalysis demonstrated that infants could *initiate* the imitative response during these passive-face periods; imitation was evidenced during the passive-face period among subjects who had not begun their responses during the modeling (and thus could not simply be repeating motor patterns that had been produced in the presence of the model). Experiments with longer delays are now under way.

MULTIMODAL REPRESENTATIONS OF HUMAN FACES AND SPEECH SOUNDS—INNATENESS AND DEVELOPMENT

The findings summarized above suggest that cognitive and neuropsychological theories will need to take into account that infants are capable of—indeed quite engaged by—complex equivalence mappings. Infants have as part of their innate representational system, or form with great facility, equivalence classes that project not only within but also across sensory modalities (for related work with animals see Fuster, this volume, and Stein & Meredith, this volume). TABLE 2 summarizes the relevant findings from the foregoing sections.

We have proposed that facial imitation in newborns is mediated by a process of active intermodal mapping (AIM). In our view infants use their representation of the adults' act as a model or guide for fashioning motor output. The AIM hypothesis would gain force if converging evidence showed that young infants are capable of other cross-modal connections, especially ones involving facial movements. It is, therefore, of special interest that another phenomenon discussed here, the cross-modal speech effect, requires that infants recognize a complex mapping between audition and oral movements. Although the data permit us to assert that the visual–motor mappings involved in facial imitation are innately structured (imitation is shown within minutes or hours of birth), the same claim cannot yet be made about the auditory–visual mappings, inasmuch as experiments with subjects that young have yet to be done.

TABLE 2. Four Phenomena and the Types of Cross-Modal Connections They Suggest

Phenomena	Type of Mapping
Visual recognition after oral exploration	Tactile → Visual
Facial imitation	Visual → Motor
Cross-modal speech effect	Auditory → Visual
Vocal imitation	Auditory → Motor

In fact, there are at least three developmental alternatives for the cross-modal speech phenomenon. (a) The infants may simply have learned which articulatory gestures go with which sounds by watching and listening to adults. This would reduce to associative learning. (b) There may be an innately specified code that unifies auditory, visual, and motor realizations of human speech acts (Kuhl & Meltzoff, 1982, 1984), in which case auditory–articulatory mappings are part of our biological endowment. If so, then a follow-up newborn study, as was performed on the gestural imitation case, would yield positive results. (c) However, there is also an intriguing third alternative that we have dubbed the "babbling account" (Kuhl & Meltzoff, 1984, 1988). The crux of the idea is that the infants' own experience in listening to themselves cooing and babbling may play an important role in the development of the cross-modal speech effect. The possibility that self-generated experience may be used by infants is sometimes overlooked by developmentalists (for exceptions in the infancy literature see Bower, 1982, 1989; Studdert-Kennedy, 1986; and for related points with birds, see Konishi, 1965; Marler & Sherman, 1983; Nottebohm, 1975). The babbling account highlights the value of self-generated experience and also illustrates a developmental framework in which innate competencies provide footholds for the infant to climb to the next level of functioning.

How could such babbling experience help infants in the cross-modal situation? It could help only if infants can relate the articulations they *see* in our experiment to the auditory–articulatory events they themselves *produced* during cooing and babbling. The research indicates that this is likely. With regard to vision, infants' ability to imitate visual gestures demonstrates that they can relate mouth movements they see to their own mouth movements. There is thus a foothold on mapping the seen articulation to their own felt articulations. Kuhl's (1979, 1983, 1985) speech categorization work demonstrates that young infants can recognize the equivalence between the vowels uttered across talkers, including those produced by children and adults. Thus, there is also a similar foothold on the auditory side for infants recognizing an equivalence between the heard adult vowels to their own.

In short, infants have the requisite tools, as manifest by facial imitation and the cross-talker categorization of vowels, to use babbling and cooing experience to help solve the cross-modal speech task. Babbling provides infants with an auditory–articulatory event in which /a/ sounds are produced by /a/ articulations with their own body. The cross-modal experiment now re-poses that question for another's body, not one's own. The information gained during their own babbling may contribute to infants' ability to recognize cross-modal equivalences for speech in others. Infants would project knowledge acquired through the self system onto the domain of the other. This hypothesis is being evaluated through careful longitudinal work tracing the development of individual subjects. If it receives support, it would provide a rather neat developmental picture in which the (innate) mechanisms involved in facial imitation become more than striking competencies, and in turn provide a means of engendering other cross-modal abilities such as speech perception abilities.

ON INFANT MEMORY AND ITS DEVELOPMENT

Cognitive and neuropsychological work with normal adults, amnesic patients, and animals has led to many distinctions within the broad concept of "memory." A point that has repeatedly emerged is that there are reasons for distinguishing between the retention of habits and skills that are acquired through incremental learning over many trials versus the retention of specific events or episodes that may have occurred only once. Discussion continues about how to best characterize that distinction, but very generally, it has been captured in the terms "procedural—declarative," (Squire, 1987), "habit formation—memory formation" (Mishkin, Malamut & Bachevalier, 1984), "early memory system—late memory system" (Schacter & Moscovitch, 1984), and "memory system I—memory system II (Sherry & Schacter, 1987). Tulving's (1983, 1985) three-tiered, hierarchical scheme of "procedural–semantic–episodic" memory also divides the landscape in a related way.

These distinctions in types of memory have been brought to the fore by cognitive and neuropsychologists, but it is surely something with which developmentalists feel familiar (Mandler, 1983; Meltzoff, 1981). Piaget also tried to capture the differences with his own terms (Piaget, 1952, 1954, 1962). He believed that young infants were capable of retaining what he called "sensorimotor habits or schemes," but that the young infant was incapable of acting on the basis of specific "mental images or representations" of perceptually absent objects or events. In essence, Piaget hypothesized that a memory system of the habit/procedural kind was the developmental precursor, the necessary prerequisite, for the later emergence of one of the non-habit, declarative/episodic variety. He postulated that this stage transition occurred at about 18 months of age.

Young Infants Are Not Limited to a Habit/Procedural Memory System

Are very young infants constrained to one variety of memory and not another? At what age do they gain access to the more mature system(s)? What is the basis for this development? The new data summarized in this chapter can be brought to bear on some of these questions. I conclude from these data that human infancy, even early infancy, is not best characterized as the operation of an exclusively habit/procedural system. A higher level memory system, a *non*-habit/procedural system is present well within the first year.[d]

The clearest data are those from the research on deferred imitation (as summarized in points #1 and #2 in the foregoing list). Deferred imitation tasks present infants with a situation that might be considered a nonverbal analogue to the cued recall tests that are used to measure memory in adults (Mandler, 1988, this volume; Meltzoff, 1985b, 1988a). Infants are shown an adult moving an object in a particular way on day 1; they return after a 24-hour delay and are re-presented with the toys (the nonverbal cue). The question is whether they can retrieve and repeat the action they saw the day before. The results show that they can.

Three features of the deferred imitation task make it particularly interesting for modern theories of memory. (a) The original display was presented for a brief period of time (20 sec). (b) The infants were not allowed to touch or handle the objects on day 1; the adult merely demonstrated the to-be-remembered target act and then removed the object from sight. (c) Infants succeeded on novel tasks that were not

[d] A good case could be made that infants' success on deferred imitation tasks manifests declarative memory (Squire, 1986), and a weaker case that it perhaps taps some sort of embryonic, nonverbal episodic-like memory (Tulving, 1983, 1985) inasmuch as the relevant information is acquired during a short exposure, without any practice period, and specific information, and in some cases novel associations, are later recalled after a significant delay. Of course, the "recall" is here indexed by infants re-creating or re-enacting the event they had seen—it is nonverbal in nature—not by repeating a previously presented word or verbally describing a particular event. One cannot directly ask preverbal infants whether they are accessing a "specific personal past experience" (Weiskrantz, 1987), which would be helpful for establishing episodic memory (Tulving, 1987). It is for this reason that I have been referring to the infant as having a functioning "non-habit" or "non-procedural" memory system. It seems judicious not to try to force our interpretations of infant behavior into pre-established taxonomies of *adult* memory phenomena, especially when there is not broad consensus about how to handle borderline cases even within the adult literature (e.g., Roediger, this volume; Roediger & Craik, 1989; Schacter, this volume; Shimamura, 1986). It is not inconceivable that infants represent information in ways that will prompt new categories, new divisions of the memory landscape—divisions that are more specifically tailored to a variety of nonverbal retention phenomena.

part of their normal routines.[e] These features are important because the demonstrations of habit/procedural memory in amnesic patients, experimental animals, and normal adults often involve a lengthy acquisition period in which the motor pattern/skill/rule is gradually acquired and well practiced (Sherry & Schacter, 1987). In the case of infant deferred imitation, the acquisition phase is not only brief, but infants do not engage in motor practice at all—infants merely watch the display, in many cases a novel one. Success on this task strains an interpretation of it as exclusively habit/procedural memory because the infants are never given a trial in which they executed the to-be-remembered behavior in the first place. In an important sense, imitation involves a kind of "no-trial learning." As summarized in point #2 on the foregoing list, infants can perform deferred imitation of a novel act under these circumstances—they can acquire new information and re-create what they had seen from memory after a significant delay.

An Innate Non-Habit Memory System?

Piaget predicted that infants would not exhibit deferred imitation (which he took as a measure of nonhabit memory) until about 18 months of age. Given the new data, one could now revise the time schedule and assert that this landmark developmental transition occurs at 9 months of age. That is, one could retain Piaget's general developmental model (non-habit/procedural memory emerging from a prior stage of an exclusively habit/procedural type) and modify the age of his stage transitions. This would be generally compatible with the work of neuropsychologists who argue that onset of non-habit memory is based on the ontogenetically late growth of limbic structures (especially the hippocampus and related structures) (Bachevalier, this volume; Diamond, this volume a; Mishkin, Malamut & Bachevalier, 1984). It would also be generally compatible with the view of cognitive psychologists who advocate a transition from "early" to "late" memory systems, but do not hold rigidly to Piaget's traditional 18-month-old timetable (e.g., Schacter & Moscovitch, 1984). In sum, a modified Piagetian view can be brought in line with modern neuropsychological and cognitive sciences views simply by shifting the age of Piaget's grand stage change from 18 months to about 9 months, based on the new data.

As inviting as this may seem, it is worth recognizing that a non-habit form of memory may be functional far earlier in development—so early, in fact, that *no* tinkering with the transition age will do (Mandler, 1988; Meltzoff, 1981, 1985a). Such a memory system may exist at birth. If this is correct, it calls for a fundamental revision in developmental theory. In particular, we would need to abandon one of Piaget's most cherished insights—that a habit/procedural system, which he dubbed the "sensorimotor period," is a necessary developmental prerequisite for the later emergence of a properly "representational" cognitive system. There may *never* be a time that the human infant is confined to a purely habit/procedural mode. *In a very real sense, there may be no such thing as an exclusively "sensorimotor period" in the normal human infant.*

[e] The most conservative reading of the published studies is that this is accomplished with facility by 14 months of age, the youngest age so far tested. Work is continuing to determine the lowest age bound of this ability.

Among the data that raise this unsettling possibility are the findings of newborn imitation (especially point #6; see also #3). The data show that newborn infants can imitate after short delays when the to-be-remembered target is no longer in the perceptual field, and the infants did not practice the response during its presence. Moreover, there is reason to believe that it is the infant's recognition of a mismatch between the event in memory (the adult presenting the tongue-protrusion gesture) and the current perception (the passive-face pose) that serves to motivate the imitative response in the first place (Meltzoff & Moore, 1989; Meltzoff, Kuhl & Moore, in press). Thus, memory of now-absent events may be an integral aspect of early imitation. On this view, the ability to act on the basis of a representation of a perceptually absent stimulus becomes the psychological starting point for infancy, not its crowning achievement.[f]

Deferred Imitation and Its Relation to Other Infant Memory Tasks

At least four tasks have been extensively used to assess infant retention: conditioning procedures (Rovee-Collier & Fagen, 1981; Rovee-Collier, this volume; Watson, 1967), visual preference for novelty (Cohen & Gelber, 1975; Fagan, 1984, this volume), object hiding and recovery (Diamond, 1985, this volume b, c; Fox, Kagan & Weiskopf, 1979; Harris, 1987; Wellman, 1985) and deferred imitation (Mandler, this volume; Meltzoff, 1985b, 1988a, 1988b, 1988c). Relations among the first three have been discussed in the literature (e.g., Mandler, 1984; Schacter & Moscovitch, 1984; Sophian, 1980). The relation of deferred imitation to these other tasks has not been so fully explored, in part because the data are more recent, but also because good animal models are impossible (and therefore this memory task has not been as widely used as others). Nonhuman animals, including primates, show little or no facility on imitation-from-memory tasks, especially if no motor practice is allowed while the target act is perceptually present and novel acts are used (for reviews see, Galef, 1988; Meltzoff, 1988d, 1988e).[g] This section briefly considers the ways in which tests of deferred imitation complement the other three techniques traditionally used for investigating retention in human infancy.

Rovee-Collier used a conditioning paradigm to study early memory and investigated length of retention interval, age differences, context, the stimulus features encoded, and memory reactivation (Rovee-Collier, 1984; this volume; Rovee-Collier & Fagen, 1981). Her stunning findings are an example of the value of programmatic research. The deferred imitation paradigm can add to the picture of infant memory provided by Rovee-Collier. Our deferred imitation tests differ from Rovee-Collier's tests in terms of the type of information retained, and the differences are relevant to

[f]Elaboration of this statement requires further research with very young infants using a three-pronged approach: longer retention intervals, intervening activity, and novel acts. That is a major focus of the current research program. That said and underscored, it is also worth underlining that the study of neonatal imitation provides one of the few available techniques for investigating the true "initial state" of the human memory system(s) if one's questions concern more than purely recognition memory.

[g]Songbirds are the exception. Note, however, that their delayed imitation is severely restricted to a specific type of auditory signal. This is in contrast to a more general capacity of infants for imitation on varied domains—gestural, vocal, and actions-with-objects.

what type of memory system may support the behavior. Deferred imitation is not based on an incrementally learned procedure (as in the case of Rovee-Collier's footkicks), but on the performance with one's own body of a specific act that was visually perceived during a brief episode. Our deferred-imitation test does not involve any motor practice during acquisition of the to-be-remembered event (no immediate imitation is allowed), and moreover, imitation is cross-modal in the sense that a target is presented visually and then matched motorically. The two tests also differ because the link between the stimulus and the infant's response is not forged through conditioning; in deferred imitation, the infant does not act on the objects in the first session, and thus no extrinsic reinforcement for producing the target response is possible.

Work with both adult amnesic patients and experimental animals shows they can retain incrementally learned motor skills, which has led some to argue that the retention demonstrated in infant conditioning paradigms is the same kind of memory that is spared in amnesia (e.g., Moscovitch, 1984). The deferred imitation paradigm now adds to our arsenal of techniques for studying infantile retention. It seems to me that there may be important dissociations between the memory of infants and adult amnesic patients and that this may be demonstrable on deferred imitation tests after 24-hour and 1-week delays, especially for novel acts for which there is no motor practice on visit 1. Young infants may remember things that are beyond the powers of amnesic patients, despite the patients' clear superiority in general intelligence. Such studies remain to be done, but this is an instance in which results from infancy may inform work in neuro- and cognitive psychology.

Similarly, the deferred-imitation paradigm also complements and broadens the type of information garnered from tests of visual novelty preference (Cohen & Gelber, 1975; Fagan, 1970, 1973, this volume). In deferred imitation, infants go beyond the regulation of attention; they do more than react to the "newness" of a pattern. In the case of deferred imitation, infants must *produce* an absent act without now seeing it and without having previously imitated it. Deferred imitation taps something more than simply habituation/attentional changes/preference for novelty and is more akin to cued-recall memory.

Certainly it is possible for an organism to demonstrate retention through measures of attentional changes and still not be able to *act* off of this stored information. Bower (1967, 1971, 1982) described object-hiding tasks in which the infant seemed to indicate knowledge about the absent object by eye that was not exhibited in manual action (see Diamond, this volume a). Indeed, on the basis of this and other work on object-hiding tasks, some developmentalists have wondered whether young infants might have a general deficit in "integrating their memory and action-generating abilities" (Baillargeon & Graber, 1988). I do not subscribe to this thesis; the work on imitation clearly requires young infants to *act* from memory. The results show they can do this by 9 months of age, and perhaps as early as birth (see the foregoing point #6). The root of infants' failures on manual search tasks is probably not a general deficit in coordinating action and memory.

Success on the manual object-hiding tasks requires more than memory for the absent object and the ability to act from memory. Among other things, it also requires executing planned means–ends sequences—itself a problem for young infants (e.g., Diamond, in press; Piaget, 1954); spatial knowledge that there is a physical place for an object to be "under" a solid occluder or that the hidden object is "to the left versus right"—another known problem (Acredolo, 1978, this volume; Bower, 1982; Butterworth, 1975; Butterworth, Jarrett & Hicks, 1982; Bremner, 1978; Piaget, 1954; Wishart & Bower, 1984); and, most important of all in my view, the belief that an object maintains its identity over disappearance transformations, that is, that the desired object remains "the same one" now that it is hidden—which is also a developmental problem area (Moore & Meltzoff, 1978). It is likely that one of these other factors, or their interactions with further components of the task (Bower, 1982; Butterworth, 1981b; Bremner, 1985; Diamond, 1988, and this volume b and c; Harris, 1987), accounts for the slow development of success in the classic infant object-permanence tests. In short, Piagetian object-permanence tests are not simple tests of retention or of the general ability to generate actions from memory; failures on such tests are difficult to attribute to these factors alone. The results from imitation-from-memory tests indicate that young infants can coordinate memory and action.

ADDING DEVELOPMENT TO COGNITIVE SCIENCE: CHANGES IN REPRESENTATION AT 18 MONTHS

Although I have embraced certain high-order cognitive functioning in early infancy, this does not mean I think there are no significant developments in infants' thought. Evidence exists that there is an important shift in the nature of children's representational capacity at about 18 months of age. Meltzoff and Gopnik (1989) have suggested that the crux of this development is the ability to consider hypothetical or *possible* objects, events, or experiences that have not been directly perceived. While pre-18-month-olds may remember certain things that they experienced in the past (using what we call *empirical representations*), they are unable to represent what they have never experienced (*hypothetical representations*). The emergence of this critical, perhaps species-specific, function appears to occur at 18 months of age.

This shift from empirical to hypothetical representations can be documented across a spectrum of behaviors including the object concept, pretend play, and language. For example, in high-level object permanence tasks that are first solved at about 18 months of age, children need to do more than remember that a hidden object continues to exist in a particular place. This can be accomplished at much earlier ages, when children solve simple hiding tasks (e.g., Diamond, this volume b). In the high-level object permanence tasks, children also need to hypothesize the existence of the object at a brand-new location in which they have never before seen it hidden. Piaget (1954) invented a hiding task, which he called a "serial invisible displacement," to tap this higher order capacity.[h] Children fail dismally on serial

[h] In this task, the experimenter hides an object in his or her hand and then moves this hidden object under a series of three occluders, surreptitiously dropping off the object at one of them. The infants are not given any perceptual evidence as to where the object is (they never actually see it dropped off). They must look in the last place they saw the object (the hand) and then deduce that because the object is not there, but continues to exist somewhere, it must be in one of the places the hand traveled along its moving path. Children younger than 18 months typically look in the hand and then are stumped. When they do not find the object in the hand, they cannot deduce where it must therefore be.

invisible displacement tasks before about 18 months, although these same children solve other, simpler hiding tasks with great facility (Gopnik & Meltzoff, 1986a, 1987; Piaget, 1954; Uzgiris & Hunt, 1975). One account of this dissociation among different kinds of object hiding tasks is that younger infants can represent the object in a place they saw it hidden (empirical representation), but cannot represent it in a place they never saw it hidden (hypothetical representation) (Meltzoff & Gopnik, 1989; Moore & Meltzoff, 1978).

This psychological shift from empirical to hypothetical representation is also reflected in changes in imitative behavior and the emergence of pretense (Leslie, 1987, 1988a, 1988b). At about 18 months of age children begin to imitate what it would be like to be someone other than themselves ("role taking"—as in pretending to be the mother). They also pretend that objects are other than what they are known and remembered to be ("symbolic play"—as in pretending, with a guffaw, that crumbled typing paper is food to eat with a make-believe spoon—an act once demonstrated to me by my own 2-year-old). True symbolic or pretend play seems to emerge at about 18 months of age (Bretherton, 1984; Leslie, 1987, 1988a, 1988b; Lézine, 1973). Such pretend play requires an "as if" stance that is beyond the capacity of the more reality-oriented, younger infant.

In the linguistic area, there are also profound changes in how children use language at about 18 months of age. Although there is ample evidence for the appearance of "first words" before 18 months, these words are used largely for social/pragmatic purposes (*thank-you, hereyare*), or to name a few salient objects (*mommy, juice*) (e.g., Gopnik, 1988). It is intriguing that at about 18 months children for the first time now begin to use words to encode contrasts between possible and actual events (Gopnik, in press; Gopnik & Meltzoff, 1985, 1986b). For example, at about this age words like *gone* begin to encode a contrast between what the child actually perceives and what the child might perceive. Children for the first time begin to say *gone* when seeing an empty slot in a novel object, thereby indicating that something that they have never seen *should* be in this place (Gopnik, 1984; Gopnik & Meltzoff, 1986b). It is also at about this time that children first begin to use the word "no" to deny propositions, as in using the phrase *hat off no* to refer to a picture of a man with his hat still on (Gopnik & Meltzoff, 1985; Pea, 1980). This again suggests that the child can entertain a relation between the actual state of affairs and a possible one.

Gopnik and I have thus suggested that these 18-month-old abilities demand more than the kind of representation that is involved in deferred imitation. Deferred imitation—even imitation over lengthy retention intervals of 1 week—involves the re-creation of a specific empirical reality that was previously perceived. It involves representation, but relies on an experience-driven or empirical representation, in the sense that the internal description concerns a state of affairs that was encountered in the real world. The content of the representations of 18-month-old infants can also be about something else. By 18 months of age there has been the growth of a kind of second-order representational system and a capacity for hypothetical representations. This enables the child to wonder "what if," to contemplate "as if," and to deduce "what must have been" in advance of, and often without, the perceptual evidence. The neural basis of this regular and (perhaps) species-specific change remains an enigma. Its impact on human cognition is, however, far reaching (Bruner, 1986).

SUMMARY

This chapter began with a query about whether there was any content to an enterprise called "developmental cognitive science," and if so, whether the findings could inform work in adult cognition and neuropsychology. Both questions can now be answered in the affirmative. Evidence has been marshaled from infant studies concerning five topics of enduring interest in the cognitive and neuro-sciences: cross-modal integration, imitation, the coordination of perception and action, memory, and representation. The data show that young human infants can detect equivalences between information picked up by different sensory modalities. This was demonstrated both in tactual–visual perception of objects and auditory–visual perception of speech. Results also show that perception and production are intertwined literally from the earliest phases of infancy, with 4-month-olds demonstrating vocal imitation and newborns reproducing elementary gestures they saw an adult perform. There seems to be a transparency between the perceptual and motor systems, and it is conceivable that they may draw on the same internal code. Infants' proclivity to imitate was used to investigate early memory. It was found that young infants were not constrained to immediate mimicry, but could imitate after significant delays. The findings support the inference that infants, perhaps as early as birth, have a functioning memory system that cannot be reduced to "habit formation" or an exclusively "procedural memory." It was proposed instead that there is a kernel of some higher level memory system right from the earliest phases of human infancy. This does not imply that there is no development in the representational world of infants. Data were reviewed suggesting that there is a watershed transformation in childhood cognition at about 18 months of age. However, this is *not* a change from a stage in which there was a purely sensorimotor or habit-based system. Rather the development was characterized as a shift from using empirical or experience-based representations to using hypothetical representations, which concern possible realities. This developmental shift allows children to project into the future "what must be" and deduce from the past "what must have been," in advance of, and sometimes in the absence of, strictly perceptual evidence. This capacity provides the underpinnings for the conduct of science itself. Its origins are to be found in infancy.

ACKNOWLEDGMENTS

I am deeply indebted to P. K. Kuhl, M. K. Moore, and A. Gopnik for their collaboration on much of the empirical work and for discussions about many of the theoretical notions expressed here. The assistance of C. R. Harris and C. Fisher in the conduct of many of the studies is gratefully acknowledged. I owe special gratitude to P. K. Kuhl, A. Gopnik, and A. Diamond for commenting on an earlier draft of this chapter.

REFERENCES

ABRAVANEL, E. & A. D. SIGAFOOS. 1984. Exploring the presence of imitation during early infancy. Child Development **55:** 381–392.

ACREDOLO, L. P. 1978. Development of spatial orientation in infancy. Developmental Psychology **14:** 224–234.

ACREDOLO, L. 1990. Behavioral approaches to spacial orientation in infancy. Annals of the New York Academy of Sciences, this volume.

BACHEVALIER, J. 1990. Ontogenetic development of habit and memory formation in primates. Annals of the New York Academy of Sciences, this volume.

BAILLARGEON, R. & M. GRABER. 1988. Evidence of location memory in 8-month-old infants in a nonsearch task. Developmental Psychology **24:** 502–511.

BOWER, T. G. R. 1967. The development of existence constancy: Some studies in existence constancy. Perception and Psychophysics **2:** 411–418.

BOWER, T. G. R. 1971. The object in the world of the infant. Scientific American **225:** 30–38.

BOWER, T. G. R. 1982. Development in Infancy, 2nd ed. W.H. Freeman. San Francisco.

BOWER, T. G. R. 1989. The Rational Infant: Learning in Infancy. W.H. Freeman. San Francisco.

BREMNER, J. G. 1978. Spatial errors made by infants: Inadequate spatial cues or evidence for egocentrism? British Journal of Psychology **69:** 77–84.

BREMNER, J. G. 1985. Object tracking and search in infancy: A review of data and a theoretical evaluation. Developmental Review **5:** 371–396.

BRETHERTON, I. 1984. Symbolic Play: The Development of Social Understanding. Academic Press. New York.

BRUNER, J. 1986. Actual Minds, Possible Worlds. Harvard University Press. Cambridge, MA.

BUTTERWORTH, G. 1975. Object identity in infancy: The interaction of spatial location codes in determining search errors. Child Development **46:** 866–870.

BUTTERWORTH, G. E. 1981a. The origins of auditory-visual perception and visual proprioception in human development. *In* Intersensory Perception and Sensory Integration. R. D. Walk, & H. L. Pick, Eds.: 37–70. Plenum Press. New York.

BUTTERWORTH, G. 1981b. Object permanence and identity in Piaget's theory of infant cognition. *In* Infancy and Epistemology. G. Butterworth, Ed.: 137–169. Harvester Press. Brighton, England.

BUTTERWORTH, G., N. JARRETT & L. HICKS. 1982. Spatiotemporal identity in infancy: Perceptual competence or conceptual deficit? Developmental Psychology **18:** 435–449.

CAREY, S. 1985. Conceptual Change in Childhood. M.I.T. Press. Cambridge, MA.

COHEN, L. B. & E. R. GELBER. 1975. Infant visual memory. *In* Infant Perception: From Sensation to Cognition. Vol. 1. L. B. Cohen & P. Salapatek, Eds.: 347–403. Academic Press. New York.

DE BOYSSON-BARDIES, B., L. SAGART & C. DURAND. 1984. Discernible differences in the babbling of infants according to target language. Journal of Child Language **11:** 1–15.

DELOACHE, J. S. 1987. Rapid change in the symbolic functioning of very young children. Science **238:** 1556–1557.

DELOACHE, J. S. 1989. Physical similarity and young children's understanding of scale models. Unpublished manuscript.

DELOACHE, J. S. In press. Young children's understanding of models. *In* Knowing and Remembering in Young Children. R. Fivush & J. Hudson, Eds. Cambridge University Press. New York.

DIAMOND, A. 1985. Development of the ability to use recall to guide action, as indicated by infants' performance on $A\overline{B}$. Child Development **59:** 523–527.

DIAMOND, A. 1988. Differences between adult and infant cognition: Is the crucial variable presence or absence of language? *In* Thought without Language. L. Weiskrantz, Ed.: 337–370. Oxford University Press. Oxford.

DIAMOND, A. In press. Neuropsychological insights into the meaning of object concept development. *In* The Epigenesis of Mind: Essays on Biology and Knowledge. S. Carey & R. Gelman, Eds. Erlbaum. Hillsdale, NJ.

DIAMOND, A. 1990a. Rate of maturation of the hippocampus and the developmental progression of children's performance on the delayed non-matching to sample and visual paired comparison tasks. Annals of the New York Academy of Sciences, this volume.

DIAMOND, A. 1990b. The development and neural bases of memory functions as indexed by the $A\overline{B}$ and delayed response tasks in human infants and infant monkeys. Annals of the New York Academy of Sciences, this volume.

DIAMOND, A. 1990c. Developmental time course in human infants and infant monkeys, and the neural bases, of inhibitory control in reaching. Annals of the New York Academy of Sciences, this volume.

DODD, B. 1979. Lip reading in infants: Attention to speech presented in- and out-of-synchrony. Cognitive Psychology **11:** 478–484.

FAGAN, J. F., III. 1970. Memory in the infant. Journal of Experimental Child Psychology **9:** 217–226.

FAGAN, J. F., III. 1973. Infants' delayed recognition memory and forgetting. Journal of Experimental Child Psychology **16:** 424–450.

FAGAN, J. F. 1984. Infant memory: History, current trends, relations to cognitive psychology. *In* Infant Memory—Its Relation to Normal and Pathological Memory in Humans and Other Animals. M. Moscovitch, Ed.: 1–27. Plenum Press. New York.

FAGAN, J. F., III. 1990. The paired-comparison paradigm and infant intelligence. Annals of the New York Academy of Sciences, this volume.

FANT, G. 1973. Speech Sounds and Features. M.I.T. Press. Cambridge, MA.

FIELD, T., S. GOLDSTEIN, N. VAGA-LAHR & K. PORTER. 1986. Changes in imitative behavior during early infancy. Infant Behavior and Development **9:** 415–421.

FIELD, T. M., R. WOODSON, D. COHEN, R. GREENBERG, R. GARCIA & K. COLLINS. 1983. Discrimination and imitation of facial expressions by term and preterm neonates. Infant Behavior and Development **6:** 485–489.

FIELD, T. M., R. WOODSON, R. GREENBERG & D. COHEN. 1982. Discrimination and imitation of facial expressions by neonates. Science **218:** 179–181.

FONTAINE, R. 1984. Imitative skills between birth and six months. Infant Behavior and Development **7:** 323–333.

FOX, N., J. KAGAN & S. WEISKOPF. 1979. The growth of memory during infancy. Genetic Psychology Monographs **99:** 91–130.

FUSTER, J. 1990. Prefrontal cortex and the bridging of temporal gaps in the perception–action cycle. Annals of the New York Academy of Sciences, this volume.

GALEF, B. G., JR. 1988. Imitation in animals: History, definition, and interpretation of data from the psychological laboratory. *In* Social Learning: Psychological and Biological Perspectives. T. R. Zentall & J. B. G. Galef, Eds.: 3–28. Erlbaum. Hillsdale, NJ.

GELMAN, R. & E. SPELKE. 1981. The development of thoughts about animate and inanimate objects: Implications for research on social cognition. *In* Social Cognitive Development: Frontiers and Possible Futures. J. Flavell & L. Ross, Eds.: 43–66. Cambridge University Press. Cambridge, England.

GIBSON, J. J. 1962. Observations on active touch. Psychological Review **69:** 477–491.

GIBSON, J. J. 1966. The Senses Considered as Perceptual Systems. Houghton Mifflin. Boston.

GIBSON, J. J. 1979. The Ecological Approach to Visual Perception. Houghton Mifflin. Boston.

GIBSON, E. J. & A. WALKER. 1984. Development of knowledge of visual-tactual affordances of substance. Child Development **55:** 453–460.

GOODMAN, N. 1968. Languages of Art: An Approach to a Theory of Symbols. Bobbs-Merrill. New York.

GOPNIK, A. 1984. The acquisition of *gone* and the development of the object concept. Journal of Child Language **11:** 273–292.

GOPNIK, A. 1988. Three types of early words: The emergence of social words, names and cognitive-relational words in the one-word stage and their relation to cognitive development. First Language **8:** 49–69.

GOPNIK, A. In press. Developing the idea of intentionality: Children's theories of mind. The Canadian Journal of Philosophy.

GOPNIK, A. & A. N. MELTZOFF. 1985. From people, to plans, to objects: Changes in the meaning of early words and their relation to cognitive development. Journal of Pragmatics **9:** 495–512.

GOPNIK, A. & A. N. MELTZOFF. 1986a. Relations between semantic and cognitive development in the one-word stage: The specificity hypothesis. Child Development **57:** 1040–1053.

GOPNIK, A. & A. N. MELTZOFF. 1986b. Words, plans, things, and locations: Interactions between semantic and cognitive development in the one-word stage. *In* The Development of Word Meaning: Progress in Cognitive Development Research. S. A. Kuczaj & M. D. Barrett, Eds.: 199–223. Springer-Verlag. New York.

GOPNIK, A. & A. N. MELTZOFF. 1987. The development of categorization in the second year and its relation to other cognitive and linguistic developments. Child Development **58:** 1523–1531.

GREEN, K. P. & P. K. KUHL. 1989. The role of visual information in the processing of place and manner features in speech perception. Perception and Psychophysics **45(1):** 34–42.

GUNDERSON, V. M. 1983. Development of cross-modal recognition in infant pigtail monkeys (*Macaca nemestrina*). Developmental Psychology **19:** 398–404.

HANNA, E. & A. N. MELTZOFF. 1989. Peer imitation in 14-month-old infants. Paper presented at the Biennial Meeting of the Society for Research in Child Development. April 27–30. Kansas City, KS.

HANNA, E. & A. N. MELTZOFF. 1990. Deferred imitation of peers by 14-month-olds. Paper presented at the International Conference on Infant Studies. April 19–22. Montreal.

HARRIS, P. L. 1987. The development of search. *In* Handbook of Infant Perception. P. Salapatek & L. Cohen, Eds.: 155–207. Academic Press. New York.

HEIMANN, M. 1989. Neonatal imitation, gaze aversion, and mother–infant interaction. Infant Behavior and Development **12:** 495–505.

HEIMANN, M., K. E. NELSON & J. SCHALLER. 1989. Neonatal imitation of tongue protrusion and mouth opening: Methodological aspects and evidence of early individual differences. Scandinavian Journal of Psychology **30:** 90–101.

HEIMANN, M. & J. SCHALLER. 1985. Imitative reactions among 14–21-day-old infants. Infant Mental Health Journal **6:** 31–39.

HUNTER, M. A., E. W. AMES & R. KOOPMAN. 1983. Effects of stimulus complexity and familiarization time on infant preferences for novel and familiar stimuli. Developmental Psychology **19:** 338–352.

JACOBSON, S. W. 1979. Matching behavior in the young infant. Child Development **50:** 425–430.

JAKOBSON, R., C. G. M. FANT & M. HALLE. 1952. Preliminaries to Speech Analysis: The Distinctive Features and Their Correlates. M.I.T. Press. Cambridge, MA.

KAITZ, M., O. MESCHULACH-SARFATY, J. AUERBACH & A. EIDELMAN. 1988. A reexamination of newborn's ability to imitate facial expressions. Developmental Psychology **24:** 3–7.

KONISHI, M. 1965. The role of auditory feedback in the control of vocalization in the White-crowned Sparrow. Zeitschrift für Tierpsychologie **22:** 770–783.

KUHL, P. K. 1979. Speech perception in early infancy: Perceptual constancy for spectrally dissimilar vowel categories. Journal of the Acoustical Society of America **66:** 1668–1679.

KUHL, P. K. 1983. Perception of auditory equivalence classes for speech in early infancy. Infant Behavior & Development **6:** 263–285.

KUHL, P. K. 1985. Categorization of speech by infants. *In* Neonate Cognition: Beyond the Blooming, Buzzing Confusion. J. Mehler & R. Fox, Eds.: 231–262. Lawrence Erlbaum Associates. Hillsdale, NJ.

KUHL, P. K. 1988. Auditory perception and the evolution of speech. Journal of Human Evolution **3:** 19–43.

KUHL, P. K. & A. N. MELTZOFF. 1982. The bimodal perception of speech in infancy. Science **218:** 1138–1141.

KUHL, P. K. & A. N. MELTZOFF. 1984. The intermodal representation of speech in infants. Infant Behavior & Development **7:** 361–381.

KUHL, P. K. & A. N. MELTZOFF. 1988. Speech as an intermodal object of perception. *In* Perceptual Development in Infancy: Minnesota Symposia on Child Development, Vol. 20. A. Yonas, Ed.: 235–266. Lawrence Erlbaum Associates. Hillsdale, NJ.

KUHL, P. K. & A. N. MELTZOFF. In press. Four-month-old infants imitate vowel sounds.

LESLIE, A. M. 1987. Pretense and representation in infancy: The origins of "theory of mind." Psychological Review **94:** 412–426.

LESLIE, A. M. 1988a. Some implications of pretense for mechanisms underlying the child's theory of mind. *In* Developing Theories of Mind. J. W. Astington, P. L. Harris & D. R. Olson, Eds.: 19–46. Cambridge University Press. New York.

LESLIE, A. M. 1988b. The necessity of illusion: Perception and thought in infancy. *In* Thought without Language. L. Weiskrantz, Ed.: 185–210. Oxford University Press. Oxford, England.

LEZINE, I. 1973. The transition from sensorimotor to earliest symbolic function in early development. *In* Biological and Environmental Determinants of Early Development. J. I. Nurnberger, Ed.: 221–232. Williams & Wilkins. Baltimore.

MACKAIN, K., M. STUDDERT-KENNEDY, S. SPIEKER & D. STERN. 1983. Infant intermodal speech perception is a left-hemisphere function. Science **219:** 1347–1349.

MANDLER, J. M. 1983. Representation. *In* Handbook of Child Psychology, Vol. 3. J. Flavell & E. M. Flavell, Ed.: 420–494. Wiley. New York.

MANDLER, J. M. 1984. Representation and recall in infancy. *In* Infant Memory. M. Moscovitch, Ed.: 75–101. Plenum Press. New York.

MANDLER, J. M. 1988. How to build a baby: On the development of an accessible representational system. Cognitive Development **3:** 113–136.

MANDLER, J. M. 1990. Recall of events by preverbal children. Annals of the New York Academy of Sciences, this volume.

MARLER, P. 1974. Constraints on learning: Development of bird song. *In* Ethology and Psychiatry. N. F. White, Ed.: 69–83. University of Toronto Press. Toronto.

MARLER, P. & V. SHERMAN. 1983. Song structure without auditory feedback: Emendations of the auditory template hypothesis. Journal of Neuroscience **3:** 517–531.

MASSARO, D. W. & M. M. COHEN. 1983. Evaluation and integration of visual and auditory information in speech perception. Journal of Experimental Psychology: Human Perception and Performance **9:** 753–771.

MCGURK, H. & J. MACDONALD. 1976. Hearing lips and seeing voices. Nature **264:** 746–748.

MELTZOFF, A. N. 1981. Imitation, intermodal co-ordination, and representation in early infancy. *In* Infancy and Epistemology. G. Butterworth, Ed.: 85–114. Harvester. Brighton, England.

MELTZOFF, A. N. 1985a. The roots of social and cognitive development: Models of man's original nature. *In* Social Perception in Infants. T. M. Field & N. A. Fox, Eds.: 1–30. Ablex. Norwood.

MELTZOFF, A. N. 1985b. Immediate and deferred imitation in fourteen- and twenty-four-month old infants. Child Development **56:** 62–72.

MELTZOFF, A. N. 1988a. Infant imitation and memory: Nine-month-olds in immediate and deferred tests. Child Development **59:** 217–225.

MELTZOFF, A. N. 1988b. Infant imitation after a 1-week delay: Long-term memory for novel acts and multiple stimuli. Developmental Psychology **24:** 470–476.

MELTZOFF, A. N. 1988c. Imitation of televised models by infants. Child Development **59:** 1221–1229.

MELTZOFF, A. N. 1988d. Imitation, objects, tools, and the rudiments of language in human ontogeny. Human Evolution **3:** 45–64.

MELTZOFF, A. N. 1988e. The human infant as *Homo imitans. In* Social Learning: Psychological and Biological Perspectives. T. R. Zentall & B. G. Galef, Eds.: 319–341. Erlbaum. Hillsdale, NJ.

MELTZOFF, A. N. 1990. Foundations for developing a concept of self: The role of imitation in relating self to other and the value of social mirroring, social modeling, and self practice in infancy. *In* The Development of the Self during the Transition from Infancy through the Preschool Years. D. Cicchetti & M. Beeghly, Eds.: 139–164. University of Chicago Press. Chicago, IL.

MELTZOFF, A. N. & R. W. BORTON. 1979. Intermodal matching by human neonates. Nature **282:** 403–404.

MELTZOFF, A. N. & A. GOPNIK. 1989. On linking nonverbal imitation, representation, and language learning in the first two years of life. *In* The Many Faces of Imitation in Language Learning. G. E. Speidel & K. E. Nelson, Eds.: 23–51. Springer-Verlag. New York.

MELTZOFF, A. N. & P. K. KUHL. 1989. Infants' perception of faces and speech sounds: Challenges to developmental theory. *In* Challenges to Developmental Paradigms. P. R. Zelazo & R. G. Barr, Eds.: 67–91. Erlbaum. Hillsdale, NJ.

MELTZOFF, A. N., P. K. KUHL & M. K. MOORE. In press. Perception and the control of action in newborns and young infants: Toward a new synthesis. *In* Newborn Attention: Biological Constraints and the Influence of Experience. M. J. Weiss & P. R. Zelazo, Eds. Ablex. Norwood, NJ.

MELTZOFF, A. N. & M. K. MOORE. 1977. Imitation of facial and manual gestures by human neonates. Science **198:** 75–78.

MELTZOFF, A. N. & M. K. MOORE. 1983a. The origins of imitation in infancy: Paradigm, phenomena, and theories. *In* Advances in Infancy Research, Vol. 2. L. P. Lipsitt, Ed.: 265–301. Ablex. Norwood, NJ.

MELTZOFF, A. N. & M. K. MOORE. 1983b. Newborn infants imitate adult facial gestures. Child Development **54:** 702–709.

MELTZOFF, A. N. & M. K. MOORE. 1989. Imitation in newborn infants: Exploring the range of gestures imitated and the underlying mechanisms. Developmental Psychology **25:** 954–962.

MEREDITH, M. A. & B. E. STEIN. 1983. Interactions among converging sensory inputs in the superior colliculus. Science **221:** 389–391.

MEREDITH, M. A. & B. E. STEIN. 1985. Descending efferents from the superior colliculus relay integrated multisensory information. Science **227:** 657–659.

MISHKIN, M., B. MALAMUT & J. BACHEVALIER. 1984. Memories and habits: Two neural systems. *In* Neurobiology of Learning and Memory. G. Lynch, J. L. McGaugh & N. M. Weinberger, Eds.: 65–77. Guilford Press. New York.

MOORE, M. K. & A. N. MELTZOFF. 1978. Object permanence, imitation, and language development in infancy: Toward a neo-Piagetian perspective on communicative and cognitive development. *In* Communicative and Cognitive Abilities—Early Behavioral Assessment. F. D. Minifie & L. L. Lloyd, Eds.: 151–184. University Park Press. Baltimore.

MOSCOVITCH, M. 1984. Infant Memory: Its Relation to Normal and Pathological Memory in Humans and Other Animals. Plenum Press. New York.

NOTTEBOHM, F. 1975. A zoologist's view of some language phenomena with particular emphasis on vocal learning. *In* Foundations of Language Development, Vol. 1. E. H. Lenneberg & E. Lenneberg, Eds.: 61–103. Academic Press. New York.

PEA, R. D. 1980. The development of negation in early child language. *In* The Social Foundations of Language and Thought. D. R. Olson, Ed.: 156–186. Norton. New York.

PÊCHEUX, M., J. LEPECQ & P. SALZARULO. 1988. Oral activity and exploration in 1–2-month-old infants. British Journal of Developmental Psychology **6:** 245–256.

PIAGET, J. 1952. The Origins of Intelligence in Children. International Universities Press. New York.

PIAGET, J. 1954. The Construction of Reality in the Child. Basic Books. New York.

PIAGET, J. 1962. Play, Dreams and Imitation in Childhood. Norton. New York.

POTTER, M. C. 1979. Mundane symbolism: The relations among objects, names, and ideas. *In* Symbolic Functioning in Childhood. N. R. Smith & M. B. Franklin, Ed.: 41–65). Erlbaum. Hillsdale, NJ.

RIEBER, R. W. 1983. Dialogues on the Psychology of Language and Thought. Plenum Press. New York.

REISSLAND, N. 1988. Neonatal imitation in the first hour of life: Observations in rural Nepal. Developmental Psychology **24:** 464–469.

ROCHAT, P. 1983. Oral touch in young infants: Response to variations of nipple characteristics in the first months of life. International Journal of Behavioral Development **6:** 123–133.

ROEDIGER, H. L., III & F. I. M. CRAIK. 1989. Varieties of Memory and Consciousness: Essays in Honor of Endel Tulving. Erlbaum. Hillsdale, NJ.

ROEDIGER, H. L. III., S. RAJARAM & K. SRINIVAS. 1990. Specifying criteria for postulating memory systems. Annals of the New York Academy of Sciences, this volume.

ROSE, S. A. 1990. Cross-modal transfer in human infants: What is being transferred? Annals of the New York Academy of Sciences, this volume.

ROSE, S. A. & H. A. RUFF. 1987. Cross-modal abilities in human infants. *In* Handbook of Infant Development. J. D. Osofsky, Ed.: 318–362. Wiley. New York.

ROSE, S. A., A. W. GOTTFRIED, P. MELLOY-CARMINAR & W. H. BRIDGER. 1982. Familiarity and novelty preferences in infant recognition memory: Implications for information processing. Developmental Psychology **18:** 704–713.

ROVEE-COLLIER, C. 1984. The ontogeny of learning and memory in human infancy. *In* Comparative Perspectives on the Development of Memory. R. V. Kail & N. E. Spear, Eds.: 103–134. Erlbaum. Hillsdale, NJ.

ROVEE-COLLIER, C. K. 1990. The "memory system" of prelinguistic infants. Annals of the New York Academy of Sciences, this volume.

ROVEE-COLLIER, C. K. & J. W. FAGEN. 1981. The retrieval of memory in early infancy. *In* Advances in Infancy Research, Vol. 1. L. P. Lipsitt, Ed.: 225–254. Ablex. Norwood, NJ.

SCHACTER, D. L. 1990. Perceptual representation systems and implicit memory: Toward a resolution of the multiple memory systems debate. Annals of the New York Academy of Sciences, this volume.

SCHACTER, D. L. & M. MOSCOVITCH. 1984. Infants, amnesiacs, and dissociable memory systems. *In* Infant Memory. M. Moscovitch, Ed.: 173–216. Plenum Press. New York.

SHERRY, D. F. & D. L. SCHACTER. 1987. The evolution of multiple memory systems. Psychological Review **94(4):** 439–454.

SHIMAMURA, A. P. 1986. Priming effects in amnesia: Evidence for a dissociable memory function. The Quarterly Journal of Experimental Psychology **38A:** 619–644.

SOPHIAN, C. 1980. Habituation is not enough: Novelty preferences, search, and memory in infancy. Merrill-Palmer Quarterly **26:** 239–257.

SPELKE, E. S. 1979. Perceiving bimodally specified events in infancy. Developmental Psychology **15:** 626–636.

SPELKE, E. S. 1987. The development of intermodal perception. *In* Handbook of Infant Perception: From Perception to Cognition, Vol. 2. P. Salapatek & L. Cohen, Eds.: 233–273. Academic Press. New York.

SQUIRE, L. R. 1986. Mechanisms of memory. Science **232:** 1612–1619.

SQUIRE, L. R. 1987. Memory and Brain. Oxford University Press. New York.

STEIN, B. E. & M. A. MEREDITH. 1990. Multisensory integration: Neural and behavioral solutions for dealing with stimuli from different sensory modalities. Annals of the New York Academy of Sciences, this volume.

STRERI, A. 1987. Tactile discrimination of shape and intermodal transfer in 2- to 3-month-old infants. British Journal of Developmental Psychology **5:** 213–220.

STRERI, A. & E. S. SPELKE. 1988. Haptic perception of objects in infancy. Cognitive Psychology **20:** 1–23.

STUDDERT-KENNEDY, M. 1986. Development of the speech perceptuomotor system. *In* Precursors of Early Speech. B. Lindblom & R. Zetterstrom, Ed.: 205–217. Stockton Press. New York.

TULVING, E. 1983. Elements of episodic memory. Clarendon Press. Oxford.

TULVING, E. 1985. How many memory systems are there? American Psychologist **40(4):** 385–398.

TULVING, E. 1987. Multiple memory systems and consciousness. Human Neurobiology **6:** 67–80.

UZGIRIS, I. C. & J. M. HUNT. 1975. Assessment in Infancy: Ordinal Scales of Psychological Development. University of Illinois Press. Urbana, IL.

VINTER, A. 1986. The role of movement in eliciting early imitations. Child Development **57:** 66–71.

WAGNER, S. H. & L. J. SAKOVITS. 1986. A process analysis of infant visual and cross-modal recognition memory: Implications for an amodal code. *In* Advances in Infancy Research, Vol. 4. L. P. Lipsitt & C. Rovee-Collier, Eds.: 195–217. Ablex. Norwood, NJ.

WATSON, J. 1967. Memory and "contingency analysis" in infant learning. Merrill-Palmer Quarterly **13:** 55–76.

WEISKRANTZ, L. 1987. Neurobiology of memory and amnesia: A case for multiple memory systems. Human Neurobiology **6:** 93–105.

WELLMAN, H. 1985. The Development of Search Ability. Erlbaum. Hillsdale, NJ.

WERNER, H. & B. KAPLAN. 1963. Symbol Formation: An Organismic Developmental Approach to Language and the Expression of Thought. Wiley. New York.

WISHART, J. G. & T. G. R. BOWER. 1984. Spatial relations and the object concept: A normative study. *In* Advances in Infancy Research, Vol. 3. L. P. Lipsitt & C. Rovee-Collier, Ed.: 57–123. Ablex. Norwood, NJ.