The Development of Declarative Memory in Human Infants: Age-Related Changes in Deferred Imitation

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In 2 experiments, deferred imitation procedures were used to trace age-related changes in declarative memory by human infants over the first 2 years of life. An adult modeled 3 actions with an object, and infants' ability to reproduce those actions was assessed 24 hr later. Some infants were tested with a new object or in a new context relative to the original demonstration. Changes in the context disrupted the performance of 6-month-olds but had no effect on the performance of 12- and 18-month-olds. Changes in the object disrupted the performance of 6- and 12-month-olds but had no effect on the performance of 18-month-olds. This age-related increase in representational flexibility may account for the decline of childhood amnesia during the 3rd year of life.

The notion that there are two or more functionally distinct memory systems began with the hallmark studies of one severely amnestic patient, H.M. (Corkin, 1968; Milner, Corkin, & Teuber, 1968; Scoville & Milner, 1957). H.M. suffered a profound impairment in forming new memories after surgical removal of most of the hippocampal formation and its associated medial temporal lobe structures. Despite the severity of his amnesia, H.M. showed almost normal retention when tested on tasks of motor skill learning or perceptual priming. This finding gave rise to the notion that memory is not a unitary process, but rather is composed of two (or more) dissociable systems that serve different functions and operate according to different principles (for reviews, see Schacter & Tulving, 1994).

A large number of dichotomous terms have been generated to describe these memory systems. Those most commonly cited are *declarative* versus *nondeclarative* memory (Cohen & Squire, 1980; Squire, 1987, 1992a, 1992b, 1994) and *explicit* versus *implicit* memory (Graf & Schacter, 1985; Schacter, 1987, 1994). Although these dichotomies are not identical, they share two common claims. The first claim is that one memory system supports conscious recollection of episodic facts and events and allows for rapid, one-trial learning (declarative or explicit memory), while the other memory system supports the retention of habits, learned skills, and priming, and is made possible through gradual or incremental learning (nondeclarative or implicit memory).

The second common claim is that different underlying neural mechanisms subserve each memory system.[1]

Although the concept of multiple memory systems was originally developed to account for memory dissociations obtained in studies with human and nonhuman adults, it has also had a major impact on theories of memory development. According to the multiple-system view, memory development occurs in a discrete, stage-like manner, with one memory system emerging significantly earlier than the other during development (Bachevalier, 1990, 1992; Bachevalier & Mishkin, 1984; Moscovitch, 1985; Nadel & Zola-Morgan, 1984; Nelson, 1995). Within this framework, the memory skills of infants are restricted to nondeclarative memory without conscious recollection of the event in which the memory was originally established. Only later in development are infants thought to gain access to the declarative memory system.

There is some evidence to support the claim that these two memory systems emerge sequentially during development in nonhuman primates (Bachevalier, 1990, 1992; Bachevalier & Mishkin, 1984). In the classic study conducted by Bachevalier and Mishkin (1984), young rhesus monkeys were tested on two tasks, delayed-nonmatching-to-sample (DNMS) and 24-hr concurrent discrimination learning. These tasks are thought to tap the memory processes that are lost (DNMS) and spared (24-hr concurrent discrimination) in amnestic adults (Mishkin, Malamut, & Bachevalier, 1984). During the course of normal development, 3-, 6-, and 12-month-old monkeys were equally proficient on the 24-hr concurrent discrimination task. Infants' performance on the DNMS task, on the other hand, varied dramatically as a function of age. Despite repeated practice, monkeys failed to solve the DNMS task until they were approximately 4 months old, and adult levels of proficiency were not achieved even by 1 year of age. Because the perceptual and motor requirements of both tasks are identical, Bachevalier

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[1] For ease of exposition, the terms *declarative* and *nondeclarative* have been adopted throughout this article.

and Mishkin (1984) concluded that the memory systems that support each task are dissociable during normal development and emerge sequentially over the first few years of life in nonhuman primates.

Whether these memory systems emerge sequentially during human development has been much more difficult to determine (cf. Rovee-Collier, 1997). The verbal nature and motor requirements of many tasks have often precluded direct comparison between the memory performance of preverbal human infants and that of human or nonhuman adults. Furthermore, as in studies conducted with rats and monkeys, it is impossible to know whether or not human infants experience conscious recollection of their prior experiences. Without exception, the existence of declarative memory in infants must be inferred on the basis of nonverbal behavior alone.

Recently, deferred imitation has emerged as a potential candidate for assessing declarative memory in human infants. In a typical deferred imitation task, the experimenter demonstrates a series of actions with objects, and the participant's ability to reproduce those actions is assessed after a delay. Imitation of the target behaviors is distinguished from spontaneous production of the behaviors by assessing baseline performance in the absence of explicit modeling (Meltzoff, 1985; Poulson, Nunes, & Warren, 1989). Because deferred imitation is based on a single, brief episode and because participants are allowed no motor practice before the test, it has been argued that deferred imitation provides a measure of declarative memory performance (Meltzoff, 1990, 1995; Nelson, 1995). The recent finding that human adults with temporal lobe amnesia fail traditional tests of deferred imitation has been used to bolster the argument that deferred imitation paradigms yield a nonverbal index of declarative memory (McDonough, Mandler, McKee, & Squire, 1995).

Empirical research using the deferred imitation paradigm with human infants has provided the opportunity to trace the emergence of declarative memory during development. Previous research has shown that 9-month-old infants exhibit deferred imitation of a single unique action after a 24-hr delay (Meltzoff, 1988). This finding is often cited as evidence that declarative memory emerges at approximately 8–9 months of age in human infants (Nelson, 1995). Recent research from our laboratory, however, has yielded evidence of deferred imitation by infants as young as 6 months of age (Barr, Dowden, & Hayne, 1996; Collie & Hayne, 1999). In the study conducted by Barr et al. (1996), for example, an experimenter performed three unique actions with a puppet, and the infants' ability to reproduce those actions was assessed for the first time after a 24-hr delay. Infants as young as 6 months of age imitated the target actions during the test, which suggests that the capacity for declarative memory emerges by at least this age, if not earlier (Meltzoff & Moore, 1994).

Although the rudiments of declarative memory emerge early in human development, there are also a number of age-related changes in infants' performance on deferred imitation tasks. First, older infants learn faster than younger infants. In the Barr et al. (1996) study described above, 12-, 18-, and 24-month-old infants exhibited deferred imitation after a 24-hr delay following 3 demonstrations of the target actions within a single 20- to 30-s period; 6-month-olds, on the other hand, required twice as much exposure to the target actions to exhibit imitation after the same delay. Second, older infants remember longer than younger infants. Although 6- and 12-month-olds exhibit no evidence of retention when tested after a delay of 2 weeks, 18-month-olds exhibit excellent retention when tested after the same delay (Barr & Hayne, 2000). Finally, older infants express their memories in a wider range of situations. For example, 18-month-olds exhibit the same level of deferred imitation when tested with objects different from those present during the original demonstration; deferred imitation by younger infants is impaired by changes in the objects at the time of the test (Barr & Hayne, 2000; Hayne, MacDonald & Barr, 1997). This latter finding has also been obtained in studies of deferred imitation conducted in other laboratories (Barnat, Klein, & Meltzoff, 1996; Hanna & Meltzoff, 1993).

In the course of their daily lives, human infants often encounter information in one context that matches information they have previously encountered in a different context. After the onset of independent locomotion, in particular, infants are faced with the ongoing challenge of transferring learned information from one setting to another (Rovee-Collier, 1996). To do this, infants must be able to recognize a familiar object or event even when it is encountered in a context that differs from that of the original learning. Despite the disruptive effects of contextual change on retention by very young infants (Borovsky & Rovee-Collier, 1990; Butler & Rovee-Collier, 1989), there is mounting evidence that, during infancy, these effects may decrease as a function of age (Hanna & Meltzoff, 1993; Hartshorn et al., 1998; Klein & Meltzoff, 1999). The earliest age at which infants first express their memories in novel contexts, however, is not yet known.

In the present experiments, we continued to trace the development of declarative memory during infancy. In particular, we examined how changes in the cues present at the time of the test influenced infants' performance in a deferred imitation task. To do this, an experimenter performed three actions with an object, and infants were tested after a 24-hr delay. Some infants were tested with a new object or in a new context relative to that of the original demonstration. To manipulate the context at the time of the test, half of the infants observed the original demonstration in their own homes and half of the infants observed the demonstration in the laboratory. At the time of the test, some infants were tested in the same context in which the demonstration occurred and some infants were tested in the other one.

Experiment 1

Method

Participants

One hundred and twenty infants were recruited from public birth records and by word of mouth. Sixty infants (31 male, 29 female)

were 12 months of age; the other 60 (30 male, 30 female) were 18 months of age. All the infants were tested within 2 weeks of their 12- or 18-month birthday, respectively.

Apparatus

Two hand puppets, a pastel pink rabbit and a pale grey mouse, were constructed for these experiments and were not commercially available. Both puppets were 30 cm in height and were made of soft, acrylic fur. A removable felt mitten (8 cm × 9 cm) was placed over the right hand of each puppet. The mitten was either pink or grey and matched the color of the rabbit or mouse, respectively. A large jingle bell was secured to the back of the puppet (control condition) or inside the mitten itself (demonstration condition). The puppets (mouse or rabbit) were counterbalanced across age, experimental condition, and test group.

Procedure

Infants from each age group were randomly assigned to the demonstration ($n = 48$) or control ($n = 12$) condition as they became available for testing. Infants in both conditions participated in two sessions, a demonstration session and a test session. These sessions were separated by 24 hr (± 5) and were scheduled at a time of day when the infant was likely to be alert and playful. At the beginning of each session, the infant was placed on the caregiver's knee and was held firmly by the hips. The experimenter interacted with the infant for approximately 5 min or until a smile was elicited.

Demonstration session. For half of the infants in the demonstration condition, the demonstration occurred in their own homes ($n = 24$), and for the remaining half the demonstration occurred in the laboratory ($n = 24$). During the demonstration session, the female experimenter knelt down in front of the infant and caregiver, and placed the puppet over her right hand. The puppet was positioned at the infant's eye level but was out of reach, 80 cm from the infant's chest. If the infant failed to orient toward the experimenter, the experimenter attracted his or her attention by saying "look" and using the child's name. For infants in the demonstration condition, the experimenter then performed three target actions with the puppet. First, she removed the mitten from the puppet's right hand. Second, she shook the mitten three times, ringing the bell inside. Third, she replaced the mitten on the puppet's right hand. This sequence of actions was then repeated two more times. The entire demonstration session lasted approximately 20–30 s. When the demonstration was complete, the experimenter put the puppet away and the session ended.

Infants in the control condition were exposed to the puppet, the mitten, the ringing of the bell, and the experimenter for the same amount of time as were infants in the demonstration condition, but the target actions were never demonstrated. During the demonstration session, the puppet was held in front of the infant but was out of reach. The experimenter shook the puppet three times, ringing the bell attached to the puppet's back. This procedure was repeated two more times. The entire control procedure lasted approximately 20–30 s. For half of the infants in the control condition, the initial session occurred in their own homes ($n = 6$), and for the remaining half it occurred in the laboratory ($n = 6$).

The experimenter's verbal comments during the demonstration session were scripted, so that the timing and the content of the comments were identical for infants in both conditions. To maintain the infants' attention during the demonstration session, the experimenter used phrases like, "isn't this fun?" or "are you still watching?" or "shall we have another look?" At no time were the target actions or the puppet described verbally. These procedures are identical to those used in our previous studies with this task (Barr et al., 1996; Barr & Hayne, 1999, 2000; Hayne et al., 1997).

Test session. The test session was conducted 24 hr (± 5) after the demonstration session. During the test, the bell was removed from the back of the puppet or from inside the mitten and the puppet was placed within reach, approximately 30 cm in front of the infant. The test session was videotaped.

In the demonstration condition, half of the infants were tested with the same puppet used during the original demonstration (same puppet) and half were tested with the other puppet (different puppet). Within each puppet test group, half of the infants were tested in the same location as the original demonstration (same context) and half were tested in the other location (different context). Thus, four respective groups of infants of each age ($n = 12$) were tested with the same puppet in the same context, a different puppet in the same context, the same puppet in a different context, or a different puppet in a different context. The distribution of contexts (home or laboratory) and puppets (mouse or rabbit) was counterbalanced within and across all test groups. All of the infants in the control condition were tested with the same puppet in the same context.

Results and Discussion

Two independent observers, one of whom was unaware of the infants' group assignments, scored each test session. Infants were allowed 90 s from the time they first touched the puppet during which to imitate the target actions. Both observers noted the presence or absence of three target behaviors during the test: (a) remove the mitten, (b) shake the mitten, and (c) put (or attempt to put) the mitten back on the puppet. A Pearson product–moment correlation yielded an interobserver reliability coefficient of .90.

An imitation score was calculated for each infant by summing the number of target behaviors he or she exhibited during the test session (range 0–3). The average imitation scores of the infants in the demonstration and control conditions are shown in Figure 1 as a function of age, condition (demonstration or control), and test stimuli. The data from infants in the demonstration condition were subjected to a 2 × 2 × 2 (Age [12 or 18 months] × Test Puppet [same or different] × Test Context [same or different]) analysis of variance (ANOVA). This analysis yielded a significant main effect of age, $F(1, 88) = 29.74, p < .0001$, and a significant main effect of test puppet $F(1, 88) = 6.14$, $p < .05$. These main effects were qualified by an Age × Test Puppet interaction, $F(1, 88) = 5.20, p < .05$. To evaluate the source of this interaction, separate one-way ANOVAs across test puppet were conducted on each age group. For the 18-month-olds, there was no effect of test puppet on the imitation scores. For the 12-month-olds, on the other hand, infants tested with the same puppet exhibited higher imitation scores than did infants tested with a different puppet, $F(1, 46) = 13.17, p < .001$. There was no main effect of test context and no interaction.

The imitation scores of infants in the control condition are also shown in Figure 1. There was no age-related difference in the spontaneous production of the target behaviors,
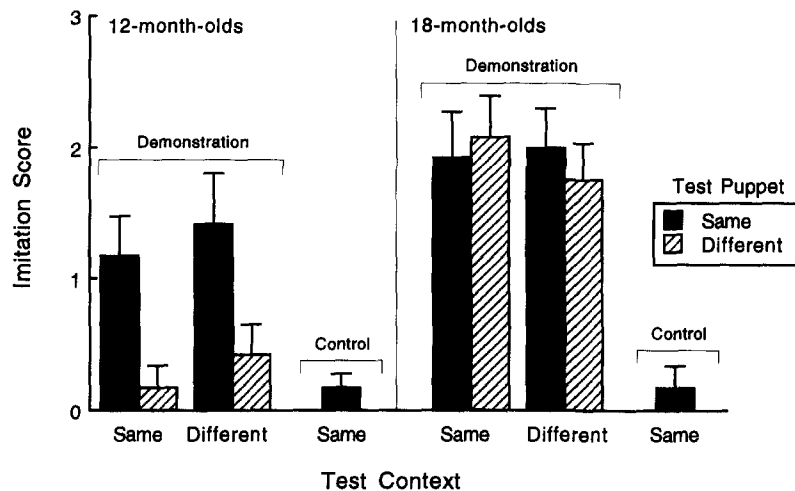
Figure 1.   The mean imitation scores (±*SEM*) for the 12- and 18-month-old infants in Experiment 1.

$t(22) = .45, p < .66$. In each age group, only 1 child in the control condition removed the mitten during the test session.

In the deferred imitation paradigm, imitation is only inferred when a group's mean imitation score is greater than the imitation score of infants in the age-matched control condition (Barr & Hayne, 1999, 2000; Meltzoff, 1985). To assess which test groups met this criterion, the data from infants in the demonstration condition and those in their age-matched control condition were subjected to a one-way ANOVA across all five groups (i.e., four demonstration groups, one control group). For each age, this analysis yielded a significant main effect of group, 12-month-olds: $F(4, 55) = 5.30, p < .001$; 18-month-olds: $F(4, 55) = 7.60$, $p < .0001$. Post hoc Student Newman–Keuls tests ($p < .05$) indicated that, irrespective of the test context, 12-month-olds who were tested with the same puppet exhibited imitation scores that were significantly above those of infants in the control group, but infants tested with a different puppet did not. For the 18-month-olds, on the other hand, the mean imitation scores of all four test groups in the demonstration condition exceeded those of infants in their age-matched control group.

Taken together, the results of the present experiment replicate and extend our previous findings with this task. Consistent with the results of Hayne et al. (1997), there were significant age-related differences in deferred imitation when the object was altered at the time of the test. Although 18-month-olds exhibited the same level of retention irrespective of the test puppet, 12-month-olds exhibited no retention whatsoever when they encountered a different test puppet. In contrast, changes in the environmental context had no effect on the performance of infants of either age. This latter finding is consistent with the findings previously obtained by Meltzoff and his colleagues (Hanna & Meltzoff, 1993; Klein & Meltzoff, 1999) and suggests that by at least 12 months of age, infants are able to generalize across contexts after a 24-hr delay. We still do not know, however, when this ability first emerges during development. Thus, Experiment 2 was designed to address this issue.

Experiment 2

The purpose of Experiment 2 was to assess the effect of altered test cues on deferred imitation by 6-month-olds. Our prior research with the task used in Experiment 1 has shown that infants as young as 6 months of age exhibit deferred imitation after a 24-hr delay (Barr et al., 1996). As described earlier, 6-month-olds do not imitate the target actions with the puppet if the demonstration session consists of only three repetitions of the target actions within a 20- to 30-s period. They do, however, imitate the target actions when the demonstration session consists of 6 repetitions of the same actions within a 40- to 60-s period. For this reason, the experimenter demonstrated the target actions six times within a single session. As in Experiment 1, the effect of changes in the test puppet or test context on deferred imitation was assessed after a 24-hr delay.

Method

Participants

Forty-eight 6-month-old infants (24 male, 24 female) were recruited from public birth records and by word of mouth. All infants were tested within 2 weeks of their 6-month birthday.

Apparatus and Procedure

The apparatus and procedure were identical to those used in Experiment 1. As infants were recruited, they were randomly assigned to the demonstration ($n = 36$) or control ($n = 12$) condition. For half of the infants in each condition, the initial session occurred in their own homes, and for the remaining half it occurred in the laboratory. As in Experiment 1, the test session was conducted 24 hr (±5) after the demonstration session. During the test, the bell was removed from the back of the puppet or from inside the mitten and the puppet was placed within reach, approximately 30 cm in front of the infant.

Within the demonstration condition, infants were randomly assigned to one of three test groups. One group was tested with the same puppet in the same context ($n = 12$), one group was tested

with the same puppet in a different context ($n = 12$), and one group was tested with a different puppet in the same context ($n = 12$). The distribution of contexts (home or laboratory) and puppets (mouse or rabbit) was counterbalanced within and across test groups. As in Experiment 1, all of the infants in the control condition were tested with the same puppet in the same context.

Results and Discussion

As in Experiment 1, the test session was videotaped, and infants were allowed 90 s from the time they first touched the puppet during which to imitate the target actions. One observer noted the presence or absence of three target behaviors during the test: (a) remove the mitten, (b) shake the mitten, and (c) put (or attempt to put) the mitten back on the puppet. A second observer, unaware of the infant's group assignment, scored 24 of the test sessions. A Pearson product–moment correlation yielded an interobserver reliability coefficient of 1.00.

The average imitation scores of the infants in the demonstration and control conditions are shown in Figure 2 as a function of condition (demonstration or control) and test stimuli. The data were subjected to a one-way ANOVA across all four groups (i.e., three demonstration groups, one control group), which yielded a significant main effect of group, $F(3, 44) = 11.05$, $p < .0001$. Post hoc Student Newman–Keuls tests indicated that infants who were tested with the same puppet in the same context exhibited imitation scores that were significantly higher than those of infants in the control group ($p < .05$). In contrast, the imitation scores of infants who were tested with a different puppet in the same context or with the same puppet in a different context were not above the imitation scores of the control group. That is, changes in either the puppet alone or in the context alone disrupted the imitation performance of 6-month-olds when they were tested after a 24-hr delay. In response to the question that originally motivated this experiment, infants apparently begin to generalize across contexts sometime between 6 and 12 months of age.
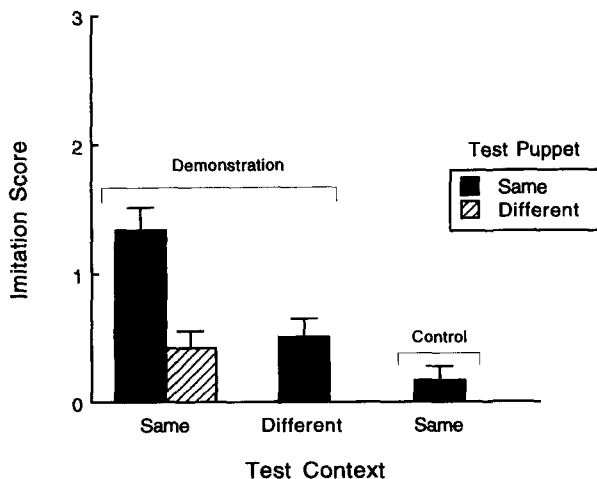

Figure 2. The mean imitation scores ($\pm SEM$) for the 6-month-old infants in Experiment 2.

General Discussion

In the present experiments, we assessed age-related changes in deferred imitation over the first 2 years of life. This task was chosen because it is thought to tap nonverbal declarative memory in human infants and adults (McDonough et al., 1995; Meltzoff, 1990, 1995; Nelson, 1995). Recent research on deferred imitation with human infants has shown that, although imitation begins to emerge early in development (Barr et al., 1996; Collie & Hayne, 1999; Meltzoff, 1988), infants' acquisition and retention of these tasks continues to improve throughout infancy (Barr & Hayne, 1999, 2000; Hayne et al., 1997). The results of the present experiments add to this growing body of research.

Eichenbaum and his colleagues recently outlined two fundamental properties that define declarative memory. Although their empirical data were collected with rats, we believe that their theoretical framework provides a valuable way to characterize the emergence of declarative memory during human development. The implications of Eichenbaum's theory for the development of declarative memory are two-fold. First, Bunsey and Eichenbaum (1995) argued that declarative memory is required for the long-term retention of information about a single episode. When tested for social transmission of food preferences, for example, rats with hippocampal lesions exhibit retention immediately after exposure to the demonstrator, but not after a 24-hr delay. In our deferred imitation task, human infants as young as 6 months exhibit retention of information about a single episode for at least 24 hr. On this basis, we would argue that these infants also exhibit evidence of declarative memory.

Second, Cohen and Eichenbaum (1993; Eichenbaum, 1997) have argued that declarative memory permits an organism to use past experiences in novel situations. Although rats with hippocampal lesions can learn a nonverbal paired-associate task, they cannot use this information to solve new problems that involve the same rules. The inferential use of prior knowledge in new situations has been referred to as *representational flexibility* (Eichenbaum, 1997). In tests of deferred imitation, 6-month-olds can perform the basic task (even after a delay), but only 18-month-olds are able to apply their original learning to new cues (objects and contexts) encountered during the test. That is, despite the precocious emergence of declarative memory during human development, representational flexibility continues to improve throughout infancy (Barr & Hayne, 2000; Hayne et al., 1997) and perhaps even longer.

We hypothesize that the age-related change in representational flexibility documented in the present study may contribute to the offset of childhood amnesia, the inability of adults to recall events that occurred during their infancy and early childhood. Freud (1905/1963) originally coined the term; he argued that the memories of our early experiences were actively blocked from consciousness due to their unacceptable aggressive and sexual content. Contemporary theories of childhood amnesia have focused on age-related changes in the encoding, organization, retrieval, and expression of memory as potential explanations for the phenomenon (for reviews, see Campbell & Spear, 1972; Howe &

Courage, 1993; Nelson, 1993; Pillemer & White, 1989). At present, however, no single theory can account for all of the available data.

One hallmark of memory development that may contribute to the offset of childhood amnesia is an increase in representational flexibility. The results of the present study, for example, indicate that for 6-month-old infants, memory retrieval was highly specific to the conditions of original encoding. Changes in either the proximal or contextual cues disrupted performance after a delay. The specificity of the cues required to initiate memory retrieval by these young infants indicates that it may be difficult if not impossible for potentially useful memories to be retrieved by cues (or in contexts) that were not a part of the original experience. As a function of both maturation and experience, however, older infants gradually begin to exploit a wider range of potential retrieval cues. This age-related change in representational flexibility may cause an increase in the accessibility of a given memory over the long term. We are currently exploring the possibility.

Finally, maturation of the medial temporal lobe has long been considered to be the rate-limiting step for the development of declarative memory (Nadel & Zola-Morgan, 1984; Schacter & Moscovitch, 1984; Squire, 1987, 1992a, 1992b). Recently, however, the focus on the medial temporal lobe alone has shifted to one that incorporates maturation of the cortical association areas as well (Bachevalier, 1990, 1992; McKee & Squire, 1993; Nelson, 1995). This shift has been motivated by at least two factors. First, the medial temporal lobe was originally thought to mature late in ontogeny (Nadel & Zola-Morgan, 1984), but it has now been shown to mature relatively early, at least in primates (Bachevalier, Ungerleider, O'Neill, & Friedman, 1986; Diamond, 1990). Second, neonatal lesions of the medial temporal lobe in monkeys impair performance on the DNMS task, but neonatal lesions of the cortical association areas (e.g., area TE) do not (Bachevalier, Brickson, Hagger, & Mishkin, 1990; Bachevalier & Mishkin, 1994; Malkova, Mishkin, & Bachevalier, 1995). Thus, maturation of the higher cortical association areas is now thought to play an important role in the development of declarative memory.

Taken together, studies with both human (Barr et al., 1996; Collie & Hayne, 1999; Diamond, 1990, 1995; Hayne et al., 1997; Experiments 1 and 2 of the present study) and nonhuman (Bachevalier, Brickson, & Hagger, 1993; Bachevalier & Mishkin, 1984) primates suggest that declarative memory begins to emerge early in infancy but continues to improve over a protracted period of development. We hypothesize that the medial temporal lobe, which matures early in development, may be sufficient to support some basic declarative memory processing, but that maturation at higher levels of the cortex may be required for the full range of declarative memory processes to emerge. This hypothesis remains to be tested.

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