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# What Infant Memory Tells Us about Infantile Amnesia: Long-Term Recall and Deferred Imitation

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Long-term recall memory was assessed using a nonverbal method requiring subjects to reenact a past event from memory (deferred imitation). A large sample of infants ($N = 192$), evenly divided between 14- and 16-months old, was tested across two experiments. A delay of 2 months was used in Experiment 1 and a delay of 4 months in Experiment 2. In both experiments two treatment groups were used. In one treatment group, motor practice (immediate imitation) was allowed before the delay was imposed; in the other group, subjects were prevented from motor practice before the delay. Age-matched control groups were used to assess the spontaneous production of the target acts in the absence of exposure to the model in both experiments. The results demonstrated significant deferred imitation for both treatment groups at both delay intervals, and moreover showed that infants retained and imitated multiple acts. These findings suggest that infants have a nonverbal declarative memory system that supports the recall of past events across long-term delays. The implications of these findings for the multiple memory system debate in cognitive science and neuroscience and for theories of infantile amnesia are considered.

Infantile amnesia refers to the difficulty adults have in accessing memories from the first years of life. One candidate explanation for this phenomenon is the immaturity of the memory system during infancy. The hypothesized immaturity has received support from two independent sources, developmental psychology and cognitive neuroscience. Regarding the former, Piagetian theory postulated that representation and recall were the product of development in infancy, not aspects of the initial state. He placed their onset at 18 to 24 months of age, during "stage 6" of the sensorimotor period. Piaget reported that a cluster of abilities synchronously emerged at this age—deferred imitation, symbolic play, high-level object permanence, and language. That all these blossomed synchronously de-

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manded an explanation; Piaget's was that younger infants were confined to sensory-motor habits ("schemes") which could be retained, but there was no representation or recall of perceptually absent events until 18 to 24 months old. When representation became possible, it enabled the aforementioned cluster of behaviors to emerge.

A second strand of related work derived from research in cognitive science and neuroscience. It was hypothesized that there are dissociable memory systems subserved by different neural structures (e.g., Sherry & Schacter, 1987; Squire, 1987). Neuropsychological studies on memory-impaired patients and experimental animals demonstrated that motor skills and habits could be learned and retained in the same individual who failed other memory tasks. A striking case derived from amnesic adults who could successfully execute motor routines they acquired over several trials, but could not remember having learned them. It was argued that there were (at least two) dissociable memory systems. One (spared in amnesia) was called habit/procedural/early/memory system I; the other (not spared) was called declarative/explicit/late/memory system II. (Different theorists use different labels, which do not carve up memory at identical places, however the terms separated by slash marks refer to related types of memory.)

Cognitive neuroscience and developmental psychology converged on the proposition that infants were restricted to habit learning and a procedural memory system, possibly because of immaturity of the neural structures needed to support declarative memory (Bachevalier & Mishkin, 1984; Diamond, 1990; Schacter & Moscovitch, 1984; Nadel & Zola-Morgan, 1984). This seemed to provide a potential explanation for infantile amnesia. If infants did not lay down declarative-like memories to begin with, they would not be accessible later for explicit recall.

This equilibrium did not last. It was disrupted both by research on memory in early childhood (Fivush & Hamond, 1989, 1990; Nelson, 1989, 1990, 1993; Newcombe & Fox, 1994; Pillemer, Picariello, & Pruett, 1994) and directly by findings on infant memory. Researchers provided surprising results about long-term retention in infancy. In studies using a novelty preference paradigm, Fagan (1973, 1990) found preferential looking to new versus previously exposed patterns in 5-month-olds after delays of 2 weeks. Using an operant conditioning procedure (mobile conjugate reinforcement), Rovee-Collier and colleagues (e.g., Rovee-Collier, 1990; Rovee-Collier & Hayne, 1987) demonstrated retention over 21 days in 6-month-old infants, as indexed by elevated levels of the conditioned response (footkicks) to a mobile. Finally, another group of researchers re-tested infants who had experienced an unusual experimental protocol 1 or 2 years earlier—reaching for luminous and sounding objects in the dark in a sound-attenuated chamber (Myers, Clifton, & Clarkson, 1987; Perris, Myers, & Clifton, 1990; see also Myers, Perris, & Speaker, 1994, for related work). The main results were that children who had practiced this skill as infants subsequently showed less discomfort with the test situation (a darkened room) than controls and were more likely to repeat actions they had previously performed in this setting (e.g., reaching out to grab/shake a rattle in the dark, something they had performed across multiple trials in a 15- to 19-visit longitudinal study). (One subject was also reported to have verbally labeled a salient object from the test situation when reintroduced to the environment, an interesting effect currently being pursued by the original research team.)



These findings show infant retention. However, two points have been made suggesting a conservative reading of the effects. Regarding novelty preference, it has been pointed out that visual recognition is different from recall. Infants may still lack any ability to generate actions based on stored representations (Flavell, 1985; Piaget, 1962), which would be very limiting. Regarding mobile conjugate reinforcement, it has been suggested that this fits the mold of procedural/implicit memory (Mandler, 1990; Squire, Knowlton, & Musen, 1993). It might be that infants, like adult amnesics, show conditioning effects over long delays but would utterly fail on tests of long-term declarative memory. The darkened room experiment (especially the dampening of emotional discomfort with the unusual situation and the increased tendency to perform previously rewarded actions) can also be assimilated to a model of procedural memory, as pointed out by the original authors (Myers et al., 1987; Perris et al., 1990) and others (Howe & Courage, 1993).

Do we have any evidence that infants are capable of recall memory of the *non*procedural type? Relevant data come from findings of imitation from memory (deferred imitation). Deferred imitation has long been accepted as an index of a different, possibly more-complex type of memory than visual novelty preference (it demands more than recognition) or conditioning (no previously-rewarded motor practice need be involved). Classical developmental theory held that the onset of deferred imitation was at 18 to 24 months of age. This view was revised when Meltzoff demonstrated that 14-month-old infants (Meltzoff, 1985) and even 9-month-old infants (Meltzoff, 1988c) were capable of deferred imitation after a 24-hr retention interval.

Deferred imitation has now been shown in several independent laboratories using increased delays, context change, and a wider variety of tasks. Using a sample of Swedish infants, Heimann & Meltzoff (in press) reported deferred imitation in 9-month-old infants and moreover found that individuals with low retention scores at 9 months also tended to score low at 14 months of age (using different objects), suggesting that this procedure might tap stable individual differences in cognitive functioning. Meltzoff (1988a) found that 14-month-old infants who saw an act displayed on television would reproduce the act from memory when presented with the real three-dimensional object after a 24-h retention interval, suggesting some stimulus generalization. Hanna and Meltzoff (1993) reported deferred imitation over a 2-day retention interval and a change in memory context (site of the test) in 14-month-olds, with evidence of poorer performance when a shift in context and increased delay were used. Meltzoff (1988b) demonstrated deferred imitation of completely *novel* acts over a 1-week retention interval in 14-month-old infants and moreover found that infants could store and retrieve multiple acts over such lengthy delays. Bauer and Hertsgaard (1993) demonstrated deferred imitation of event sequences after a 1-week delay in 13.5- to 16.5-month-old infants, and Bauer and Mandler (1989) found deferred imitation of event sequences over a 2-week delay in 16- and 20-month-old infants. Bauer and Shore (1987) reported that with the aid of verbal support by the adult and motor practice by the infant, there was deferred imitation for certain acts and over a 6-week delay by 21-month-olds.

In sum, deferred imitation has emerged as a useful new technique for assessing infant memory and cognition. The time is ripe for using it as a tool to investigate infant memory over even longer delays. Several laboratories have been working on this problem (Bauer, Hertsgaard, & Dow, 1994; McDonough & Mandler, 1994; Meltzoff, 1992, 1993). There are similarities in the approaches used across these laboratories, but one difference is that I have concentrated on a particularly stringent kind of deferred imitation. I have investigated memory-based imitation when the infant is not permitted to perform immediate imitation before the delay is introduced. In the experiments in my laboratory (e.g., Meltzoff, 1985, 1988b, 1988c; Hanna & Meltzoff, 1993) the infants were shown the adult demonstration but were not allowed to touch or handle the test objects. A delay was then imposed (1 day to 1 week) and the infants were tested for the first time to see what they retained. In the majority of the work from the Bauer and Mandler-McDonough laboratories, infants were provided with the opportunity for motor practice and immediate imitation before the delay was imposed. This latter approach supports the inference of memory and recall; however, the most conservative reading would be that infants are retaining their own already performed motor acts (which again raises the issue of procedural memory of some sort). It has been previously demonstrated that motor practice through immediate imitation can influence the amount of subsequent recall under certain circumstances (Meltzoff, 1990a).

The purpose of the present experiments was to test deferred imitation over significant delays, both with and without the opportunity for motor practice (immediate imitation). Over two experiments, a large sample of infants was used, $N = 192$. In both experiments the infants were 14 and 16 months old at the time of encoding. In Experiment 1 the delay was 2 months; in Experiment 2, the delay was 4 months. An interesting feature of Experiment 2 is that the delay forced infants to straddle the 18-month-old boundary—



a time of significant cognitive change often implicated in infantile amnesia (Howe & Courage, 1993; White & Pillemer, 1979), particularly changes in language (e.g., Bloom, 1973; Gopnik & Meltzoff, 1987; Nelson, 1973) and the self-concept (e.g., Lewis & Brooks-Gunn, 1979). In both experiments, three independent groups of children were tested. The $\text{Model}_{\text{obs+immed}}$ group assessed infants' retention and imitation in the case that they were allowed immediate imitation before the delay. The $\text{Model}_{\text{obs only}}$ group provided the more conservative test of memory, by eliminating imitation of the target acts at visit-1. Infants in this group were simply shown the target acts with no opportunity to touch or handle the novel test objects in any way. The index of recall was the number of target acts infants produced when presented with the objects after the delay, with no explicit reminding other than the objects and the test situation itself (long-term, cued recall memory). An age-matched Control group was used in both experiments to assess infants' spontaneous production of the target acts in the absence of seeing the target demonstrations before the delay.

## EXPERIMENT 1

### Method

*Subjects*

The subjects were 96 normal infants, 48 of whom were 14 months old ($M = 60.64$ weeks, $SD = .59$ weeks) and 48 of whom were 16 months old ($M = 69.84$ weeks, $SD = .58$ weeks) at the time of their first visit to the laboratory. Half the subjects at each age were female. The subjects were recruited by telephone from the University of Washington's computerized subject pool, containing names of families who had returned a recruitment postcard mailed soon after the birth of their child. Preestablished criteria for admission into the experiment were that infants be of normal birth weight (2.5–4.5 kg), normal length of gestation (40 ± 3 weeks), and have no known visual, motor, and mental handicaps.

*Test Room*

The test was conducted in a small room, unfurnished save for the test apparatus. Infants were seated on their parent's lap across a table from the experimenter. The top surface of the table (1.2 × .76 m) was covered with black contact paper. One video camera recorded a close-up image of the infants and most of the table top; another camera recorded the experimenter's stimulus presentations on a separate videotape to facilitate subsequent blind scoring. The experiment was electronically timed by a character generator that inserted elapsed time onto both video records. The character generator also controlled a small light, behind the infant but visible to the experimenter, that signaled the end of each 20-s response period.

*Stimuli*

Four novel objects served as test stimuli. All but possibly one (the collapsible cup) were objects that the infants could not have seen or played with before, because they were specially constructed in our laboratory. The first object was a 12.5-cm dumbbell-shaped toy consisting of two wooden cubes, each with a length of plastic extending from it. One length of plastic fit snugly inside the other tubular piece. The act demonstrated was to grasp the cubes and pull outwards until the object separated into two pieces. The second object was a flat rectangular box (19 × 26.7 cm) with a translucent orange plastic panel for a top surface. The act demonstrated was for the experimenter to lean forward from the waist and touch the panel with the top of his forehead. When touched by the head, the panel was illuminated by a light inside the box. The light bulb was controlled by a footpedal so that the panel did not accidentally illuminate if the adult or infant touched it when picking it up, etc. The third object was a collapsible plastic cup (6.5 cm high) made of a graded set of bands. The target act was to use a flat palm to push down on the top of the cup and make it collapse. The fourth object was a small black box (16.5 × 15 × 5.5 cm) with a small circular hole (1.5 cm) on the top surface; slightly below the hole was a black button. The act demonstrated was to put the index finger inside the hole and push the button, which activated a buzzer inside the box.

*Design and Procedure*

The 96 subjects were randomly assigned to three independent groups: Control, $\text{Model}_{\text{obs only}}$, and $\text{Model}_{\text{obs+immed}}$. Half of the subjects within each condition were 14 months old and half were 16 months old at visit-1. Sex of subject was counterbalanced within each age × condition cell.

*Visit-1.* Upon arriving at the laboratory, families were escorted to a waiting room in which the necessary consent forms were completed. The infant was then led to the experimental room and seated on the parent's lap across the table from the experimenter. The experimenter handed the infant a series of small rubber warm-up toys to play with while explaining the general procedure to the parent. When the infant seemed acclimated to the room and experimenter, which usually took about 1–3 min, the warm-up toys were withdrawn and the test began.

In the $\text{Model}_{\text{obs only}}$ condition each subject was shown the four target acts. For each infant, the acts were presented in one of four randomly-selected test orders (across which each object occurred in every possible position). Each test object was kept hidden from view in a container below the table before it was brought to the table for its demonstration and was returned to the container before the next object was presented. Each demonstration consisted of a 20-s period in which the target act was repeated three times. The demonstration took place out of reach of the subject so that he or she could not touch or play with the object, but was confined to observing the event. If the infant became distracted during the presentation the experimenter would call the child's name, say "look here" or "oh, see what I have," but would never use words describing the materials or target acts (such as "touch head," "pull toy," "poke button," "imitate," and so forth). At the end of the first round of demonstrations, this same process was duplicated two more times.



The $\text{Model}_{\text{obs+immed}}$ condition was similar to the previous one. The critical difference was that immediately after the first round of demonstrations for the four stimuli, the infants were handed the test objects one at a time and allowed to play with each for 20 s. This provided a test of immediate imitation. At the end of these four 20-s response periods, there was one more round of demonstrations. Thus, the $\text{Model}_{\text{obs+immed}}$ subjects saw the demonstrations and were also given an opportunity for immediate imitation, whereas the $\text{Model}_{\text{obs only}}$ group were merely shown the target acts with no opportunity for immediate imitation.

The procedure in the Control condition was similar to the modeling groups. Parents and infants were escorted to the waiting room to complete the forms. They were next led to the test room where they sat at the table. Again, the experimenter spoke to the parent while handing warm-up toys to the child until he or she seemed to acclimate. The only difference between the control and the two modeling conditions was that the subjects were not ever exposed to the toys or the adult modeling on the first visit. The goal of the control was to assess whether infants would *spontaneously* produce the target acts on the second visit after the delay, even in the absence of seeing any modeling in the first visit.

*Visit-2.* For all three groups a 2-month delay was interposed between the first and second visit ($M$ = 8.13 weeks, $SD$ = .55 weeks). Subjects in all three groups were treated identically on visit-2. Infants were led into the test room and seated at the table, and the experimenter again provided warm-up toys for about 1–3 min, until the subject acclimated. At that point the warm-up toys were removed and the test objects were presented in their original order. Each object was placed on the table directly in front of the infant. The response period for each object was 20 s starting from when the infant made first contact with the object. The response periods were electronically timed and video recorded for subsequent scoring. The first four response periods (one for each test object) constituted block-1, and an identical block-2 immediately followed in which the test objects were re-presented for 20 s each. Pilot studies had shown that some infants seemed hesitant to respond in the first 20-s exposure, but that response periods of longer duration seemed to bore other infants. For reasons of experimental rigor I wanted to use response periods of fixed length regardless of experimental condition (rather than to have variable response period lengths that were regulated by the $E$), therefore two blocks of 20-s response periods were used for all subjects in all groups.

*Scoring*

There were no artifactual cues on the video record as to the subjects' treatment condition. A scorer who was naive to the structure of the experiment, the hypothesis, and the group assignment viewed the subjects in a random order and provided a dichotomous yes/no code as to whether the target act was produced in each response period. The video segments from Experiments 1 and 2 had the identical format and were randomly intermixed for scoring. This facilitated comparisons across experiments.

To assess scoring agreement, the primary scorer and an independent scorer both coded the entire data set, and the primary scorer also recorded a randomly selected 10% of the subjects. Intra- and interscorer agreement on the number of target acts performed was high, as evaluated by both Pearson $r$ (.99 and .97 respectively) and kappa (.94, .91 respectively).

## Results and Discussion

For the purposes of the main analyses, each subject was assigned a score ranging from 0 to 4 according to the mean number of target acts he or she produced across the two blocks of response periods. Table 1 (2-month delay panel) displays the mean number of target acts performed as a function of the experimental condition. As can be seen, there was strong evidence for memory and deferred imitation after a 2-month delay. Infants who saw the adult demonstrations on visit-1 produced more target behaviors after the delay than controls who had not seen the demonstrations.

The data were analyzed using a two-way analysis of variance (ANOVA) to examine the effects of Condition (3) and Age (2). There was a highly significant main effect of Condition, $F(2,90) = 9.56$, $p < .001$. There was no significant effect of Age or Condition × Age interaction, $p > .35$ in both cases. The data were therefore collapsed across age, and pairwise comparisons conducted using the Tukey HSD procedure. The results showed that mean scores for the $\text{Model}_{\text{obs only}}$ group ($M = 1.67$, $SD = 1.11$) and the $\text{Model}_{\text{obs+immed}}$ group ($M = 1.89$, $SD = 1.32$) did not differ significantly from each other, but that each was significantly greater ($p < .05$) than the Control group ($M = .75$, $SD = .82$). (For these analyses each infant's mean score was used; but the results remained significant if only the data from block-1 or block-2 were analyzed in isolation.)

Forgetting can be examined by assessing each infant's decrement in imitative performance between the immediate test and the test of imitation from memory (after the 2-month delay). Infants in the $\text{Model}_{\text{obs+immed}}$ group ($n = 32$) had an opportunity for immediate imitation in visit-1. These same infants returned after a 2-month delay and were presented with the same four test objects for the same length of time in the first trial block. Thus their immediate imitation scores (ranging from 0 to 4) and their responses in block-1 after the 2-month delay (ranging from 0 to 4) are directly comparable. (Note that to insure strictly comparable data, infants' responses on the first block of trials after the delay were used—i.e., the first time the infants handled the objects, not the mean score for two trial blocks. This was because infants only had one response block for the immediate imitation test, which was done to limit their motor practice on the first visit.) The mean number of target acts produced in immediate imitation was 2.65 ($SD = 1.29$) as contrasted with 1.75 ($SD = 1.59$) after the delay, and this difference was significant, $t(31) = 2.93$, $p < .01$. This suggests that forgetting occurred during the 2-month delay.

There is an alternative account for this decline that does not involve forgetting. One might suppose that older infants are *less* likely to produce the target actions than younger infants, and thus that the decline over time was solely attributable to the infants being older at the second test. This intuitively unlikely possibility was, however, countered by other data. The number of target acts produced by infants in the 16-month-old control group was greater (though not significantly so) than that produced by the 14-month-old control group. This indicates that there was no natural decline in these acts over this age span. This was the case in both Experiment 1 and 2. Similar results were also obtained from other developmental studies using these objects in tests of infants between 14 and 24 months old (Hanna & Meltzoff, 1993; Meltzoff, 1985). Thus, the most parsimonious account is that the decline in imitative performance over the delay is due to forgetting.

In summary, the results of this experiment indicated highly robust memory and imitation over a 2-month delay. Infants who had seen the demonstration of the target acts on visit-1 were significantly more likely to produce these targets on visit-2 than were infants in the control group. There was significant retention and imitation not only for infants who were al-

TABLE 1
Mean Number of Target Acts Produced as a Function of Condition, Age, and Delay

| | 14 months old | | 16 months old | | Combined | |
|---|---|---|---|---|---|---|
| Condition | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| | | | 2-Month delay | | | |
| $\text{Model}_{\text{obs only}}$ | 1.75 | 1.22 | 1.59 | 1.02 | 1.67 | 1.11 |
| $\text{Model}_{\text{obs + immed}}$ | 1.66 | 1.45 | 2.13 | 1.18 | 1.89 | 1.32 |
| Control | .59 | .80 | .91 | .84 | .75 | .82 |
| | | | 4-Month delay | | | |
| $\text{Model}_{\text{obs only}}$ | 1.38 | .74 | 1.28 | 1.06 | 1.33 | .90 |
| $\text{Model}_{\text{obs + immed}}$ | 1.34 | 1.11 | 1.47 | .83 | 1.41 | .96 |
| Control | .72 | .80 | .84 | .77 | .78 | .77 |

*Note.* Total $N = 192$. $n = 16$ for each Condition × Age × Delay cell. The entries in the table are the mean of two response blocks.

lowed to imitate immediately in visit-1, but also for subjects restricted merely to observing the adult demonstration without being able to handle the test objects before the 2-month delay (the $\text{Model}_{\text{obs only}}$ group). Further analyses showed that forgetting occurred over the delay. It can be concluded that performance has begun to decline over a 2-month delay, but it is still higher than baseline levels.

## EXPERIMENT 2

The results of Experiment 1 demonstrated that 14- and 16-month-old infants can reproduce acts on the basis of memory after a 2-month delay; the data also indicated that there was some loss over the delay. Experiment 2 was modeled on the first experiment but differed in the length of delay that was imposed. In Experiment 2, the memory interval was 4 months. Infants first seen at 14 months were tested for recall at 18 months of age, and those first seen at 16 months were tested for recall at 20 months of age. Comparisons with Experiment 1 were facilitated because infants were tested in the same laboratory using the same procedure and materials.

### Method

*Subjects*

The subjects were 96 normal infants, half of whom were 14 months old ($M$ = 61.06 weeks, $SD$ = .54 weeks) and half 16 months old ($M$ = 69.77 weeks, $SD$ = .55 weeks) at the time of visit-1. Half the subjects at each age were female. The preestablished criteria for admission into the study were the same as in Experiment 1 (normal birth weight, gestational age, and free of handicaps), and the recruitment procedure was the same.

*Test Room, Stimuli, Design, and Procedure*

The laboratory set up and stimuli were identical to those used in Experiment 1. The design and procedure differed only in that the delay interval imposed was 4 months ($M$ = 17.28 weeks, $SD$ = .46 weeks).

*Scoring*

The data were coded by both the primary and an independent scorer to assess interscorer agreement, and a randomly selected 10% of the subjects were used to assess intrascorer agreement. Intra- and interscorer agreement on the number of target acts performed were both high, $r$ = .97, .96 and kappa = .92, .89, respectively.

### Results and Discussion

The data were analyzed using a two-way ANOVA examining the effects of Condition (3) and Age (2). Table 1 (4-month delay panel) provides the mean number of target behaviors as a function of experimental factors. There was a significant main effect of Condition, $F(2,90) = 4.63, p < .05$.



There was no significant effect of Age nor a Condition × Age interaction, $ps > .50$ in both cases. Pairwise comparisons (Tukey HSD procedure) on the data collapsed across age indicated that the $\text{Model}_{\text{obs only}}$ group ($M$ = 1.33, $SD$ = .90) and the $\text{Model}_{\text{obs+immed}}$ group ($M$ = 1.41, $SD$ = .96) did not significantly differ from each other, but that each was significantly greater ($p < .05$) than the Control group ($M$ = .78, $SD$ = .77).

The analysis used to evaluate forgetting was the same as in Experiment 1. Infants in the $\text{Model}_{\text{obs+immed}}$ group ($n$ = 32) had an opportunity for immediate imitation in visit-1. These same infants returned after the 4-month delay and were presented with the same four test objects for the same length of time in the first trial block. As described in Experiment 1, a comparison can be made between the immediate imitation scores and the responses in block-1 after the delay. The mean number of target acts produced in immediate imitation was 2.66 ($SD$ = 1.13) as contrasted with 1.22 ($SD$ = .98) in the first block after the delay. This difference was significant, $t(31) = 6.54, p < .001$. There was a 54% reduction in the number of target acts produced by the infants after the 4-month delay.

In summary, this study shows memory across a substantial delay interval, 4 months. Infants who had seen an adult demonstrate particular target acts were more likely to reproduce these same behaviors when presented the objects after a 4-month delay than were infants in a control group who had visited the same laboratory and played with the same experimenter for the same length of time, but who did not see the demonstrations 4 months earlier. There was also evidence of a substantial decline in the number of target acts performed over the delay, indicating that imitative performance is not immune to degradation.

*Comparisons across Experiments*

Because the same experimenter, laboratory, test materials, and procedure was used, it is reasonable to make comparisons across the two experiments, which differed in the length of delay interval. Two comparisons using a larger $N$ are illuminating. The first illustrates the strength of the effect at the level of individual subjects; the second compares forgetting as a function of three levels of delay (no delay, 2-month delay, and 4-month delay).

Regarding individual subjects, Table 2 shows the number of infants performing different numbers of target acts. In the Control group only 6.3% of the infants (4 of 64) averaged more than two of the four target acts. Thus in the absence of modeling, the *spontaneous* production of this number of target acts is rare. In the $\text{Model}_{\text{obs only}}$ group 23.4% (15 of 64) of the infants reached this level of performance as did 25% (16 of 64) in the $\text{Model}_{\text{obs+immed}}$ group. A chi-square analysis of the corresponding 3 (Condition) × 2 (Response Level) contingency table was significant, $\chi^2(2, N = 192) = 11.67, p < .01$.

TABLE 2
Number of Subjects Producing Different Numbers of Target Acts as a Function of Condition

| | Number of target acts[a] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Condition | 0 | .5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | Total $n$ |
| $\text{Model}_{\text{obs only}}$ | 8 | 5 | 18 | 9 | 9 | 8 | 4 | 0 | 3 | 64 |
| $\text{Model}_{\text{obs + immed}}$ | 10 | 6 | 10 | 6 | 16 | 5 | 3 | 4 | 4 | 64 |
| Control | 22 | 13 | 16 | 5 | 4 | 2 | 2 | 0 | 0 | 64 |

[a] The number of target acts is the mean of two response blocks.

Regarding the effects of delay on memory, 128 of the infants can be grouped according to the three levels of delay imposed before their first test of imitation. There were 64 infants who were assessed after no delay (the immediate imitation test of the 32 *S*s from each experiment in the $\text{Model}_{\text{obs+immed}}$ groups), another independent group of 32 infants who were first assessed after a 2-month delay (Experiment 1: $\text{Model}_{\text{obs only}}$ group), and a further independent group of 32 infants who were first assessed after a 4-month delay (Experiment 2: $\text{Model}_{\text{obs only}}$ group). To ensure strictly comparable data across groups, infants' responses on the first block of four trials were used, i.e., the first time the infants handled the objects. Thus infants in each of the three groups were treated identically and differed only in whether their first test of imitation occurred after no delay, 2-months delay, or 4-months delay. A one-way ANOVA revealed a highly significant difference in the number of target acts produced as function of delay level, $F(2,125) = 22.75$, $p < .0001$. There was a progressive decline in imitative performance as a function of delay: No delay, $M = 2.66$ ($SD = 1.20$), 2-Month Delay, $M = 1.53$ ($SD = 1.22$), and 4-Month Delay, $M = 1.09$ ($SD = .99$). This graded delay effect suggests forgetting. Pairwise comparisons using the Tukey HSD procedure showed that there was a significant difference ($p < .05$) between the immediate test and each level of delay, but that the difference between the 2- and 4-month delay did not reach significance. This indicates that although there was a monotonic decline in performance as a function of delay, the sharper drop off was between the immediate and 2-month delay, rather than between the 2- and 4-month delay.

## GENERAL DISCUSSION

Two experiments were conducted using a large sample of subjects ($N = 192$), encompassing a total of 384 laboratory visits. Memory was indexed by subjects' nonverbal reenactment of an event they saw in the past (deferred imitation). The results showed that infants reproduced target acts they had seen either 2 months (Experiment 1) or 4 months (Experiment 2) earlier. Four aspects of these experiments make them relevant for theories



of memory development and for modern issues in cognitive science and neuroscience.

First, the findings demonstrate that information stored from the original visual event formed the basis of the *subsequent action.* The infants did not simply manifest visual recognition, but recreated an event themselves from memory. The test objects themselves do not spontaneously evoke the motor responses in infants at the ages tested. This is shown by the low rates for the target acts in the absence of modeling. Second, the results show that *specific* information about the adult's act can be retained, not merely an emotional tone or general properties of the original event. This is inherent to the finding that infants are imitating at all, but is most clearly illustrated by the fact that a significant number of infants (23%) who saw the novel act of head touching imitated after the delay ($p < .05$ versus the controls). In other words, infants do more than retrieve general goal or end-state information ("the panel can be lit"), which would not necessarily mandate use of the head. They can remember the specific way something was done; they imitate the means used, not solely the general ends achieved (Meltzoff, 1988b). Third, the fact that the memory was based on a *brief,* one-session exposure is noteworthy. At maximum, infants had 1-min exposure to each test object during their first visit. Fourth, the results demonstrated that infants were capable of remembering *multiple targets,* not just one of them. A significant number of infants in the modeling groups produced more than two target acts, and 7 of them reached ceiling, reproducing all four of the targets (none of the control infants reached this level of performance).

The experimenters tested imitation and retention of two different types. In one group ($\text{Model}_{\text{obs+immed}}$) infants saw the demonstrations on visit-1 and were given the opportunity for immediate imitation before the delay was imposed. In the other group ($\text{Model}_{\text{obs only}}$) the infants were restricted merely to seeing the demonstrations in visit-1. Imitation after the delay was demonstrated in both groups, and no significant difference was found between them (although the overall means were in the direction favoring the $\text{Model}_{\text{obs+immed}}$ group). Using a different protocol than the one used here, Meltzoff (1990a) found that recall was enhanced when motor practice and immediate imitation were allowed prior to the delay. I am now exploring whether the boost due to immediate imitation varies as a function of the amount of immediate practice, the length of delay, or the specific tasks administered. Regardless of this ongoing research, the findings reported here are among the first demonstrating imitation from memory over delays of months using a design that completely rules out motor practice through immediate imitation. The results are compatible with other emerging reports showing deferred imitation over significant delays (Bauer et al., 1994; McDonough & Mandler, 1994). Three contributions of the present findings that go beyond other research are: (a) long-term memory with no immediate-imitation experience, (b) memory for multiple targets, and (c) a demonstrated recall of the specifics of the modeled act.

### *Implications for Cognitive Science and Neuroscience: The Nature of Nonverbal Memory*

The memory demonstrated here and in other deferred imitation experiments bears on current debates about multiple memory systems. Three methods used to assess infant memory in humans are: novelty preference (e.g., Fagan, 1990), conditioning (mobile conjugate reinforcement) (Rovee-Collier, 1990; Rovee-Collier & Hayne, 1987), and deferred imitation (Bauer & Hertsgaard, 1993; Mandler, 1990; Meltzoff, 1985, 1988b, 1990b). All three techniques are useful, but they differ in terms of the theoretical inferences that can be drawn. The novelty preference paradigm assesses whether infants perceive a pattern as different from one to which they have been previously exposed. In deferred imitation the infant must do more than register a target as being familiar or novel. The infant must generate a motor act on the basis of memory. Imitating an act from memory entails recall, not simply recognition memory.

Both the mobile conjugate reinforcement procedure and deferred imitation involve motor production. However, deferred imitation differs from the conditioning procedure in at least two ways. First, the target behavior is not shaped, learned, or practiced over a series of trials but rather is picked up by observation after brief displays. It is no exaggeration to call the learning in the Model$_{\text{obs only}}$ "no trial" learning, because the infant is simply never allowed to handle the toys at visit-1. Infants learned purely by observing, not by doing. Second, in visit-1 there was no reinforcement for pairing the visual stimulus with the response, because the infant was not allowed to generate the response in the first place. Although the type of memory demonstrated in conditioning procedures has been characterized as habit learning or procedural memory (Howe & Courage, 1993; Mandler, 1990; Squire et al., 1993; but see Rovee-Collier, 1990), the long-term retention manifest by deferred imitation does not fit into this mold. Deferred imitation (at least using Meltzoff's 1985, 1988b, 1988c paradigm) cannot be reduced to habit learning or procedural memory, because there was no habit established to begin with—no trials were allowed, no practice given.

Deferred imitation taps a form of nonverbal declarative memory. It is nonverbal because what the infant remembers is not described in words; however, the subject must reconstruct the past from memory. Other than the nonverbal nature, the results from deferred imitation seem to meet the other classic criteria for declarative memory (McKee & Squire, 1993; Mandler, 1990; Meltzoff, 1990b; Squire et al., 1993). This idea is buttressed by a recent report that adult amnesics, who do not have an intact declarative memory system (Squire, 1987), do not succeed on deferred imitation tasks (McDonough, Mandler, McKee, & Squire, 1994). Thus, deferred imitation is



not spared in amnesia, although tasks measuring procedural memory are spared. As a working hypothesis, it seems legitimate to characterize infants as having long-term, nonverbal declarative memory involving recall.

I am here treating as an empirical question whether infants have a nascent declarative-like memory system that can be tapped using nonverbal procedures—in other words, nonverbal organisms are not being excluded, simply by definition, from having such memory. If one wished to be more conservative, the term *non*procedural or *non*habit memory could be substituted for "nonverbal declarative" without altering the arguments offered here. This approach was advocated in Meltzoff (1990b) to underscore that preverbal infants were capable of more than sensory-motor schemes or habits, but without invoking the baggage of the "declarative" label. In truth, deferred imitation and other findings from infancy (Kuhl & Meltzoff, in press) do not always fit easily into the extant classification schemes derived from research with adults and laboratory animals; and there is some danger of confusion if we simply adopt terms wholesale without caveats of the type offered here and elsewhere (Meltzoff, 1990b). If we can avoid such pitfalls, the infant work promises to enrich the debate within cognitive science and neuroscience by providing novel examples of nonverbal memory that stretch the limits of current taxonomies and suggest new categories. This is as it should be. The membrane between human developmental work and cognitive neuroscience is a thin one, and information needs to flow in both directions if we are to make progress in understanding the complexities of mind and brain.

### *Implications for Infantile Amnesia*

These findings about infant memory raise a paradox about infantile amnesia, the difficulty adults have in remembering events from the first years of life (for recent discussions see: Fivush & Hamond, 1990; Howe & Courage, 1993; Nelson, 1990; Newcombe & Fox, 1994; Pillemer & White, 1989; Usher & Neisser, 1993). One classic account of infantile amnesia is that infants cannot lay down memories of the proper type the first place. It has been argued that they lack maturity of neural structures (especially the hippocampus and related structures) necessary to form or retain declarative-like memories (Bachevalier & Mishkin, 1984; Diamond, 1990; Schacter & Moscovitch, 1984; Nadel & Zola-Morgan, 1984; but see, Bachevalier, 1990; McKee & Squire, 1993). This idea from cognitive neuroscience fits hand in glove with cognitive-developmental theory (Piaget, 1952, 1962), which proposes the ontogenetically late emergence of representation and recall. However, it now appears that human infants have a more sophisticated memory and representational system than previously assumed—crucially, the findings show long-term declarative memory at least by 14 months of age (related evidence has been reported at 9 months of age and younger, Meltzoff, 1988c, 1990b; Meltzoff & Moore, 1994). The findings reported here demonstrate long-term recall of events, even those that have not been practiced.

If infants can form such memories, why infantile amnesia? One possibility is that nonverbal declarative memories can be formed and retained, but are only accessible within the infancy period itself. Infants may remember for 2 months, 4 months, or even a year, as long as the to-be-remembered event is both encoded and retrieved within a the same ontogenetic epoch. What, then, would render infant memories relatively inaccessible to the older individual? One obvious possibility is the transition from nonverbal to verbal functioning. The details of the current findings and others (e.g., Myers et al., 1987) do not favor this. In the present work, a significant number of infants who were first shown material at 14 months of age recalled it at 18 months of age; another group exhibited recall over the transition from 16 months to 20 months of age.

The definition of what it is to be a "verbal" child is notoriously difficult, but 18 months old is well documented as the age of the "language explosion" (e.g., Bloom, 1973; Nelson, 1973; Goldfield & Reznick, 1990; Gopnik & Meltzoff, 1987, 1992). It is hard to see how the present results could obtain if there was a radical change, a psychological chasm that was crossed at about 18 months of age that prevented humans from accessing earlier memories. (This does not rule out some modified version of the language hypothesis, however. Events experienced in the preverbal period may be relatively inaccessible in adulthood by purposeful verbal recall of the type: "I remember the specific time when I saw such and such an event.")

Future research should vary the encoding and recall dates to systematically straddle other significant boundaries in brain and psychological development during infancy and early childhood (Howe & Courage, 1993; Pillemer & White, 1989). However, the intuitively plausible age of 18 months—complete with the language explosion and other significant cognitive changes—no longer seems as appealing a candidate for a sharp dividing line in memory development as it once did. These facts about infant memory only make the phenomenon of infantile amnesia even more intriguing.

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