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Long-term memory, forgetting, and deferred imitation in 12-month-old infants

Pamela J. Klein and **Andrew N. Meltzoff**
University of Washington, USA

Abstract

Long-term recall memory, as indexed by deferred imitation, was assessed in 12-month-old infants. Independent groups of infants were tested after retention intervals of 3 min, 1 week and 4 weeks. Deferred imitation was assessed using the 'observation-only' procedure in which infants were not allowed motor practice on the tasks before the delay was imposed. Thus, the memory could not have been based on re-accessing a motor habit, because none was formed in the first place. After the delay, memory was assessed either in the same or a different environmental context from the one in which the adult had originally demonstrated the acts. In Experiments 1 and 3, infants observed the target acts while in an unusual environment (an orange and white polka-dot tent), and recall memory was tested in an ordinary room. In Experiment 2, infants observed the target acts in their homes and were tested for memory in a university room. The results showed recall memory after all retention intervals, including the 4 week delay, with no effect of context change. Interestingly, the forgetting function showed that the bulk of the forgetting occurred during the first week. The findings of recall memory without motor practice support the view that infants as young as 12 months old use a declarative (nonprocedural) memory system to span delay intervals as long as 4 weeks.

Research with adults and animals has revealed that not all memory is of the same kind. Human infants can remember the past, but what kind of memory do they use? Evidence of *recognition* memory derives from studies showing that infants can recognize their mother's face and can be habituated to visual patterns and events. Less work has been done on infant *recall* memory.

Imitation after an act has disappeared from view provides one powerful technique for investigating infant recall. Such deferred imitation requires infants to encode, retain and retrieve a memory, and then to use that memory as the basis for action. Thus deferred imitation demonstrates more than reactions to familiarity or novelty. It is an index of prelinguistic recall in which infants reproduce the now-absent event from memory instead of describing it in words.

Classical developmental theory made explicit predictions about the ontogenesis of deferred imitation. Young infants were said to be capable of recognition memory, but not capable of

Address for correspondence: Andrew N. Meltzoff, Department of Psychology, Box 357920, University of Washington, Seattle, WA 98195, USA; Meltzoff@u.washington.edu.

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recalling absent objects or events without prior motor practice until late in the second year of life. Thus, deferred imitation was thought to be a late-emerging skill. For example, Piaget (1952, 1962) held that very young infants could recognize people, rattles and scenes as familiar or novel, and could retain and duplicate motor habits ('circular reactions'); however, the onset of recall memory, as indexed by deferred imitation, was said to occur at about 18 to 24 months of age during 'stage 6' of the sensorimotor period.

This timetable has now been revised, with substantial implications for theories of the development of representation and recall (Meltzoff & Moore, 1998). For example, deferred imitation of object-related acts has been reported in the second half-year of life (Meltzoff, 1988b; Carver, 1995; Barr, Dowden & Hayne, 1996; Heimann & Meltzoff, 1996) and even earlier when the acts do not involve objects (Meltzoff & Moore, 1994, 1997). Before 18 months, the acts that can be imitated from memory do not appear to be severely constrained. Imitation from memory has been reported for completely novel acts having a 0% baseline probability (Meltzoff, 1988a) and for behavioral sequences of low probability (Bauer & Mandler, 1992; Bauer & Hertsgaard, 1993; Barr & Hayne, 1996). The length of retention interval that can be spanned is impressive. In one study, infants who witnessed demonstrations at 14 months old subsequently imitated these acts after delays of 4 months even though motor practice with the objects during the first session was precluded (Meltzoff, 1995). Converging evidence of very-long-term recall comes from studies using motor practice at time t_1 and verbal cues to imitation after the delay (e.g. Bauer, Hertsgaard & Dow, 1994; Mandler & McDonough, 1995). In summary, recent research shows that infants under 18 months of age can perform deferred imitation of familiar acts, novel acts and behavioral sequences, and they can imitate after lengthy delays.

The time is ripe for studies on the nature and limits of deferred imitation in infancy. Can infants imitate across changes in context? Is there a decrement in performance when a delay and context change are combined? If deferred imitation in the first year of life is highly context bound, it would limit its utility for infants in everyday life and impact theory construction.

Research suggests that memory in early infancy is susceptible to disruption due to changes in context. For example, studies by Rovee-Collier and colleagues investigated infant memory using a conditioning procedure in which infants learned to foot-kick to move a mobile (for reviews see Rovee-Collier, 1990, 1997). After the delay, the mobile was reintroduced and memory measured by increased foot-kicks over appropriate control conditions. The results revealed a stunning limitation of infant memory. The research found that at delays when infants demonstrated significant memory with no context change, performance fell to chance when the context was altered. The context could be as simple as altering the pattern on the crib liner between the training and memory sessions (for related context changes producing the same effect, see Hayne, Rovee-Collier & Borza, 1991). For example, 3-month-old memory performance fell to chance levels when the crib liner was changed after a delay greater than or equal to 3 days, despite robust memory when there was no context change (Rovee-Collier, Griesler & Earley, 1985; Butler & Rovee-Collier, 1989). Rovee-Collier and colleagues have found related context effects for 6-month-olds (Hill, Borovsky & Rovee-Collier, 1988; Borovsky & Rovee-Collier, 1990) and most recently have extended this research on context change to 9- and 12-month-old infants by using an operant procedure involving lever pressing (Hartshorn *et al*., 1998). In all these studies, deleterious effects of context change have been demonstrated, with differences in how context change interacts with the length of delay at different ages (Hartshorn *et al*., 1998). Related findings of the deleterious effects of context change on memory have been reported in the animal literature (Solheim, Hensler & Spear, 1980; Riccio, Richardson & Ebner, 1984; Richardson, Riccio & McKenney, 1988).

Two previous studies from our laboratory investigated the effect of context change on deferred imitation, but in each, context was manipulated in conjunction with other factors. Hanna and Meltzoff (1993) found that 14-month-olds imitated other children's acts after a 2 day delay plus a context change (laboratory to home), but the results showed a decrement in performance relative to infants tested immediately in the same context. Barnat, Klein and Meltzoff (1996) found that 14-month-olds imitated after changes in context and test object (color and size), but the results also showed a decrement compared with conditions in which context and object remained unchanged. Because these studies were not designed to disentangle the relative contributions of delay, change in context and change in object features, the present experiments were undertaken.

The experiments reported here systematically investigate the effects of length of delay, change of context, and their interaction on deferred imitation. The experiments also mark an advance in studies of deferred imitation by incorporating a new methodological refinement. In previous studies, the parent watched the experimental demonstration along with the child. This raises the possibility, however unlikely, that parents could have rehearsed the events with their infants during the retention interval. (This is true for all the studies done in the Meltzoff, Bauer, Mandler and Hayne laboratories, save for Hanna & Meltzoff, 1993, Experiment 3.) In the current experiments, the parent wore a blindfold and was therefore unaware of both the experimental objects and the target acts. In Experiment 2, the adult experimenter was changed between encoding and recall. Therefore, neither the parent nor the experimenter was aware of the infant's test condition. Only the infant could be carrying the memory from the past, which enhances the rigor of the assessment.

In the current studies, independent groups of 12-month-olds were tested after retention intervals of 3 min, 1 week and 4 weeks, either with or without context change. The context was changed using two methods – a switch in rooms at the University (Experiments 1 and 3) and a change from home to laboratory (Experiment 2). In all experiments, the 'observation-only' (Meltzoff, 1985, 1995) deferred imitation procedure was used, and thus infants were confined simply to observing the adult's act at time t_1 without handling the objects. This means that infants' recall at time t_2 could not be based on a repetition (completion) of their already performed movements with these objects.[1] We interpret significant deferred imitation as showing that infants in the first year of life are not limited to a procedural or habit memory system, but instead are capable of what cognitive scientists and

[1]More work is needed investigating the impact of providing infants with motor practice with the to-be-remembered material (immediate imitation) before the delay is imposed (e.g. Meltzoff, 1990b, 1995; Barr & Hayne, 1996, in press). The observation-only procedure is a very stringent test of infant recall memory without motor practice and therefore was used in the current work.

neuroscientists call ‘declarative memory’ (for related arguments see also Mandler, 1990; Meltzoff, 1990a, 1995; Rovee-Collier, 1997; Meltzoff & Moore, 1998).

Experiment 1

In Experiment 1, independent groups of 12-month-old infants were given a test of recall memory after two different retention intervals (3 min or 1 week) either with or without context change. The contexts were either a normal laboratory room or a highly unusual and distinctive environment – a specially designed orange and white polka-dot tent. The test of deferred imitation occurred in the normal laboratory room. This allowed a systematic assessment of the effects of delay and context change on recall memory as assessed by deferred imitation.

Method

Participants—The participants were 96 12-month-old infants who were recruited by telephone from a computerized subject pool maintained by the University. Infants were recruited for the study if they had a normal birth weight (2.5–4.5 kg), a normal gestational length (37–43 weeks) and had no known visual, motor or mental handicaps. All infants were tested within one week of their 1-year-old birthday (M = 366.57 days). An equal number of male and female infants were tested; 91 of the 96 infants were white. Eleven additional infants were dropped from the study due to procedural error (7), refusal of the infant to participate (3) and parental refusal to wear the blindfold (1).

Design—Each infant was assigned to one of six independent groups, with sex counterbalanced within each: Control(baseline), Control(adult manipulation), Imitation(3 min delay + no change), Imitation(3 min delay + context change), Imitation(1 week delay + no change) and Imitation(1 week delay + context change). Infants in the Control(baseline) group assessed the likelihood that infants of this age would spontaneously produce the target acts even in the absence of previously seeing the objects or modeling by the adult. Infants in the Control(adult manipulation) group observed the experimenter manipulate the test objects in interesting ways (see ‘Stimuli’) but did not see the target acts. This controlled for the possibility that infants are prompted to explore the objects after seeing the adult play with them, and this play leads to greater production of the target acts even in the absence of specific modeling (the animal-behavior literature calls this ‘stimulus enhancement’). On methodological grounds, the inclusion of both types of controls provides a rigorous assessment of imitation (Meltzoff, 1988a), but it should also be noted that previous work in this laboratory has not found a significant difference in performance between them. Both groups were included in Experiment 1, because this was the first time some of the test objects had been used with this age group.

Stimuli—The five test objects were either specially constructed for the experiment or modifications of commercially available items. (a) The first object was dumbbell shaped. It was made of two wooden cubes (2.5 cm^3), each with a piece of off-white tubing (7.5 cm) extending from it. One length of the tubing was slightly narrower and fit inside the other. The target act demonstrated was to grasp the dumbbell by the wooden cubes and pull apart until the object separated into two pieces. (b) The second object consisted of a yellow plastic cup (10.5 cm high, 7.3 cm diameter) and a circular string of pink plastic beads (7 cm diameter). The target act was to pick up the beads and place them in the cup. (c) The third object consisted of two wooden blocks (one 5 cm^3 and the other 16.6 × 3.9 × 3.9 cm). There was a hole in the top face of the smaller block (2.2 cm diameter, 3 cm deep). The target act was to pick up the two blocks and tap them against one another. (d) The fourth object was a blue plastic box (7.8 × 7.5 × 5 cm) with an open top and a rectangular wooden stick (11.8 × 1.8 × 1.8 cm). The target act was to pick up the stick and make a ‘stirring’ motion inside the box. (e) The fifth object was an L-shaped, wooden construction consisting of a vertically mounted rectangle (9.2 × 10.2 × 0.9 cm) connected by a hinge to a larger base plate (15.2 × 23.5 × 0.9 cm). The target act was to fold the smaller rectangle from a vertical position to one flush with the base.

Adult-manipulation control acts consisted of the experimenter playing with the test objects in similar but not identical ways to the target acts. The target and control acts were well matched. They involved the same objects, moved by the same experimenter, across the same distance in space, at the same speed, for the same 20 s stimulus-presentation period. The control acts were the following. (a) The dumbbell was placed on the table in the already-pulled-apart state. Thus, the end-state (affordance) was presented. The adult grasped the objects by the cubes and moved them in a way that equated for the extent of movement in the target demonstration. However, the movement was in the vertical plane: Both pieces were raised and then lowered. The vertical distance moved matched the horizontal distance moved during the target demonstration. (b) For the cup, the distance the beads moved was equated with the distance moved during the target act demonstration. The beads were picked up and moved away from the cup and lowered onto the table. (c) The blocks were picked up in the same orientation as for the target act. They were then lowered and tapped on the table. The vertical distance moved during tapping was equated with the horizontal distance moved during the target act demonstration. The sound (the ‘affordance’ of a banging made by these wooden blocks) was virtually identical. (d) For the box and stick, the stick was picked up and held parallel to the table top with one end pointing toward the infant and the other end pointing toward the experimenter. The stirring motion was made next to the base of the box such that the stick touched the side of the box, just as the stick touched it in the target act. (e) The wooden construction was presented with the smaller rectangle resting flat against the base. The control action was to lift the smaller rectangle above the base and then lower it again. The height that the rectangle was raised equaled the distance the rectangle traveled when it was folded. The rectangle ended up flat on the base plate after both the target and control demonstrations; thus the end-state of the action was shown to the infants. (The rectangle was not connected to the base by a hinge for this control act.)

Test rooms—The test room in which infants’ responses were assessed was identical for all groups of infants. It was a normal white-walled laboratory room containing a table with a black top. Infants in the no-change groups also viewed the original demonstrations in this room. For infants in the context-change groups, the demonstrations occurred in a highly unusual context, a three-walled tent constructed from garish orange fabric with white polka-dots (Figure 1). The walls of the tent reached from the edge of the ceiling to the floor, filling the infant’s entire field of vision. Inside the tent was a brown, wood-grain table. The different tables in the demonstration and test rooms ensured that not only the room walls but also the more immediate background context was altered between the encoding and recall sites.

Procedure—Upon arrival at the University, the infant and parent were brought to a large waiting room, where the parents were given a description of the study and asked to fill out consent forms. Depending upon the infant's group assignment, the parent and infant were escorted either to the tent or to the normal room. In either case, the parent was seated at the table with the infant on his/her lap facing the experimenter. Both the demonstration and response periods were preceded by a warm-up during which the infant and experimenter exchanged small rubber toys that were unrelated to the test objects.

Parents of infants in the imitation and Control(adult manipulation) groups were asked to wear a blindfold so they would not know what acts were shown to the infant. Parents were assured that they would be able to watch their infant during the infant's response period. Only one parent refused to wear the blindfold, and that infant was not included in the study.

The objects were presented in five test orders (each object occurred in each position across the orders). Each object was put on the table one at a time. Once the infant fixated on the object, the experimenter demonstrated the target act three times in approximately 20 s. The object was then returned to a box below the table and the next object was placed on the table. An 'observation-only' test procedure was used (Meltzoff, 1985). Using this procedure, infants were confined purely to watching the displays. The demonstrations were presented out of reach of the infants, and infants were not allowed to touch or play with the test objects at any time before the retention interval. The experimenter also did not use words that described the target acts or the objects. If the infant became distracted, the experimenter would attempt to regain the infant's attention by calling the infant's name, saying 'look over here' or 'see what I have'. The stimulus presentations were thus well controlled but had a natural character of introducing a series of toys at an interesting pace that seemed to keep the infants comfortable and engaged.

After the demonstration, a delay of either 3 min or 1 week was imposed. During the 3 min delay, the parent was asked to take the infant into the hallway. Infants in the 1 week delay groups left the laboratory and returned 7 days later (M = 7.0 days, SD = 0.0).

All infants' memory tests occurred in the normal laboratory room. Each object was presented to the infant for an electronically timed 20 s response period beginning when the infant first touched the object. The order of object presentation was the same during the demonstration and response periods. The infants' behavior was video recorded for subsequent analysis.

Scoring—The videotapes were scored by a coder who was uninformed of the infants' test conditions. The video record for each infant was identical, containing five 20 s response periods. The infants were scored in a random order. In sum, there was no artifactual information about group assignment anywhere on the scoring tape.

The coder provided a dichotomous yes/no score as to whether the target act was produced for each object. The operational definitions of the target acts were the following. A 'yes' was scored for the dumbbell if the two halves of the dumbbell visibly separated. A 'yes' was scored for the cup and beads if three or more beads passed the lip of the cup. A 'yes' was scored for the blocks if infants banged the blocks together three or more times (sliding and dropping did not meet the definition). A 'yes' was scored for the box and stick if the stick was inserted into the box and moved back and forth (changing directions at least twice) or the stick was inserted into the box at least three times. A 'yes' was scored for the L-shaped object if the infant used his/her hand to fold the rectangular piece flat against the base plate.

The primary coder scored the entire data set, and both the primary coder and a secondary coder re-scored a randomly selected 20% of the data set. Intracoder and intercoder agreement on the number of target acts produced was high as evaluated by Pearson's r (1.0 and 0.97 respectively) and kappa (1.0 and 0.96 respectively). Analyses were based upon the primary coder's scoring.

Results and discussion

Each infant was presented with five test objects and thus was assigned a score ranging from 0 to 5 depending on the number of target acts produced. Figure 2 displays the mean number of target acts produced by each of the six experimental groups. The results of a one-way analysis of variance (ANOVA) show that the number of target acts varies as a function of group, $F(5, 90) = 5.67$, $p<0.0001$. As expected, performance was low in both controls and they were collapsed for further analyses (means for the baseline and adult-manipulation controls were respectively $M = 1.56$ and $M = 1.81$, $t(90) = 0.52$, $p>0.60$). Planned contrasts indicated that infants in each imitation group performed significantly more target acts than the combined controls, with p ranging from 0.01 to 0.0001. The length of the retention interval influenced memory performance. Subjects produced more target acts after a 3 min delay ($M = 3.47$, SD = 1.27) than after a 1 week delay ($M = 2.78$, SD = 1.43), $t(90) = 2.03$, $p<0.05$. Changing the context between encoding and recall did not affect memory performance after either delay, $p>0.85$ at both the 3 min and 1 week delays.

In sum, infants who saw the demonstrations produced significantly more target acts than the controls, demonstrating long-term recall memory in 12-month-olds. The results also show a decrement in imitation as a function of delay, indicating forgetting. Finally, a context change between encoding and retrieval caused no decrement in memory as measured by deferred imitation at these delay intervals.

Experiment 2

Experiment 2 built on the prior one, but a different context change was implemented. The shift from the orange and white polka-dot tent to the normal laboratory room is a perceptually salient one to an adult. However, both rooms were in the same building and were preceded by the same series of events (an elevator ride, a walk down a strange hallway etc.). Within this larger context or 'script', a critic might argue that the featural differences between rooms are not important to 12-month-olds. In an effort to achieve a more dramatic (or at least different) change and one of greater ecological validity, Experiment 2 used infants' homes as the encoding site and the normal laboratory room as the test site. Moreover, the adult experimenter was changed between the home and the laboratory visit. Using two different adult experimenters, coupled with blindfolded parents, made for an especially rigorous test, since none of the adults present at the test knew what the infant had seen. If infants can recall what to do with the test objects under these circumstances, this would illustrate very powerful and decontextualized deferred imitation in 12-month-old infants.

Method

Participants—The participants were 32 12-month-old infants, recruited in the same manner as in the previous experiment. The mean age at testing was 365.44 days (range 359–372 days); 29 of the 32 infants were white. Four additional infants were dropped from the study due to procedural error (1), refusal of the infant to participate (2) and parental interference (1).

Stimuli—The five objects and target acts were identical to those used in Experiment 1.

Design and procedure—The 32 infants were randomly assigned to one of two groups, counterbalanced for sex of subject: Control(baseline) or Imitation(1 week delay + home/lab context change). The procedure was similar to Experiment 1 but the first visit occurred in the infant's home. The Control(adult manipulation) group was not deemed necessary, because the two control groups yielded virtually identical performance in Experiment 1, and the test objects and age of the infants were unchanged in the current study. In most cases, the child sat in the parent's lap across the kitchen or dining room table from the experimenter. In a few cases a coffee table or high-chair was used. All parents wore a blindfold. All infants were subsequently tested in a normal university laboratory.

For the first visit, Adult #1 drove to each subject's home. She gave consent and information forms to the parent and explained the test procedure. After a brief acclimation period, the target acts were demonstrated for the infants in the imitation group. For infants in the control group, the home visit ended after the acclimation period.

After the 1 week delay (*M* = 7 days, SD = 0.0), infants were brought to the University laboratory. The infants did not see Adult #1 during this session. They were tested by Adult #2 who was blind to the infant's test condition. After the initial warm-up period (with toys not used at the home visit), infants were presented with each test object for a 20 s response period, following the same procedure as in Experiment 1. Responses were videotaped for subsequent analyses.

Scoring—The operational definitions and scoring procedures were the same as those used in Experiment 1. The coder was kept uninformed about each infant's test condition. The primary coder scored the entire data set, and both the primary coder and the secondary coder re-scored a randomly selected 50% of the data. Intracoder and intercoder agreement on the number of target acts produced was high as evaluated both by Pearson's *r* (0.97 and 0.98 respectively) and kappa (0.95 and 0.97 respectively).

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Results and discussion

Each infant was assigned a score ranging from 0 to 5 according to the number of target acts produced. As shown in Figure 3, infants in the imitation group produced significantly more target acts ($M = 2.81$, SD = 1.05) than infants in the control group ($M = 1.50$, SD = 1.03), $t(30) = 3.57$, $p<0.001$. This effect was shown despite a 1 week delay, a change in context from the familiar home to the novel laboratory environment, and a change in the adult experimenters. Because the parent had been blindfolded at home and the second experimenter was not informed of the infant's test condition, the only person who could be carrying the memory of the target acts was the infant. The findings suggest that the cue for recall must be the object itself and that object recognition at this age for this delay does not require contextual support. This is compatible with Meltzoff and Moore's (1998) theory of an 'object-organized' representational system.

Experiment 3

Experiment 3 lengthened the delay between encoding and retrieval to 4 weeks. The removal of contextual support may significantly dampen performance on deferred imitation tests after delays of this magnitude. Of course, the maximum length of retention interval that can be spanned in 12-month-old deferred imitation tests has not been established, but investigating imitation after delays as long as 4 weeks significantly expands the data base for theorizing about infant memory and facilitates comparisons to other work on memory and context change using conditioning procedures in the first year of life (Hartshorn *et al*., 1998).

Method

Participants—The participants were 48 12-month-old infants. The sample was recruited from the same pool and in the same manner as in the previous experiments. The mean age at visit 1 was 366.46 days (range 360–372 days). Four additional infants were dropped from the study due to procedural error (2), equipment malfunction (1) and refusal of the parent to wear the blindfold (1).

Stimuli—The five objects and target acts were identical to those used in Experiments 1 and 2.

Design and procedure—Each infant was assigned to one of three independent groups counterbalanced for sex of subject: Control(baseline), Imitation(4 week delay + no change), Imitation(4 week delay + context change). The procedure was identical to that of Experiment 1 except that the delay between the first visit and the second visit was 4 weeks ($M = 28$ days, SD = 0.56, range 25–29 days). The normal and polka-dot rooms were the same as in Experiment 1.

Scoring—The scoring procedures were identical to those used in Experiments 1 and 2. The primary coder scored the entire data set, and both the primary coder and the secondary coder re-scored 50% of the data set. Intracoder and intercoder agreement on the number of target acts produced was high as evaluated by Pearson's *r* (0.97 and 0.98 respectively) and kappa (0.97 and 0.98 respectively).

Results and discussion

Each infant was assigned a score ranging from 0 to 5 according to the number of target acts produced. The results of a one-way ANOVA show that the number of target acts varies as a function of group, $F(2, 45) = 4.77$, $p<0.05$, Figure 4. A follow-up test showed that both the Imitation(4 week delay + no change) ($M = 2.56$, SD = 1.21) and Imitation(4 week delay + context change) ($M = 2.25$, SD = 0.77) groups produced significantly more target acts than the controls ($M = 1.50$, SD = 1.09), $p<0.05$, and that these two experimental groups do not significantly differ from one another (Newman–Keuls test). This documents long-term memory and deferred imitation over a 4 week delay, and no decrement due to shift in context.

Comparison across experiments: the forgetting function

To further examine the effects of delay on memory and deferred imitation, the data from Experiments 1, 2 and 3 were combined. (The test objects and the procedures remained the same across the studies. Preliminary analysis showed no significant difference in the number of target acts performed by the control groups in the three studies.) For this analysis, there were three levels of delay, 3 min, 1 week and 4 weeks, and a large number of subjects ($N = 176$). A one-way ANOVA shows that the number of target acts produced by infants varied as a function of experimental group, $F(10, 165) = 5.84$, $p<0.0001$. Figure 5 depicts the forgetting function. As shown, there was a monotonic decrease in the number of target acts performed with increased delay. The shape of the function is interesting, because it reveals that the bulk of the forgetting occurred in the first week after learning, with little forgetting thereafter. Planned contrasts reveal that there were significantly fewer target acts performed after a 4 week delay than after a 3min delay, $t(165) = 3.47$, $p<0.001$, and no evidence of significant forgetting between a 1 week delay and a 4 week delay, $t(165) = 1.38$, $p>0.15$. This forgetting function is similar to that found in previous work using deferred imitation (e.g. Meltzoff, 1995) and operant conditioning procedures (e.g. Rovee-Collier, 1997).

General discussion

Three experiments with 12-month-olds investigated infant recall memory as indexed by deferred imitation. The results showed significant deferred imitation after retention intervals of 3 min, 1 week and 4 weeks, both with and without context change. This replicates and extends previous research and documents deferred imitation after lengthy retention intervals at a young age. Rather than deferred imitation and the ability to act on the basis of a long-term representation developing during 'stage 6' at approximately 18 months of age, this capacity seems to be in place much earlier (see Meltzoff & Moore, 1997, 1998, for a theory concerning the first half year of life).

The methodological safeguards used in these experiments are noteworthy. The research is unique in using a parental blindfold. This ensured that parents remained uninformed of what acts were demonstrated. In Experiment 2 there were two adults. Adult #1 demonstrated target acts and Adult #2 tested infants' memory 1 week later. This second experimenter was uninformed as to whether the infants were in the imitation or control group. The blindfolded parent, coupled with the change in adults, ensured that the infant was the only one who could be carrying the memory.

Most previous studies of deferred imitation did not directly assess infant forgetting functions because only one delay interval was used. Although infants at all delays in the current experiments showed significant memory, the results also revealed that the length of the retention interval affected performance. Infants in the 3 min delay groups imitated more target acts than infants in the 1 week or 4 week delay groups. The forgetting function showed that the bulk of infant forgetting occurred within the first week, with no significant reduction in performance after that (up to the 4 week delay). One speculative idea is that the significant decrement in performance is due to the transfer of the acquired information to very-long-term memory, perhaps because different brain sites are involved. In future research, neuroscience techniques (e.g. Carver, 1995; Nelson, 1995) could be used to pinpoint what aspects of brain structure and functioning are implicated in the significant drop off in performance in the first 7 days. In any case, the current procedures seem to offer a sensitive behavioral assay for measuring infant recall memory inasmuch as they simultaneously show memory (performance greater than controls) and forgetting (drop off in performance).

The current results indicate that 12-month-olds' deferred imitation is not damaged by context change across retention intervals ranging from a few minutes to 4 weeks. The number of target acts performed was nearly identical whether infants learned and recalled the acts in the same context or learned them within a polka-dot tent and recalled them in a different room. This was true at both the short and long delays. In Experiment 1 both the encoding and test rooms were in the same university building; each session was preceded by an elevator ride and a walk down a long unfamiliar hallway. From these results alone, a critic could still maintain that this larger setting linked the events, or perhaps that young infants treat all episodes in the laboratory as occurring in the one undifferentiated setting, 'not-at-home'. However, the results from Experiment 2 rule these objections out. Infants saw demonstrations in their homes and were subsequently tested in the laboratory. During the home visit infants sat at their kitchen table, in their high-chair or, most strikingly of all, at a picnic table in the sunny backyard (which was different from the windowless laboratory room in which recall was tested). Moreover, the experimenter was also switched between encoding and recall. The results showed recall memory and successful deferred imitation even under these conditions.[2]

This finding that infant recall memory, as indexed by deferred imitation, is not reduced by context changes differs from Rovee-Collier's classical findings using mobile conjugate reinforcement in 2- to 6-month-olds (e.g. Rovee-Collier, 1990). Future work needs to be

[2]Although context change did not impede deferred imitation in the current work, this does not imply that context is not encoded or cannot serve as a retrieval cue at this age. Contextual support may be needed for successful deferred imitation when featural alterations are made in the test objects (Bauer & Dow, 1994; Barnat *et al*., 1996; Hayne, MacDonald & Barr, 1997) or after delays that stretch to the end of the forgetting function (Hartshorn *et al*., 1998). Moreover, if both encoding and recall occur in the same unique context, memory performance may be enhanced relative to appropriate control conditions.

directed at whether the difference is attributable to the age of the infants or the type of memory tapped by these two different methods, conditioning and deferred imitation. Data are emerging to suggest that age plays a key role. In particular, newer operant procedures from Rovee-Collier's laboratory show that 12-month-olds perform well after context changes except for very long delays (Rovee-Collier, 1997; Hartshorn *et al*., 1998). There thus appears to be important developmental changes in infant memory; younger infants are more highly context bound than older ones. Certainly, the 12-month-olds in the current experiments demonstrated impressive recall memory for novel events across changes in time, space and context. This flexibility is compatible with the emergence in the second year of decontextualized functioning in other domains demanding recall memory, such as symbolic play and language.

A theoretical question posed by these findings concerns the *type of memory* that mediates deferred imitation. Research in cognitive science and neuroscience shows that all memory is not the same, which has led to the notion of multiple memory systems. The core idea is that there are functionally dissociable memory systems that are mediated by different brain structures (e.g. Mishkin, Malamut & Bachevalier, 1984; Tulving, 1985; Sherry & Schacter, 1987; Squire, 1987, 1992). A key distinction has been drawn between a lower-order memory system, often called habit or procedural memory, and a higher-order system, called declarative memory. Amnesic patients who are profoundly impaired in tests of declarative memory often exhibit normal functioning on tests of procedural memory (Squire, 1992; Squire, Knowlton & Musen, 1993). It has sometimes been argued that infants in the first 18 months of life are confined to a procedural memory system, which dovetails nicely with Piagetian claims of a shift from a strictly sensorimotor to a representational system (e.g. Moscovitch, 1984). Contrary to this, Meltzoff (1988a, 1990a, 1995), Mandler (1990) and Rovee-Collier (1997) have argued that young infants are not limited to habit or procedural memory and can access a nonverbal declarative memory system. The research reported here provides further empirical support for this view in four ways.[3]

First, deferred imitation involves recall rather than recognition. Infants did not simply recognize the object at time t_2 as familiar or novel. Instead, they had to retrieve and produce an act they had not done with this object in the past. Second, the typical cases of declarative memory involve learning through observation without the aid of motor practice or habit formation. The experiments reported here used the observation-only procedure in which infants were confined simply to watching the adult at time t_1. Infants were not allowed to manipulate or even to touch the objects during the first visit. Deferred imitation using the observation-only procedure does not fit within the framework of a habit or procedural memory, because no habit was established in the first place. Third, declarative memory concerns a specific, one-time event, whereas habit or procedural memory is typically memory established over multiple training trials. In the current experiments, deferred imitation is based upon a brief event – each target act was demonstrated for only 20 s.

[3]This assumes that the term 'declarative memory' is not restricted, as a purely definitional matter, to verbally reported material. Researchers in cognitive science and neuroscience argue that nonverbal measures can tap declarative memory (e.g. Squire, 1992; McKee & Squire, 1993). Similar arguments have been advanced by developmentalists (e.g. Meltzoff, 1990a, 1995; Rovee-Collier, 1997). In this view, it is an empirical question whether prelinguistic infants exhibit declarative memory.

Fourth, the finding that deferred imitation is not rigidly context bound is compatible with declarative memory. Taken together, the data provide empirical support for the inference that infants in the first year of life are capable of nonverbal declarative memory (or one might be more conservative and call it '*non*procedural' memory as advocated by Meltzoff, 1990a, 1995).

The findings reported here also have practical, social-developmental implications. Infants may observe their mother manipulating an object in the kitchen and only later gain access to the object in the living room. Similarly, while visiting a neighbor, the infant may observe a child playing with a new toy, but immediate imitation will be precluded if there is only one object. In order for the information acquired through observation to be of use in these everyday instances, infants must retrieve a memory after a substantial delay and a change of context. The current experiments document this ability.

At a more theoretical level, the results demonstrate that infants can use the behavior of other people to learn how to use novel objects (Meltzoff & Moore, 1998, 1999). Infants need not depend on independent discovery or trial and error manipulation of the objects. They can learn about object functions from observing how other people use the objects, prior to and without motor involvement of their own. Such perceptually derived information can be retrieved in a variety of environments differing from the original learning context. If a one-time laboratory exposure to the acts of others has such long-lasting influence (here demonstrated up to 4 weeks), it becomes easy to see that the more pervasive and repetitive effects of 'culture' will have profound influence on infant behavior. Infants watch and remember what adults do, and this subsequently alters their own behavior over the long term.

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Figure 1.
The polka-dot context used for demonstrating the target acts.

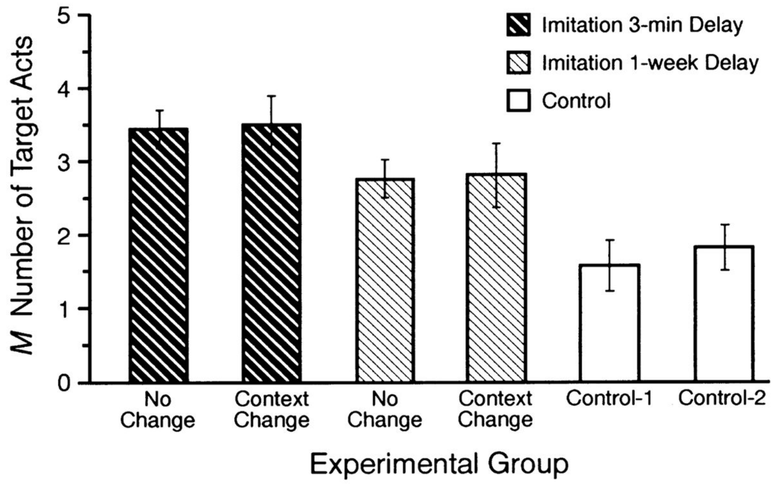

Figure 2.

Experiment 1: Mean number of target acts produced as a function of experimental group (±1 SE). Control-1 indicates the baseline control, and Control-2 indicates the adult-manipulation control (see text for details).

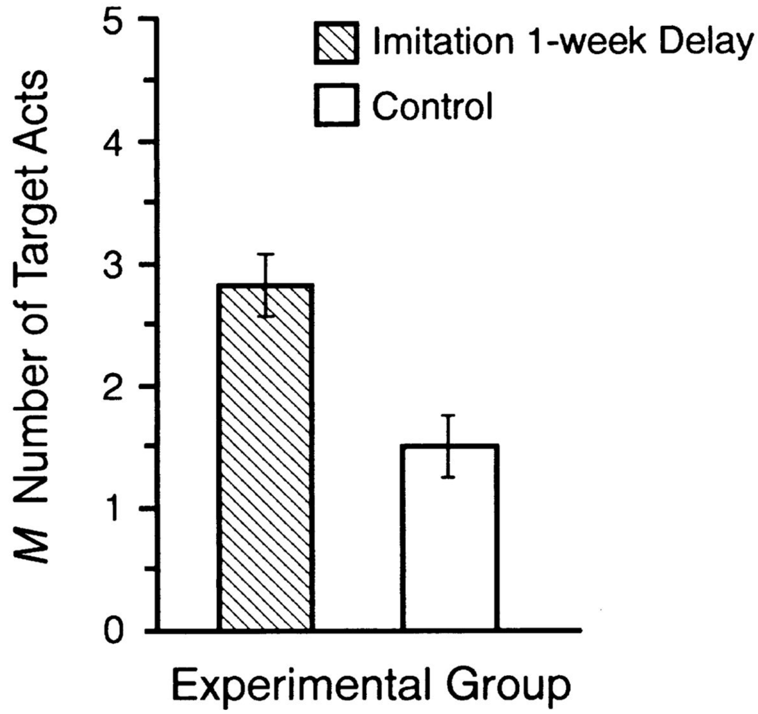

Figure 3.
Experiment 2, 1 week delay: Mean number of target acts produced as a function of experimental group (±1 SE).

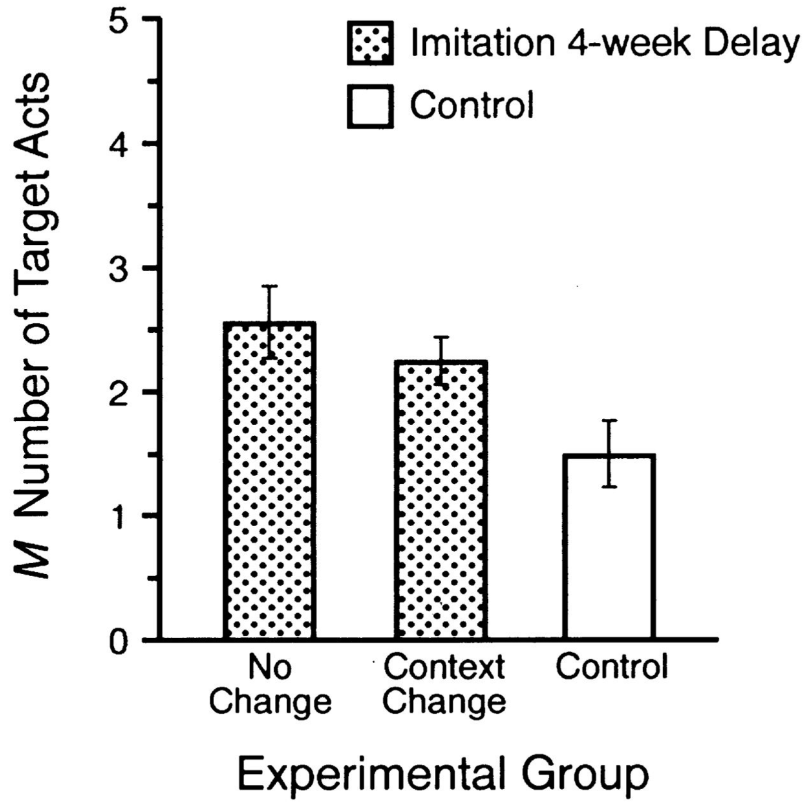

Figure 4.
Experiment 3, 4 week delay: Mean number of target acts produced as a function of experimental group (±1 SE).

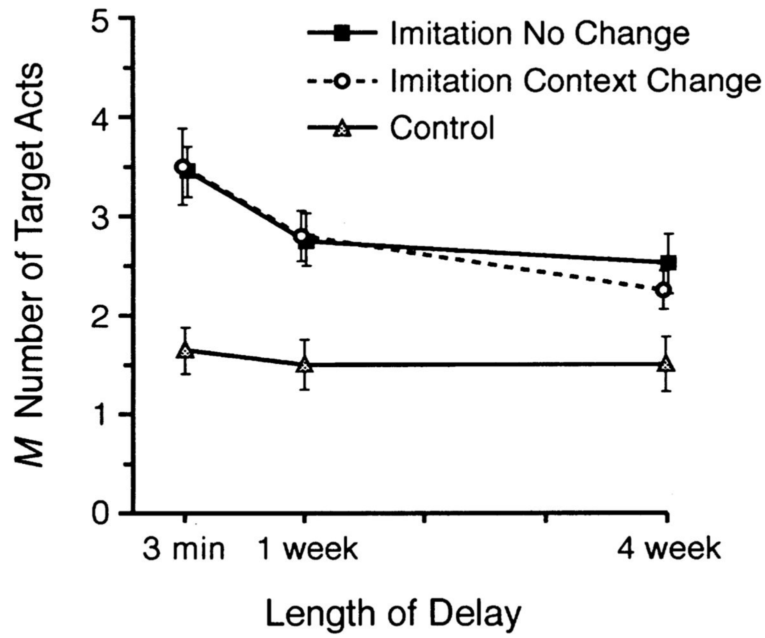

Figure 5.
All experiments: Mean number of target acts produced as a function of experimental group (±1 SE). At each length of delay, performance in the imitation groups significantly exceeded the controls. There was a significant forgetting between the 3 min and 1 week delay, and no significant forgetting between the 1 week and 4 week delays. (For ease of illustration in the figure, control groups 1 and 2 from Experiment 1 were combined, as were the two groups assessing imitation after a 1 week delay + context change from Experiments 1 and 2. Statistical analyses showed no significant differences between these groups, which legitimized the collapsing for graphical purposes.)