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## Mediated Imitation in 6-Month-Olds: Remembering by Association

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In two experiments with 72 6-month-olds, we examined whether associating an imitation task with an operant task affects infants' memory for either task. In Experiment 1, infants who imitated target actions that were modeled for 60 s on a hand puppet remembered them for only 1 day. We hypothesized that if infants associated the puppet imitation task with a longer-remembered operant task, then they might remember it longer too. In Experiment 2, infants learned to press a lever to activate a miniature train—a task 6-month-olds remember for 2 weeks—and saw the target actions modeled immediately afterward. These infants successfully imitated for up to 2 weeks, but only if the train memory was retrieved first. A follow-up experiment revealed that the learned association was bidirectional. This is the first demonstration of mediated imitation in 6-month-olds across two very different paradigms and reveals that associations are an important means of protracting memories. © 2001 Academic Press

*Key Words:* infant memory; imitation; operant conditioning; implicit memory; explicit memory; associative priming; association; retention.

As early as 1890, William James argued that event processing occurs continuously in memory in a manner that is most aptly described as a “stream of thought . . . or subjective life” (p. 239). A vital capacity of the human memory system, however, is to extract and associate useful information from the continuous stream when it co-occurs (Rescorla, 1967). James (1890) argued that such associations occur “when two elementary brain-processes have been active together or in immediate succession, one of them, on reoccurring, tends to propagate its excitement in the other” (p. 566). Current theoretical accounts of memory processing share several underlying assumptions. First, theorists generally assume that a memory is a hypothetical collection of attributes that represent what the subject noticed at the time of original encoding (Estes, 1955; Spear, 1978; Tulving, 1983; Underwood, 1969). Second, they assume that these

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attributes represent characteristics of the nominal stimulus as well as of the context in which it appeared. Finally, they assume that the memory can be retrieved only if the subject reencounters stimuli with attributes that match those in the original memory representation.

Some theorists have proposed that the brain stores information hierarchically, linking new information with old (Bourne, Dominowski, & Loftus, 1979; Bower, 1998; Collins & Quillian, 1969). As a result, when a situation is either partially or fully reinstated, the memory for the original event is activated and, in turn, activates other memories that are linked to it in the same associative network (Bourne et al., 1979; Estes, 1976; Loftus, 1973). The mechanism by which such associated memories are activated is called *associative priming* (McNamara, 1992b). Priming refers to the facilitative effect on retention of the prior presentation of an item or event (Tulving & Schacter, 1990). Lexical decisions about a word such as *black* are faster, for example, if it is preceded by an associated word (e.g., *white*) rather than by an unrelated word (e.g., *bread*) (McNamara, 1992b; Warren, 1977). Priming is viewed as an automatic retrieval process that is initiated when a preexisting memory representation is activated (Musen & Treisman, 1990; Schacter, Bowers, & Booker, 1989). Primes are effective only if they perceptually match the encoding conditions (for review, see Richardson-Klavehn & Bjork, 1988). In a typical associative priming study, adults study novel word–word paired associates to establish new associations between them (Schacter et al., 1989; Warren, 1977). During testing, words are presented in rapid succession, and only if the second word had been paired with the first rapidly presented word during the study phase is the word correctly identified.

In infants, associative priming has been studied by successively presenting two discrete events in a common context (Greco, Hayne, & Rovee-Collier, 1990; Hayne, Greco-Vigorito, & Rovee-Collier, 1993; Rovee-Collier, Greco-Vigorito, & Hayne, 1993; Timmons, 1994). In one study, for example, Greco et al. trained 3-month-old infants to move a series of category exemplars (different mobiles) by kicking. After training, some infants were exposed to a physically dissimilar but functionally similar (i.e., moving) novel object—a butterfly windchime—for 3 min. Other infants were exposed for 3 min to the physically dissimilar novel object while it was motionless. The following day, only infants who had seen the physically dissimilar mobile move recognized it during the test, indicating that they had associated it with the prior training memory.

Apparently, infants responded on the basis of the functional context that the training mobiles and the novel moving windchime shared and not simply because the windchime had been seen before. Two weeks later, when the original training memory was forgotten, the windchime was able to reactivate it so that infants again responded to another category member during testing. The fact that a novel windchime which infants had merely witnessed successfully primed the training memory confirmed that the training memory and the novel windchime had been linked in an associative network (Greco et al., 1990).

In another study, 3-month-olds were again trained with a series of different mobiles, but this time, a red-and-blue-striped liner was draped around the crib on the final training day as a distinctive context (Hayne et al., 1993). Immediately after training, infants were briefly shown the novel, highly dissimilar windchime, motionless, for 3 min. When the exposure took place in the same, highly distinctive training context, infants kicked when tested with the motionless windchime the next day, even though the red-and-blue-striped context was not present. When training and exposure took place in a nondistinctive context (without the crib liner), however, infants did not kick when tested with the motionless windchime the next day. In other words, the distinctive physical context acted as a catalyst to integrate the memory of training and the memory of the windchime. Once the memories were associated, the presence of the distinctive context was no longer necessary.

Timmons (1994) subsequently demonstrated the associative principle with 6-month-olds using two separate paired-associate tasks. Infants learned to move a mobile by kicking and to turn on music box by arm waving or vice versa. These tasks were independent and highly specific. Three days elapsed between successive training on the two tasks. Three weeks after learning the second task, when infants had forgotten *both* cue–response pairs, some infants received the mobile as a reactivation cue and others received the music box. When tested with the *mobile* the next day, both groups produced the response that had originally been paired with the mobile. Because the mobile task was forgotten at the time of priming, the music box prime must have *indirectly* reactivated the memory of the mobile task, enabling infants to produce the mobile-appropriate response. Apparently, these two tasks had been associated by virtue of being acquired in a common context (the-red-and-blue-striped playpen liner) (Timmons, 1994).

In the present study, infants' memories of two very different tasks—a deferred imitation task with a hand puppet and an operant conditioning task with a train—were associated by occurring in a common context. These tasks were selected because infants showed markedly different retention for them. We hypothesized that infants' memory for the short-lived task (puppet imitation) would be protracted if it were associated with the longer remembered operant train task. In the following experiments, we first determined the forgetting function of the puppet imitation task using a delayed recognition procedure. Then we established the forgetting function for the puppet imitation task after it had been associated with the operant train task. Finally, we explored the necessary and sufficient conditions under which this association could protract retention of the imitation task.

## EXPERIMENT 1: FORGETTING FUNCTION OF THE IMITATION TASK

Imitation is an important way by which infants acquire a wide range of new behaviors. An infant's imitation of a modeled behavior can occur immediately or after a delay. In order to be used in the future, however, the modeled information must be stored in long-term memory and subsequently retrieved in the appropriate context. Previously, we demonstrated that 6-month-old infants could imitate

modeled actions after a 24-h delay if they observed a demonstration of the actions for 60 s but not for only 30 s (Barr, Dowden, & Hayne, 1996). The first experiment, therefore, was designed to replicate this finding and to determine the maximum duration of retention of the puppet imitation task at 6 months. To this end, we exposed independent groups of infants to a demonstration of the target actions on the puppet for 60 s, allowed them to imitate immediately, and then tested them after increasing delays until they no longer imitated the target actions.

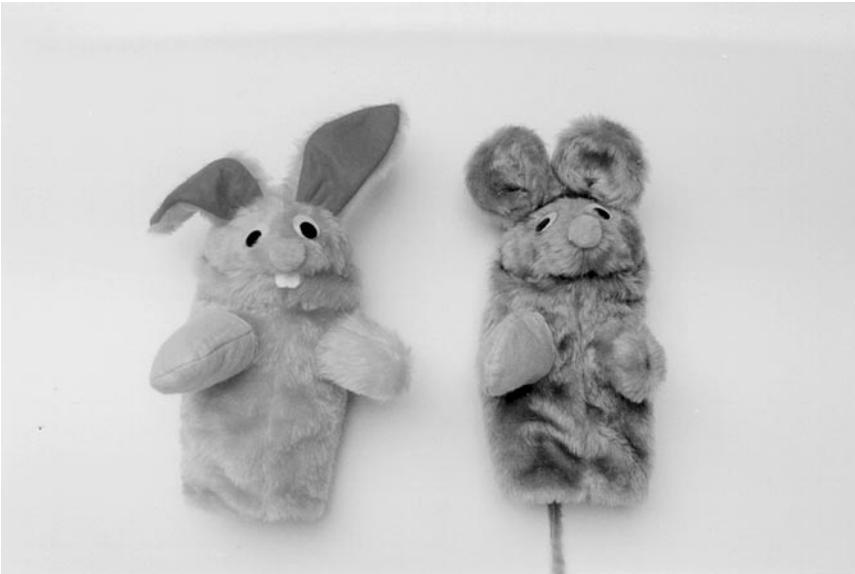
### *Method*

*Participants.* The final sample consisted of 24 (7 boys and 17 girls) full-term 6-month-old infants who were recruited from public birth announcements and by word of mouth. Infants ranged in age from 178 to 219 days ( $M$  age = 191.2 days,  $SD$  = 11.5) on the first day of the study. Participants were African American ( $n$  = 1), Latino ( $n$  = 2), and White ( $n$  = 19). For one infant, ethnic identity was not reported. Their parents' mean educational attainment was 15.6 years ( $SD$  = 1.2) and mean rank of socioeconomic status (Nakao & Treas, 1992) was 65.6 ( $SD$  = 18.2). (These means were based on 96% of the sample). Four infants were not included in the final sample due to technical error ( $n$  = 1), crying for 2 continuous min ( $n$  = 1), and failure to reach for the puppet ( $n$  = 2). Based on the total number of opportunities (sessions) for a given infant to be lost from the sample, the rate of attrition was 8.6%.

*Apparatus.* Two hand puppets, a pastel pink rabbit and a pale gray mouse (see Fig. 1), 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 ( $8 \times 9$  cm) in a matching color covered each puppet's right hand. A large jingle bell was secured to the inside of the mitten during the demonstration but was removed during testing. The puppets were counterbalanced within groups.

*Procedure.* Infants were tested in their own homes at a time when they were most likely to be alert and playful. This time varied across infants but remained relatively constant across sessions for the same infant. Infants were randomly assigned to three experimental groups as they became available for study and were tested after delays of 1, 2, or 3 days. A baseline control group was included to test for the spontaneous production of the target behaviors. Infants in the control group did not see the original puppet demonstration and were not previously exposed to either the puppet or the experimenter but participated only in the test session (see also Barr & Hayne, 1999; Meltzoff, 1985, 1988).

*Puppet demonstration (session 1):* All experimental groups participated in this session. The infant sat on the caregiver's knee, and a female experimenter, kneeling at the caregiver's feet, placed the puppet over her right hand and positioned it at the infant's eye level, approximately 80 cm from the infant's chest. The experimenter removed the mitten from the puppet's right hand and shook it three times, ringing the bell that was attached inside, and then replaced the mitten. This sequence was repeated six times and lasted, on average, a total of 60 s. After the demonstration, infants were allowed three opportunities to reproduce the target



**FIG. 1.** The rabbit (*left*) and mouse (*right*) puppets used in the imitation task.

actions; the infants' immediate imitation period lasted approximately 2–3 min, depending upon how quickly each infant responded ( $M = 178.5$  s,  $SE = 69.7$ ).

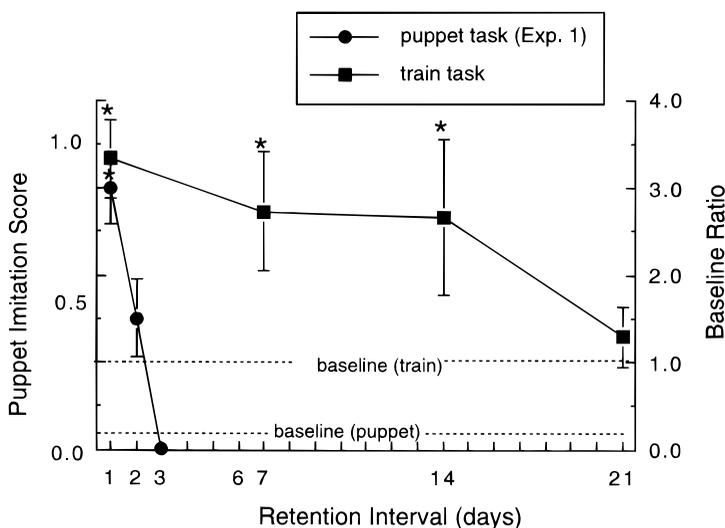
*Test (session 2):* The test session was identical for the experimental groups and the baseline control group. During the entire test session, the infant's behavior was videotaped. Infants were tested with the same puppet they had seen before, but the bell was removed from the mitten.

### *Results and Discussion*

A trained observer scored each videotaped test session for 120 s from the time that the infant first touched the puppet. A second trained observer, blind to the infants' group assignments, scored 96% of the test sessions. An imitation score was calculated for each infant by summing the number of target behaviors (remove the mitten, shake the mitten, and attempt to put the mitten back on the puppet) that were produced during the test (range 0–3). Interobserver reliability was 98.6% ( $\kappa = 0.95$ ).

The mean imitation scores of the infants in the four groups were subjected to a one-way analysis of variance (ANOVA). This analysis yielded a significant effect of Group,  $F(3, 20) = 6.18$ ,  $p < .01$  (see Fig. 2, solid circles).

Although ANOVAs indicate whether groups differ, they do not answer our primary question, namely whether any experimental group performed significantly better than the baseline control group. We used Dunnett's  $t$  tests to assess whether the mean imitation score of each experimental group (1-, 2-, and 3-day test) was significantly higher than that of the baseline control group ( $p < .05$ ). This test



**FIG. 2.** The mean imitation score (+1 *SE*) of 6-month-old infants tested with the puppet (Experiment 1, solid circles) and the mean baseline ratio of 6-month-olds tested with the train (from Hartshorn & Rovee-Collier, 1997, solid squares) as a function of the retention interval. The dotted lines represent the mean performance of the baseline control group (baseline puppet) and baseline performance in the train task (baseline train). An asterisk indicates that a group's test performance was significantly above its corresponding baseline.

controls for Type I errors across multiple comparisons with a control group (Dunnnett, 1955). Because the variance of the control and experimental groups differed, the variance for each group was used to calculate the *t* value in all experiments (Winer, Brown, & Michels, 1991). Whereas the mean imitation score of the 1-day test group was significantly higher than that spontaneously produced by the baseline control group,  $t(5) = 3.93$ ,  $p < .05$ , the scores of the 2- and 3-day test groups were not,  $t(5) = 1.49$ , *ns*, and  $t(5) < 1$ , respectively. The fact that infants in the baseline control group did not spontaneously produce the target behavior confirmed that the performance of the 1-day group was due to infants' memory of the puppet demonstration.

To ensure that infants in the baseline control group were interacting with the puppet as much as infants in the 1-day experimental group, we calculated the amount of time that infants touched the puppet during the 2-min test. All infants interacted with the puppet for most of the test session. Infants in the baseline control group touched the puppet an average of 96 s during the 120-s response period, and infants in the 1-day test group touched the puppet an average of 80 s during the 120-s period. An unpaired *t* test indicated that the amount of time that the baseline control group and the 1-day test group touched the puppet did not differ,  $t(10) < 1$ .

Infants' long-term test performance was also compared with their own immediate imitation performance in separate paired *t* tests. For infants tested after 1

day, the immediate and long-term test performance did not differ,  $t(5) = 1.00$ ,  $ns$ . For infants tested after 2 or 3 days, however, performance was significantly lower during the long-term test,  $t(5) = 6.71$ ,  $p < .01$ , and  $t(4) = 11.00$ ,  $p < .01$ , respectively, indicating significant forgetting across the delays. These findings demonstrate that infants exhibit robust memory for the puppet task for only 1 day. We note, however, that when imitation performance was scored for 180 s rather than 120 s, baseline level remained unchanged, but the 2-day test group now performed significantly above baseline,  $t(5) = 2.71$ ,  $p < .02$ . The 3-day test group, however, still did not,  $t(5) < 1$ . Bjork (1975) suggested that retrieval becomes more difficult as the retention interval increases and that subsequent processing is altered by the retrieval process per se. We take the finding that infants removed the mitten 2 days after training within 180 s but not within 120 s as evidence of the increasing difficulty of retrieval. We conclude, therefore, that infants' forgetting was gradual rather than all-or-none across the 3 days.

#### EXPERIMENT 2A: PROLONGING RETENTION OF THE PUPPET IMITATION TASK

Having established that the puppet task is forgotten after 1–2 days, we next attempted to protract its retention by associating it with the operant train task, which, like the puppet task, is used with infants 6 months and older ([Hartshorn & Rovee-Collier, 1997](#)). The imitation and operant tasks were chosen for two reasons. First, the two paradigms are very different. Whereas in the imitation task an adult demonstrates the target actions for the infant for 60 s on a single occasion, in the operant train task infants learn a response that moves a train around a circular track in two 8-min sessions over consecutive days. Second, infants' retention of the two tasks is dramatically different. Whereas 6-month-olds remember the puppet task for 1–2 days (cf. Experiment 1), they remember the train task for 2 weeks ([Hartshorn & Rovee-Collier, 1997](#); see Fig. 2, solid squares).

An important function of associative priming might be to protract short-lived memories. In Experiment 2a, therefore, we asked if infants' retention of the puppet imitation task would be protracted if it were associated with the operant train task. That is, would retrieving the memory of the train task enable the memory of the puppet task to be retrieved as well? To answer this, we modeled the target actions on the puppet immediately after infants had learned the train task and while the train was still in view, and then we tested infants 6, 14, or 21 days later. Although infants typically remember the train task for 2 weeks, we did not know how long the associated puppet task memory might be protracted, if at all; nor did we know if associating the shorter lived puppet memory with the train memory would attenuate retention of the train task.

#### Method

##### *Participants*

The final sample consisted of 30 (17 boys and 13 girls) full-term 6-month-old infants, recruited as outlined above. Participants were African American ( $n = 2$ ),



**FIG. 3.** A 6-month-old pressing the lever to move the toy train that is housed inside a painted wooden box. Each lever press moves the train for 2 s.

Latino ( $n = 2$ ), Asian ( $n = 5$ ), and White ( $n = 21$ ) and ranged in age from 181 to 200 days ( $M$  age = 190.0 days,  $SD = 4.6$ ) on their first day of training. Their parents' mean educational attainment was 15.4 years ( $SD = 1.4$ ), and their mean rank of socioeconomic status (Nakao & Treas, 1992) was 68.4 ( $SD = 17.0$ ). (The latter was based on 96.6% of the sample; not reported = 3.4%). Additional infants were not included in the final sample due to failure to meet the original learning criterion on the train task ( $n = 8$ ), equipment failure ( $n = 2$ ), illness ( $n = 6$ ), crying for 2 continuous min in any session ( $n = 8$ ),<sup>1</sup> scheduling conflict ( $n = 1$ ), and refusal to touch the puppet or train ( $n = 2$ ). Based on the total number of opportunities for a given infant to be lost from the final sample in each task, the rate of attrition was 15.6%. This rate is typical when infants participate in three sessions and is consistent with that found in similar studies (e.g., Greco et al., 1990; Gulya, Rovee-Collier, Galluccio, & Wilk, 1998). A separate analysis indicated that infants who were not included in the final sample did not differ from those who were on any factor—age, ethnicity, gender, socioeconomic status, or parental educational attainment.

<sup>1</sup> This study was run during the winter, which increased the incidence of sickness, and some homes were noticeably hot, which also affects attrition in lengthy operant tasks.

### *Apparatus*

The operant apparatus consisted of an HO-scale (miniature) train in a wooden box ( $58 \times 58 \times 35$  cm), three sides of which were enclosed by a colorful, patterned curtain. The window of the box was Plexiglas ( $58 \times 35$  cm). Protruding below the front window was a Plexiglas lever ( $30 \times 12.5$  cm) which, when depressed, operated a microswitch connected to an interface box and an IBM Thinkpad-350 laptop computer. A Quick Basic computer program timed the experimental phases, delivered the reinforcement, and registered all microswitch operations in 10-s bins. The train consisted of an engine and three brightly colored rail cars. At the outset of each session, it was positioned immediately behind the front window on a circular track (47.5 cm in diameter). Two train sets, counterbalanced within and across groups, were used. One train set had a Plexiglas green lever and was housed in a green wooden box that was enclosed by a yellow curtain with green squares. The box contained a blue-and-white engine with a brown rail car, a silver rail car, and a purple caboose. The second train set had a pink wooden lever and was housed in a pink wooden box that was enclosed by a blue-and-red vertically striped curtain. The box contained a black engine with a brown rail car, a green rail car, and a red caboose. A 40-W white light bulb in the upper right-hand corner inside the train box continuously illuminated it during experimental phases.

For the puppet task, the hand puppets were those that were used in Experiment 1.

*Training procedure: Train task (session 1).* The train was placed on a table, and the infant sat on his/her caregiver's lap with the lever chest high. Each session lasted 8 min on consecutive days. The first session began with a 1-min nonreinforcement period (*baseline*), during which the lever was deactivated, and the infants' unlearned rate of lever pressing (operant level) was measured. The second phase was a 6-min reinforcement period (*acquisition*), when the lever was active, and each lever press moved the train for 2 s (see Fig. 3). Presses that occurred while the train was in motion were registered by the computer but had no effect on the delivery of reinforcement. The session ended with a 1-min nonreinforcement phase, when the lever was deactivated, and lever presses did not move the train.

*Train task (session 2).* The second training session was procedurally identical to the first except that the final 1-min nonreinforcement phase constituted *the immediate retention test*. At this time, the infants' final level of learning and retention after zero delay was measured. To be eligible for retention testing, an infant was required to attain an initial learning criterion (responding at least 1.5 times the baseline rate in any 2 of 3 consecutive min of acquisition during either training session).

*Puppet demonstration.* Immediately following the completion of session 2 of the train task, an adult demonstrated the target actions on the puppet for 60 s. The caregiver, with the infant on her lap, turned her chair to the side so that the train remained visible on the left or the right of the infant (see Fig. 4). The experi-



**FIG. 4.** The experimental arrangement used with 6-month-old infants in the puppet imitation task. The target actions were modeled on the puppet immediately after the end of session 2 while the train set was still in view. Testing for imitation occurred in this same context.

menter then knelt and positioned the puppet in front of the infant. The time between the end of the train session and the beginning of the puppet demonstration was less than a minute. The puppet procedure was the same as in Experiment 1. As before, infants were allowed to imitate the target actions three times immediately after the demonstration. The mean duration of the immediate imitation phase was 114.2 s ( $SE = 58.2$ ).

#### *Retention Test Procedure*

Infants were randomly assigned to one of five groups as they became available for study. The three train–puppet groups were tested 6, 14, or 21 days after session 2. The single puppet–train group was tested 6 days after session 2. The train–puppet and puppet–train groups differed only in the order in which the tasks were tested: The train–puppet groups were tested with the train first, whereas the puppet–train group was tested with the puppet first. (The train was not in view during the puppet test for infants in the puppet–train group.) The puppet baseline control group did not originally learn the train task and did not see the original puppet demonstration and was not previously exposed to either the puppet or the experimenter. Rather, this group participated only in the puppet test session.

*Train test.* During the long-term retention test with the train, the infant sat on the caregiver's lap, as before, and the lever was deactivated for a 2-min test period. Immediately after the long-term test, reinforcement was reintroduced to ensure that infants who did not respond during the test were not ill or unmotivated on that particular day. None were. After the train test, the mother again turned her chair to the side and, with the train in view, the infant then participated in the puppet imitation test (see Fig. 4).

*Puppet test.* As in Experiment 1, infants were tested with the same puppet that they had seen before. As before, the experimenter knelt before the infant and positioned the puppet within the infant's reach.

### Results and Discussion

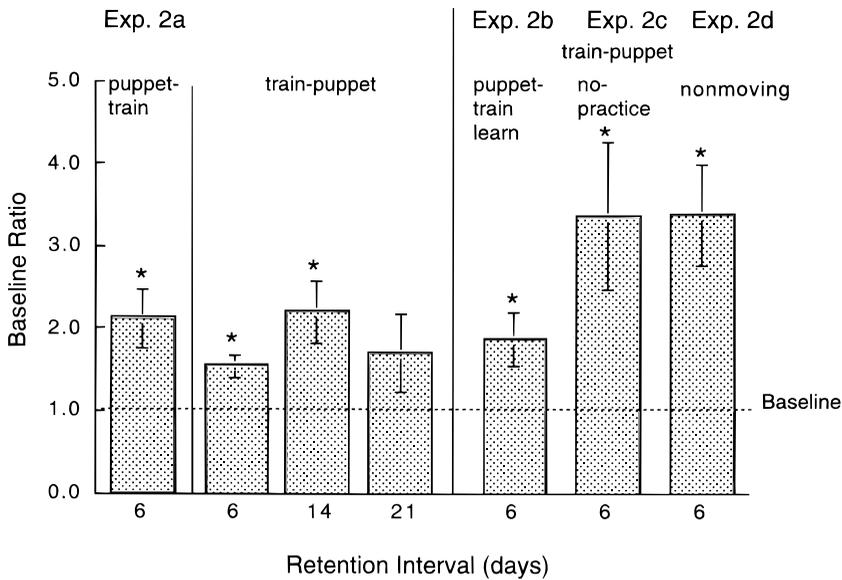
*Train test.* Retention was assessed using an individual measure of relative response, the *baseline ratio*, that has been used in previous operant studies of infant memory conducted in our laboratory (Rovee-Collier, 1996). This measure is calculated by dividing each infant's response rate during the long-term retention test by that same infant's response rate during the baseline phase. A mean baseline ratio of 1.00 indicates that a group responded at operant level during the long-term retention test (i.e., no retention); a mean baseline ratio significantly greater than 1.00 indicates significant retention. Prior to performing all analyses, we tested the baseline ratios in each group for outliers (Tukey, 1977, pp. 43–44). Any ratio falling above the value of the 90th percentile (the outer fence) was replaced with the next highest baseline ratio in that group, and one *df* was subtracted.

One-way ANOVAs indicated that the mean response rates of the train–puppet and puppet–train groups did not differ during either the baseline phase,  $F(3, 20) < 1$ , or the immediate retention test,  $F(3, 20) = 1.05$ , *ns*. These results eliminated group differences in baseline activity and the final level of learning as the basis for any subsequent group differences in retention.

To determine whether any group demonstrated retention of the train task during the long-term test, directional *t* tests between the mean baseline ratio of each group and a theoretical population baseline ratio of 1.00 (i.e., no retention) were calculated. The mean baseline ratios of puppet–train 6-day group,  $t(4) = 2.12$ ,  $p < .01$ , the train–puppet 6-day group,  $t(4) = 3.85$ ,  $p < .01$ , and the train–puppet 14-day group,  $t(5) = 3.18$ ,  $p < .01$ , were significantly greater than 1.00, but train–puppet 21-day group,  $t(5) = 1.48$ , *ns*, was not (see Fig. 5, left panel).

*Puppet test.* As before, a trained observer scored each videotaped test session and calculated an imitation score for each infant. A second trained observer, blind to the infants' group assignments, scored 93% of the test sessions. The interobserver reliability was 100% ( $\kappa = 1.00$ ). A one-way ANOVA over the mean imitation scores of the five groups yielded a significant effect of Group,  $F(4, 25) = 5.41$ ,  $p < .01$  (see Fig. 6, left panel).

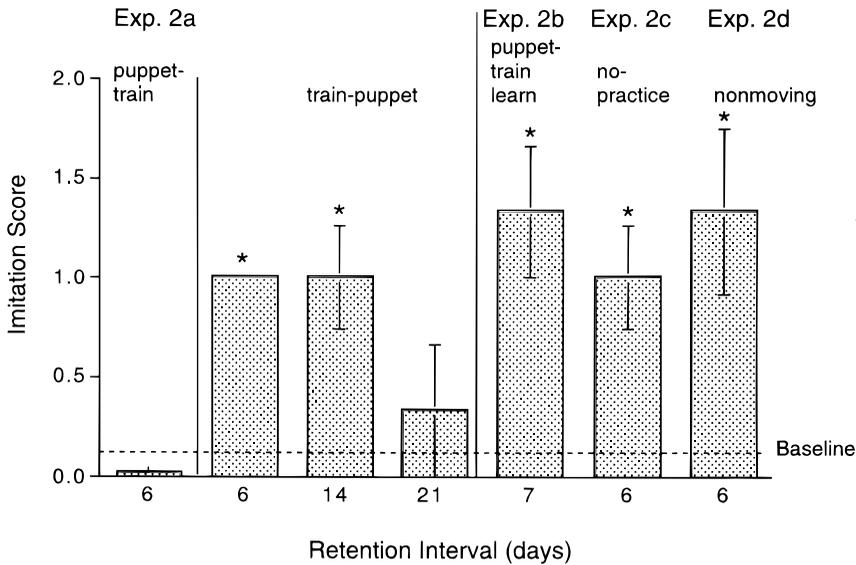
To determine whether any test group performed significantly better than the baseline control group, we used Dunnett's *t* tests ( $p < .05$  across multiple com-



**FIG. 5.** Data from the operant train task. (Left) The mean baseline ratio (+1 SE) of 6-month-old infants in the puppet–train test group and the train–puppet test group who were tested with the train as a function of the retention interval (6, 14, and 21 days) in Experiment 2a. (Right) The mean baseline ratios (+1 SE) of 6-month-olds in the puppet–train 6-day group who learned the puppet task first and were tested with the train in Experiment 2b, the no practice train–puppet test group who did not immediately imitate the target actions on the puppet in Experiment 2c, and the nonmoving train–puppet test group who were tested with the nonmoving train in Experiment 2d. The dotted line indicates baseline (i.e., no retention). An asterisk indicates significant retention.

parisons) to compare the mean imitation score of each experimental group with the mean imitation score of the puppet baseline control group. These analyses revealed that the mean imitation scores of the train–puppet 6-day and the train–puppet 14-day groups were significantly higher than the score of the baseline control group,  $t(5) = 5.00$ ,  $p < .05$ , and  $t(5) = 3.54$ ,  $p < .05$ , respectively. In contrast to infants' performance on the train test, the puppet–train 6-day group failed to perform the target actions on the puppet. Its mean imitation score was not significantly higher than that of the baseline control group,  $t(5) = 1$ , *ns*. The mean imitation score of train–puppet 21-day group was also not significantly higher than that of the baseline control group,  $t(5) < 1$ . Infants in the baseline control group did not spontaneously produce the target behavior, confirming that the performance of train–puppet 6- and 14-day groups was due to their memory of the prior event.

Once again, infants' performance during the long-term imitation test was compared to their immediate imitation performance by means of paired  $t$  tests. The train–puppet 6- and 14-day groups showed no evidence of forgetting over either



**FIG. 6.** Data from the puppet imitation task. (Left) The mean imitation score (+1 SE) of 6-month-old infants in the puppet–train test group and the train–puppet test group who were tested with the puppet as a function of the retention interval (6, 14, and 21 days) in Experiment 2a. (Right) The mean imitation scores (+1 SE) of 6-month-olds in the train–puppet test group who learned the puppet task first and were tested 7 days later with the puppet in Experiment 2b, the no practice train–puppet group who had not interacted with the puppet prior to the 6-day imitation test in Experiment 2c, and the nonmoving train–puppet group who had not seen the train move prior to being tested with the puppet 6 days later in the train–puppet test group in Experiment 2d. An asterisk indicates that a group’s mean imitation test score was significantly higher than that of the baseline control group represented by the dotted line.

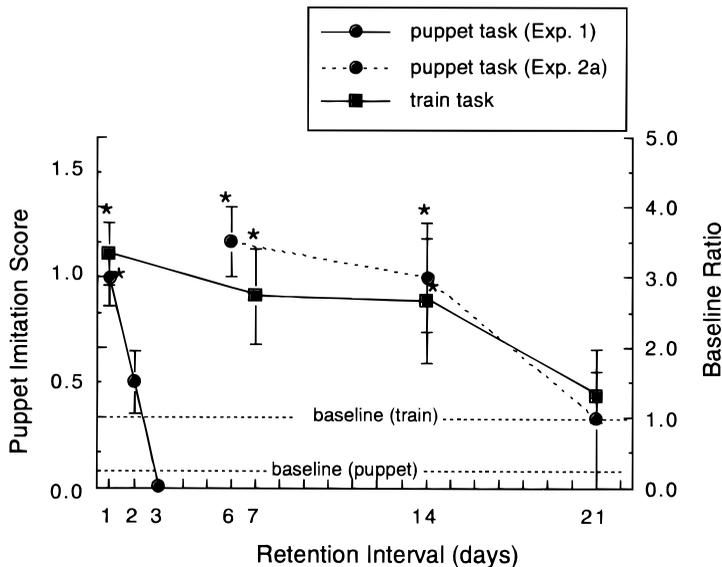
the 6-day or 14-day retention interval [ $t(5) = 2.20$ , *ns*, and  $t(5) = 2.00$ , *ns*, respectively], but the puppet–train 6-day group and the train–puppet 21-day group did [ $t(5) = 11.00$ ,  $p < .01$ , and  $t(5) = 3.80$ ,  $p < .01$ , respectively]. The finding that the puppet–train 6-day group did not imitate the target actions on the puppet 6 days after training confirms that the puppet task remained forgotten *unless the train memory was retrieved first*. (Recall that the train was not in view during the puppet test for the puppet–train 6-day group). Finally, the finding that train–puppet 21-day group did not exhibit retention of either task confirms that after 21 days, forgetting was complete (see also [Hartshorn & Rovee-Collier, 1997](#); [Hildreth & Rovee-Collier, 1999](#)).

At the outset of Experiment 2a, we had assumed that the puppet memory would be associated with the train memory because both were acquired in the same temporal and physical context. We found that retrieving the train memory after delays of 6 and 14 days enabled the puppet memory to be retrieved after those delays as well, despite the fact that it otherwise would have been forgotten.

These results replicate earlier findings that two discrete events that occur in a common context become associated (Rovee-Collier et al., 1993; Timmons, 1994). Subsequently, retrieving the memory of one event—here, the train task—facilitated the retrieval of the memory of the other event—here, the puppet imitation task—protracting its retention from 1 day to 2 weeks. In fact, infants' memory of the puppet task was protracted for the same duration as the train memory (see Fig. 7); once the train memory could no longer be retrieved, the puppet memory could not be retrieved either. The fact that the puppet task was remembered for the duration of the train task suggests that associated information can be maintained for the duration of the longest remembered associate without affecting retention of the latter (see also Hockley, 1991).

### EXPERIMENT 2B: DIRECTIONALITY OF THE ASSOCIATION

The finding that infants in the train–puppet group but not in the puppet–train group remembered the puppet task in Experiment 2a raised questions about



**FIG. 7.** (Left) The mean imitation score ( $+1 SE$ ) of 6-month-old infants who received a cued-recall test with the puppet as a function of the retention interval in Experiment 1. (Right) The mean imitation score ( $+1 SE$ ) of 6-month-old infants who were tested with the puppet as a function of the retention interval in Experiment 2a (solid circles). For these groups, the train and puppet memories had initially been associated, and retrieval of the train memory essentially primed the puppet memory. Also shown is the mean baseline ratio of 6-month-old infants who received a delayed recognition test after the same retention interval (from Hartshorn & Rovee-Collier, 1997, solid squares). The dotted lines represent the mean performance of the baseline control group (baseline puppet) and baseline performance in the train task (baseline train). An asterisk indicates that a group's test performance was significantly above its corresponding baseline.

whether the order in which the tasks were learned led to this outcome. Conceivably, the puppet memory could be protracted only if it were learned *after* the train task had been learned; that is, the serial order in which the two tasks were initially encoded may have determined whether retrieval of the train memory could associatively prime the memory of the puppet task. Perhaps seeing the puppet demonstration first would not have allowed the two associates to be retrieved in reverse order. To test the directionality of the train–puppet association, we trained infants as in Experiment 2a except that they learned puppet task before the train task rather than after it. Infants were tested 6 days after completion of the train task, and their test performance was compared with that of the baseline control group from Experiment 2a.

### *Method*

*Participants.* The final sample consisted of six (two boys and four girls) full-term 6-month-old infants, recruited as outlined above. They were Latino ( $n = 1$ ) and white ( $n = 5$ ) and ranged in age from 184 to 212 days ( $M$  age = 194.8 days,  $SD = 10.1$ ) on their first day of training. Their parents' mean educational attainment was 16.0 years ( $SD = 0.0$ ), and their mean rank of socioeconomic status (Nakao & Treas, 1992) was 62.4 ( $SD = 11.2$ ). The attrition rate for this group was 0%.

*Apparatus and procedure.* Infants were assigned to the puppet–train learn group. The apparatus, training, and test procedures were identical to those used in Experiment 2a with train–puppet 6-day group except that infants learned the puppet task prior to learning the train task. Importantly, however, the puppet demonstration still occurred in the visual presence of the train. Again, the total duration of the immediate imitation phase lasted 2 to 3 min ( $M = 145.5$  s,  $SE = 17.3$ ). The puppet–train learn group was tested first with the train and then with the puppet 6 days after the end of operant training (7 days after seeing the puppet demonstration).

### *Results and Discussion*

*Train test.* To determine whether retention of the train task was affected by whether it was learned first or second, we conducted separate analyses across the train data from Experiments 2a and 2b. Preliminary one-way ANOVAs over the lever presses of all experimental groups in Experiments 2a and 2b indicated that groups did not differ during either the baseline phase,  $F(4, 25) = 1.15$ , *ns*, or the immediate retention test,  $F(4, 25) = 1.32$ , *ns*. These results eliminated differences in baseline activity and final level of learning as a basis for any subsequent differences in retention. A directional *t* test comparing the mean baseline ratio of puppet–train learn group with a theoretical population baseline ratio of 1.00 (i.e., no retention) indicated that this group exhibited significant retention during the long-term retention test with the train. Its mean baseline ratio was significantly greater than 1.00,  $t(5) = 1.87$ ,  $p < .02$ . These data, then, replicated the result in Experiment 2a when the train task was learned first (see Fig. 5, *right panel*).

*Puppet test.* Two trained observers, one blind to the infants' group assignment, scored each videotaped puppet imitation test session. Their interobserver reliability was 100% ( $\kappa = 1.00$ ). A Dunnett's  $t$  test revealed that the mean imitation score of puppet–train learn group was significantly higher than that of the baseline control group from Experiment 2a,  $t(5) = 4.43$ ,  $p < .05$ . When their long-term test performance was compared to their immediate imitation performance, infants trained on the puppet task first showed no evidence of forgetting across the 7-day delay,  $t(5) < 1$ . As shown in Fig. 6 (*right panel*), these results are identical to those of the original train–puppet 6-day group who learned the train task first. Thus, the order in which the two tasks were acquired did not affect whether infants associated the puppet task with the train task or whether the task learned last could subsequently prime the one learned first. Instead, the association between the train and the puppet was *bidirectional*. Taken together, the results of Experiments 2a and 2b demonstrate that although retrieval of the train memory was requisite for the retrieval of the puppet memory, the order in which the two tasks were initially associated was not relevant.

## EXPERIMENT 2C: ASSOCIATIVE PRIMING WITHOUT IMMEDIATE IMITATION

In all of the preceding experiments, infants imitated the target actions on the puppet immediately after the demonstration, prior to the retention interval. The most stringent test of deferred imitation requires that the infant imitate the target behavior(s) for the first time after a delay, at the time of the long-term test. This requirement is thought to present a greater cognitive challenge than imitation tasks that require infants to reproduce actions that they have actually performed in the past ([Meltzoff, 1990](#)). The effects of imitating immediately after the demonstration on infants' later retention, however, are not yet fully understood (for review, see Barr & Hayne, 2000). In the preceding experiments, for example, it was unclear whether infants had to actively interact with the puppet in the presence of the train set in order for the puppet demonstration to be associated with the train task, which does require infants' active participation. By prohibiting infants from imitating immediately, we would be able to determine whether infants associated their *actions* with the train task or whether they associated the *demonstration* with the train task. Experiment 2c was designed to allow us to select between these possibilities.

### *Method*

*Participants.* The final sample consisted of six (three boys and three girls) full-term 6-month-olds, recruited as outlined above. All were White. They ranged in age from 186 to 201 days ( $M$  age = 193 days,  $SD = 2.4$ ) on their first day of training. Their parents' mean educational attainment was 15.3 years ( $SD = 0.7$ ), and their mean rank of socioeconomic status ([Nakao & Treas, 1992](#)) was 64.7 ( $SD = 10.1$ ). Additional infants were excluded from the final sample due to fail-

ure to meet the original learning criterion ( $n = 3$ ), crying for 2 consecutive min during any session of each task ( $n = 1$ ). The rate of attrition over multiple opportunities to be lost in each task was 11.4%.

*Apparatus and procedure.* Infants were assigned to a no-practice train–puppet 6-day group. The apparatus, training, and test procedures were identical to those used in Experiment 2a with the train–puppet 6-day group except that on day 2 of training, infants were shown the target actions nine times instead of six times, and they did not imitate the target actions immediately after the demonstration. For these infants, the puppet demonstration lasted an average of 95 s ( $SE = 2.6$ ) and infants looked at the demonstration for an average of 89 s ( $SE = 7.6$ ).

### *Results and Discussion*

*Train test.* To ensure that infants' learning of the train task was the same as in Experiment 2a, we conducted separate analyses across the train data from Experiments 2a and 2c. Preliminary one-way ANOVAs over the lever presses of all experimental groups in Experiments 2a and 2c indicated that groups did not differ during either the baseline phase or the immediate retention test, both  $F_s(4, 25) < 1$ . These results eliminated differences in baseline activity and final level of learning as a source of any subsequent differences in retention. A directional  $t$  test comparing the mean baseline ratio of the no-practice train–puppet 6-day group with a theoretical population baseline ratio of 1.00 indicated that this group exhibited significant retention during the long-term retention test with the train. Its mean baseline ratio was significantly greater than 1.00,  $t(5) = 2.63$ ,  $p < .03$ . These data, then, replicated the result obtained in Experiment 2a (see Fig. 5, *right panel*).

*Puppet test.* Two trained observers, one blind to the infants' group assignment, scored each videotaped puppet imitation test session. Their interobserver reliability was 100% ( $\kappa = 1.00$ ). The puppet imitation test performance of this group was compared with that of the baseline control group from Experiment 2a. A Dunnett's  $t$  test revealed that the mean imitation score of the no-practice train–puppet 6-day group was significantly higher than that of the baseline control group,  $t(5) = 3.54$ ,  $p < .05$ . As shown in Fig. 6, these results are identical to those of the original train–puppet 6-day group who immediately imitated the target actions on the puppet prior to the retention test. Thus, whether infants immediately imitated the target actions that were demonstrated by the adult had no effect on whether infants associated the puppet imitation task with the operant train task. That is, the train task primed the puppet task whether or not infants had imitated the target actions immediately. These data, then, allow us to conclude that infants associated the *demonstration* of the target actions with the train task instead of their own behavior of imitating the target actions immediately afterward.

[Rovee-Collier \(1997\)](#) argued that priming is a perceptual identification process that proceeds automatically, like parallel processing, and reveals what informa-

tion was originally encoded in a memory. Delayed recognition reveals what encoded information continues to be accessible in the memory at the time of retrieval. It involves more steps in the processing sequence than perceptual identification or priming, which may actually be the first step. Thus, priming might be conceptualized as defining one end of a memory-processing continuum, and delayed recognition (or, perhaps, free recall) as defining the other end. Although imitation is usually considered to be an explicit memory task, and operant conditioning is usually considered to be an implicit memory task ([Bauer, 1996](#); [Nelson, 1997](#)), we argue that a task per se is neither implicit nor explicit; rather, *any given memory task can be explicit or implicit*, depending on how it is used—that is, whether it involved recognition/recall or priming, respectively (see also [Rovee-Collier, Hayne, & Colombo, 2001](#)). *When the memory of the puppet demonstration was primed by the initial retrieval of the train memory, then the deferred imitation task was an implicit task.*

## EXPERIMENT 2D: ASSOCIATIVE PRIMING VIA A RECOGNITION TEST

In Experiments 2a–2c, the specific aspect of the train task that was essential for priming the associated puppet memory was unclear. Was the train's movement during reacquisition after the long-term test the essential aspect? Or was the initial retrieval of the train memory during the long-term test, when the train was not moving, the essential aspect? To answer this, we trained another train–puppet group as in Experiment 2a, except that we tested them with the puppet immediately after the 2-min long-term retention test with the nonmoving train, instead of testing them after they had seen the train move during the reacquisition phase that usually follows the test. Thus, on the test day these infants did not see the train moving before the puppet imitation test. The test performance of this group was compared with that of the baseline control group from Experiment 2a.

### *Method*

*Participants.* The final sample consisted of six (two boys and four girls) full-term 6-month-olds, recruited as outlined above. They were Native American ( $n = 1$ ) and White ( $n = 5$ ) and ranged in age from 184 to 191 days ( $M$  age = 187.5 days,  $SD = 2.5$ ) on their first day of training. Their parents' mean educational attainment was 15.7 years ( $SD = 0.8$ ), and their mean rank of socioeconomic status ([Nakao & Treas, 1992](#)) was 64.5 ( $SD = 13.9$ ). Additional infants were excluded from the final sample due to failure to meet the original learning criterion ( $n = 2$ ), crying for 2 consecutive min during any session of each task ( $n = 1$ ), and illness ( $n = 1$ ). The rate of attrition over multiple opportunities to be lost in each task was 10.5%.

*Apparatus and Procedure.* Infants were assigned to the train–puppet 6-day nonmoving group. The apparatus, training, and test procedures were identical to those used with the Experiment 2a train–puppet 6-day group except that infants participated in the 2-min delayed recognition test with the nonmoving train and

then were immediately tested with the puppet. After the puppet demonstration, the mean immediate imitation phase again lasted 2–3 min ( $M = 143.0$  s,  $SE = 20.9$ ).

### *Results and Discussion*

*Train test.* To determine whether the results were comparable across the moving and nonmoving conditions, separate analyses were conducted across the train data from Experiments 2a and 2d. Preliminary one-way ANOVAs comparing the performance of the train–puppet 6-day nonmoving group with those of the four experimental groups from Experiment 2a indicated that their number of lever presses did not differ during either the baseline phase,  $F(4, 25) < 1$ , or the immediate retention test,  $F(4, 25) < 1$ . Directional  $t$  tests comparing the mean baseline ratio of the train–puppet 6-day nonmoving group with a theoretical baseline ratio of 1.00 revealed that the train–puppet 6-day nonmoving group exhibited significant retention during the long-term retention test with the train. Its mean baseline ratio was significantly greater than 1.00,  $t(5) = 3.18$ ,  $p < .01$  (see Fig. 5, *right panel*).

*Puppet test.* Two trained observers, one blind to infants' group assignments, scored 100% of the videotaped test sessions. Their interobserver reliability was 100% ( $\kappa = 1.00$ ). A Dunnett's  $t$  test revealed that the mean imitation score of the train–puppet 6-day nonmoving group was significantly higher than that of the baseline control group from Experiment 2a,  $t(5) = 3.98$ ,  $p < .05$ . When infants' long-term imitation test performance was compared to their immediate imitation performance, no evidence of forgetting was found across the 6-day delay,  $t(5) = 1.46$ , *ns*.

As shown in Fig. 6 (*right panel*), the train–puppet 6-day nonmoving group performed exactly like the original train–puppet 6-day group who saw the train move before the 6-day test. These data, then, reveal that retrieving the train memory during the delayed recognition test was the critical factor in priming the associated puppet memory. Seeing the train actually move before the puppet imitation test was not.

## GENERAL DISCUSSION

In the present experiments, when a short-lived memory was associated with a long-lived one, the shorter memory was protracted for the same duration as the longer one. Thus, retention of the imitation puppet task was protracted from 1 day to 14 days when infants associated the imitation task with an operant task that they remembered for 14 days. This facilitation was observed, however, only if the longer remembered train memory was retrieved first; the short-lived memory, by definition, could not be retrieved “on its own” after a long delays longer than 1–2 days. Recall that the train memory was still active 6 and 14 days later, but the puppet memory was not (cf. [Lewis, 1979](#)). As a result, it was necessary to retrieve the memory of the train task into working memory before the associated memory of the puppet task could be retrieved as well. The association between the two tasks was established by introducing one task in the physical context of the other. Moreover,

the association between the two tasks was formed whether the puppet imitation task was encoded first or second, revealing that the association between the two tasks was *bidirectional*. In other words, the cue from the task that was learned last could prime or activate the memory of the task that was learned first. From a theoretical perspective, this result is important because it reveals that the two memories are not represented hierarchically, which would have been inferred from a unidirectional or order-of-encoding effect. Instead, either activation flowed equally between the nodes representing the memories of the two events, or the memories of the two events were stored under the same node by virtue of their common context.

### *Spreading Activation*

The associative priming effects demonstrated in the present experiments are usually explained by the mechanism of spreading activation, which was first proposed by Collins and Quillian (1969), and a spreading-activation component is now common to many theories of memory processing and retrieval (e.g., Bower, 1998; Loftus, 1973; McNamara, 1992a). In their initial study, Collins and Quillian created sentences that corresponded to information stored at different levels of a hypothetical hierarchy. For example, the hierarchy might consist of animals at one level, birds at a lower level, and a particular type of bird at the lowest level. The authors hypothesized that concepts that shared common properties would be stored together under a common node; thus, all animals have skin (level 1), birds can fly (level 2), and canaries are yellow (level 3). Participants were asked to judge if sentences such as “birds can fly” and “a canary has skin” were true or false. The authors hypothesized that moving from one level of the hierarchy to another would require longer processing time and that the time required to move from one level to the next would be additive. Consistent with their hypotheses, they found that participants took longer to decide whether a sentence was true or false when it was separated by one or more hypothetical storage levels. They viewed priming as a special case of spreading activation in which activation spreads from the primed concept to the target and facilitates its subsequent retrieval.

McNamara (1992a) outlined three main assumptions of the mechanism of spreading activation. First, activation spreads through an interconnected network of memory traces. Second, when an item is retrieved from memory, its internal representation is activated. And third, the residual activation that is accumulated at memory traces facilitates the retrieval of related information. According to Collins and Loftus (1975), information is stored in hierarchical concept nodes that share common properties. In addition, closely related concept nodes may share many links. As a result, activation spreads throughout the associative network, but it continues longer in the network the longer the prime is processed, and it attenuates as links branch from the original prime. Once attention shifts from the prime, however, activation may decay rapidly (Collins & Loftus, 1975; McNamara, 1992a; Warren, 1977).

Theoretically, the target memory and the prime are independent (Bower, 1998; Ratcliff & McKoon, 1998). In her first experiment, Timmons (1994) demonstrat-

ed that the music box memory and the mobile memory were independent. Subsequently, exposure to the music box reactivated the forgotten mobile task, irrespective of which of the two tasks was learned first. Similarly, in the present study, the train and the puppet memories were initially established on different days and were independent. Moreover, the order in which infants learned the tasks did not affect their subsequent retention of either task. The present results demonstrate that the concept of spreading activation applies not only to short-term associations, as in typical semantic memory tasks with adults, but also to long-term associations between independent events (see also Bower, 1998; [McKoon & Ratcliff, 1992](#); [Ratcliff & McKoon, 1988](#)). This demonstration extends the utility of priming and spreading activation as fundamental retrieval mechanisms (see also McNamara, 1992a).

The present study also suggests that spreading activation may have particular explanatory value for developmental data because children, with an incomplete knowledge of the world, lack more of the critical links between nodes than adults ([Collins & Loftus, 1975](#)). Spreading activation thus enables the memory system to be more flexible than a simple matching or mismatching process. Not only is spreading activation developmentally heuristic, but also associative priming and spreading activation can be studied most readily during the infancy period, when the individual's hierarchical networks are simpler (i.e., they contain fewer links), and new links that are established between two events can be systematically examined.

#### *What is the Adaptive Significance of Associations?*

The ability to associate otherwise-disparate information has important and practical implications for memory development. As presently demonstrated, short-lived memories can be protracted if they are associated with longer remembered memories. This process also allows memories of brief events to be incorporated into increasingly complex networks, thereby supporting more complex behaviors. Consistent with this argument, McNamara and Diwadkar (1996) concluded that "the retrieval of information from memory may be guided by the functional role that the information plays in the context in which it occurs" (p. 891). Likewise, according to Estes (1973), "memory alone does not generate performance. . . [performance] always reflects the interaction of stimulus (or memory for stimulus) and context" (p. 283). The ability to store and later retrieve memories that were encoded in the same context is fundamental to episodic memory and is the foundation of the memory retrieval process (Bower, 1998; [Estes, 1973, 1976](#); [McKoon & Ratcliff, 1992](#); [Tulving, 1983](#)). This was seen in the present experiments: The puppet memory was initially encoded in the context of the train and was later retrieved in that context—and not otherwise.

These findings and those of Timmons (1994) also have important implications in terms of both what an infant perceives as related and, in a similar vein, what they learn incidentally. In both the [Timmons \(1994\)](#) study and the present one, two functionally and physically different tasks—kicking to move a mobile and

arm waving to start a music box (Timmons, 1994) and lever pressing to move a train and pulling a mitten off the puppet's hand (Experiments 2a–2d)—were associated by virtue of occurring in the same physical context. Because preverbal infants, by definition, do not store information linguistically, the physical context may be an alternative means by which they can conceptually relate and store information. That is, if two events are spatially contiguous or occur in the same physical context, then infants are likely to associate them. Associative priming, therefore, will necessarily require that infants be cued with an aspect of an event that occurred in the same context as the event whose memory is being primed.

It is interesting that infants pick up potentially predictive contextual information incidentally. Although the training context is extraneous to the contingency and is not critical for the infant's task interactions, it does predict the occasion of the task (i.e., when the task occurs) and apparently is highly salient. In fact, infants as young as 3 months not only encode the incidental context in which training occurs, but also that context alone is an effective reminder for the training memory after it has been forgotten (Hayne & Findlay, 1995; Rovee-Collier, Griesler, & Earley, 1985). In the present experiments, infants similarly learned information about the context in which the puppet imitation task occurred (i.e., in the visual presence of the train set), even though there was no requirement that they do so. The incidental nature of this learning was particularly apparent in the case of infants who learned the puppet task *before* learning the train task. For this group, the train set had no special significance whatsoever; yet, the infants subsequently associated the two tasks via of this shared context, and retrieving the train memory was able to activate the memory of the puppet imitation task that was associated with it. As at 3 months, then the incidental context in which an event occurs can serve as a reminder for events that occurred in its presence. We see, therefore, that contextually based encoding is highly adaptive—and may be particularly so for organisms without language.

Over time, the development of an increasingly complex mnemonic network(s) of associations should further enhance retrieval and enable more flexible memory representations (see Estes, 1973, 1976, 1997). These outcomes, in turn, may make a fundamental contribution to the acquisition of language and autobiographical memory (see also Bower, 1998). Correspondingly, the increasing number of associations may also increase interference in processing and increase memory distortions (see Estes, 1997). Finally, associations between memories permit infants to respond adaptively when they encounter situations that they otherwise would have forgotten. We think it likely that both their greater number of associations and the greater complexity of their mnemonic network(s) contribute significantly to the documented ability of infants and children to remember increasingly longer with age.

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