Mem Cogn (2011) 39:625–636
DOI 10.3758/s13421-010-0037-0

Potentiation in young infants: The origin of the prior knowledge effect?

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Published online: 16 November 2010

Abstract In two experiments with 6-month-old infants, we found that prior learning of an operant task (remembered for 2 weeks) mediated new learning of a modeling event (remembered for only 1 day) and increased its recall. Infants first learned to associate lever pressing with moving a toy train housed in a large box. One or 2 weeks later, three target actions were modeled on a hand puppet while the train box (a retrieval cue) was in view. Merely retrieving the train memory strengthened it, and simultaneously pairing its retrieved memory with the modeled actions potentiated their learning and recall. When paired 1 week later, deferred imitation increased from 1 day to 4 weeks; when paired 2 weeks later, it increased from 1 day to 6 weeks. The striking parallels between potentiated learning in infants and the prior knowledge effect in adults suggests that the prior knowledge effect originates in early infancy.

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Keywords Association · Deferred imitation · Facilitated learning · Human infants · Mediated learning · Operant conditioning · Potentiation · Prior knowledge effect · Recall

Introduction

Since the time of Aristotle, associations have been the cornerstone of accounts of learning and memory. Ebbinghaus (1885/1964) famously used nonsense syllables to eliminate the influence of preexisting associations on the formation of new associations between successive and remote items on his study lists. In recent years, researchers have examined the circumstances in which adults' prior learning can be used to facilitate new learning relative to when new learning occurs alone—a phenomenon known as the *prior knowledge effect.* The facilitation can be either direct or indirect (mediated) and can occur whether the prior knowledge is related to what is being learned or not (Bellezza & Buck, 1988; Kole & Healy, 2007; Morris, Gruneberg, Sykes, & Merrick, 1981; Van Overschelde & Healy, 2001).

In a series of experiments, for example, Kole and Healy (2007) documented that prior knowledge not only mediates the learning of new information but also significantly enhances it. In their first experiment, adults learned 12 facts about each of 12 highly familiar (HK: High Prior Knowledge condition) or unfamiliar (LK: Low Prior Knowledge condition) individuals, while a third group learned to associate the names of 12 highly familiar individuals and 12 unfamiliar individuals (MK: Mediated Prior Knowledge condition) before they learned the 12 facts about each of the 12 unfamiliar individuals. During the learning phase, adults in the MK condition were instructed to recall the highly familiar associated name as each new fact about an unfamiliar individual was presented. Relative to the LK condition, prior knowledge significantly facilitated both learning and retention in the HK and MK conditions, which did not statistically differ from each other.

In a sequel, the prior knowledge and the to-be-learned information were unrelated. In both the MK and LK conditions, adults learned 12 facts about each of 12 countries, but in the MK condition, they first associated the names of 12 highly familiar individuals with the names of the 12 countries. As before, prior knowledge facilitated retention in the MK condition relative to the LK condition, but it did not differentially facilitate learning because the level of learning in the LK condition was already near ceiling.

In an initial study of the facilitation of new learning by prior learning with young infants, we examined whether an event with a "longer-lived" or stronger memory that infants had previously learned might potentiate their new learning of an event with a "shorter-lived" or weaker memory (Barr, Vieira, & Rovee-Collier, 2001). First, we taught 6-month-olds a response-outcome (R-O) association—lever pressing (R) moves a toy train (O)—which they remember for 2 but not 3 weeks after two training sessions (Hartshorn & Rovee-Collier, 1997). Immediately following the second training session, we modeled a series of target actions on a hand puppet for 60 s *in the presence of the train*. At 6 months, infants remember this modeling event for 1 but not 2 days (Barr, Dowden, & Hayne, 1996; Barr et al., 2001).

According to modern associative theory, when two events occur in close temporal succession, the activation produced by the initial event is still present when the second event occurs and, when the representations of two events co-occupy short-term memory, they are associated. As a result, the associative strength of one event will transfer to the other event and strengthen its learning (Dwyer, Mackintosh, & Boakes, 1998; Hall, 2003; Holland, 1981, 1983; Rescorla, 1981; Rescorla & Wagner, 1972; Wagner, 1981, 2003). We predicted, therefore, that the modeling event would be associated with the previously learned train task when they occurred together, the greater associative (memory) strength of the train task would transfer to the modeling event, and the modeled actions would be learned better than when they are learned alone.

This is the result we obtained: Infants remembered the train task for 2 weeks as usual, and they also recalled the modeled actions for 2 weeks instead of only 1 day as well. These results suggested to us that the phenomenon of potentiated learning and memory in infants might be related to the prior knowledge effect in adults and motivated the present study.

Kole and Healy (2007) demonstrated that adults' prior knowledge mediated their new learning and increased its strength two-fold, even when the prior knowledge and new learning were unrelated. If the potentiation effect in infants and the prior knowledge effect were related phenomena, then infants' prior learning of the train task should similarly mediate their learning of the modeling event and increase its memory strength. The current study was designed to examine this possibility.

To this end, we again taught 6-month-olds the R-O association in the train task and then modeled the target actions *in the presence of a retrieval cue* for its memory either 1 week (Experiment 1) or 2 weeks (Experiment 2) after the second training session. As before, we assessed the duration of infants' deferred imitation in the same conditions that were present when the modeling event was encoded. We expected the retrieved representation of prior learning to be associated with the modeling event and mediate its new learning. During the deferred imitation test, we expected the retrieved representation of prior learning to mediate recall of the modeled actions as well.

Experiment 1: Mediated learning 1 week after operant training

In Experiment 1, we asked whether a preexisting learned association (R-O) could mediate infants' new learning of a modeling event and prolong its retention. To answer this question, we repeated the original potentiation procedure of Barr et al. (2001) except that we modeled the target actions in the presence of a retrieval cue for the R-O association 1 week after it was acquired instead of immediately afterward. We hypothesized that seeing the retrieval cue would activate infants' memory of the R-O association, which would then be associated with the modeling event and facilitate its learning.

Method

Participants

The final sample contained 24 full-term 6-month-olds (11 boys, 13 girls) whose mean age was 193.2 days (SD = 14.5) on the first day of training. Infants were recruited from public birth announcements, commercial mailing lists, and by word of mouth and were assigned to groups ($n = 6$) as they became available for study. The participants were Asian ($n = 2$), Hispanic ($n = 2$), Caucasian ($n = 19$), and of mixed origin ($n = 1$). Their parents' mean educational attainment was 15.8 years (SD = 0.9), and their mean socioeconomic index (SEI; Nakao & Treas, 1992[1]) was 71.5 (SD = 16.8). Testing was discontinued on four additional infants who failed to meet the learning criterion.

Apparatus

The operant apparatus consisted of a miniature (HO-scale) train inside of a painted wooden-framed box (58 × 58 × 35 cm), three sides of which were enclosed by a distinctive curtain. A 40 W white light bulb in the upper right corner continuously illuminated the interior of the box. The front of the box was Plexiglas (58 × 35 cm), and a painted Plexiglas response lever (30 × 12.5 cm) was mounted at its base. Each discrete lever press 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 reinforcer for 2 s, and registered all microswitch operations in 10-s bins.

Two train boxes, counterbalanced within groups, were used. One box was blue with red curtains displaying yellow squares and housed a train with a black engine and three rail cars. The second box was pink with blue-and-red striped curtains and housed a train with a blue-and-white engine and three differently colored rail cars. At the outset of each session, the train was positioned immediately behind the front window on a circular track (47.5-cm diameter).

Two hand puppets, counterbalanced within groups, were used in the deferred imitation task. They were constructed for our research and were not commercially available. The puppets—a pink rabbit and a gray mouse—were made of soft acrylic fur and were 30 cm tall. Each puppet wore a removable felt mitten in a matching color on its right hand. A jingle bell was pinned inside the mitten during the demonstration, but the bell was removed during testing. All test sessions were videotaped for later scoring with a Panasonic VHS-C camcorder on a tripod that was placed at right angles to the infant.

Procedure

Infants were tested in their own homes at a time when they were playful. This time varied across infants but remained relatively constant across all sessions of the same infant. The experimental procedure consisted of two phases and a retention test.

Phase 1: Forming the R-O association

Initially, infants learned that lever pressing (R, response) moved the train (O, outcome). The train box was placed on a table, and the infant sat on the caregiver's lap in front of it with the lever within reach. The two training sessions lasted 8 min each on 2 consecutive days. Each session began and ended with a 1-min nonreinforcement period, when the lever was deactivated. At the outset of Session 1, this period was the *baseline phase*, when the unlearned rate of lever pressing (operant level) was measured; at the end of Session 2, it was the *immediate retention test*, when each infant's final level of conditioning—and retention after zero delay—was measured (rate of lever pressing).

In each session, a 6-min reinforcement period (*acquisition*), when each discrete lever press moved the train for 2 s, was interpolated between the two nonreinforcement periods. Presses that occurred when the train was in motion were registered by the computer but did not affect delivery of the reinforcer. To ensure that only infants who had actually learned the R-O contingency in the first place proceeded to the retention phase (Phase 2) of the study, an individual who did not meet a stringent learning criterion (i.e., responding 1.5 times above the individual's operant level during 2 of 3 consecutive min of acquisition) was excluded from the study at that point.

The experimental design did not include a yoked noncontingent (response-independent) reinforcement control group that would reveal whether the reinforcing stimulation per se increased responding during reinforcement phases.[2] Because stimulation-induced arousal is transient and time-locked to the arousal-inducing stimulus, we always assess an individual's final level of learning at the end of the final training session, after the reinforcing stimulation has been withdrawn.

[1] In the socioeconomic index (SEI), the recommended source for occupational status, ranks of occupations range from 1–100, with higher-paying occupations (e.g., physician and lawyer) being assigned higher ranks.

[2] In initial studies using the train task with 6- to 18-month-olds, yoked noncontingent reinforcement control groups never responded significantly above operant level in any acquisition minute of either session, during the immediate retention test at the end of session 2, or during the long-term retention test 24 h later (e.g., Hartshorn & Rovee-Collier, 1997; Hartshorn, Rovee- Collier, Gerhardstein, Bhatt, Wondoloski, Klien, et al., 1998b). Because these data were identical to data from noncontingent-reinforcement control groups in our prior operant studies using an equivalent mobile task with 6-month-olds (Hill, Borovsky, & Rovee-Collier, 1988) and 3-month-olds (e.g., Rovee-Collier, Morrongiello, Aron, & Kupersmidt, 1978; Rovee & Rovee, 1969), we discontinued the use of noncontingent reinforcement control groups and instituted a conservative individual learning criterion to ensure that only infants who had learned the train task in the first place were included in the final sample.

Phase 2: Associating the retrieved memory and the modeling event

Phase 2 occurred 1 week after Phase 1. At this time, the train box was placed on a side table in the infant's view, but the infant's attention was not explicitly directed to it. The infant sat on the caregiver's lap, while the experimenter knelt in front of the infant and held the puppet at the infant's eye level but out of reach (see Fig. 1). She then removed the mitten from the puppet's hand, shook it three times to ring the bell pinned inside, and replaced it. This sequence was repeated five more times for a total demonstration time of 60 s. Immediately after the demonstration, the infant received an immediate imitation test. For infants who failed to touch the puppet at this time, the experiment was terminated.

Retention tests

Retention of the R-O association was always tested first. In the original potentiation study, the experimental group had not remembered the modeled actions longer than 1 day unless retention of the R-O association was tested first (Barr et al., 2001). Activating the memory of the R-O association during the test presumably activated the representation of the modeling event that was associated with it, enabling infants to imitate the modeled actions during the deferred imitation test. During the R-O test, the infant sat in front of the train box, and his or her rate of lever pressing was recorded for 2 min while the lever was deactivated. The long-term retention test was followed by a 6-min *motivational control phase,* when the R-O contingency was reinstated. This phase was included to ensure that infants who had performed poorly during the long-term test were not ill, fatigued, or unmotivated on the test day.

Fig. 1 The experimental arrangement used in Phase 2, shown here with a 6-month-old infant. The target actions were modeled on the puppet 1 or 2 weeks after operant training while the train box was in view (from Barr et al., 2001)

Immediately after the operant test, the caretaker (with the infant still seated on her lap) rotated her chair to the side, and the experimenter knelt in front of the infant, positioning the puppet as before but within the infant's reach. The infant was allowed 120 s, timed from when he or she first touched the puppet, to imitate the modeled actions. All infants were tested with the demonstration puppet, but the jingle bell had been removed from the mitten.

Because infants can remember the R-O association for 2 weeks (Barr et al., 2001; Hartshorn & Rovee-Collier, 1997), we began testing infants 2 weeks after operant training ended (1 week after the modeling event) and thereafter increased the retention interval for independent test groups until a group exhibited no retention on both tasks. This strategy yielded three experimental groups that were tested 1, 4, or 6 weeks after the modeling event (2, 5, or 7 weeks after operant training).

There were also two control groups. The *no-association control group* learned the R-O association and then watched the modeling event 1 week later, but the train box was not physically present when the target actions were modeled. The memory of operant training was not retrieved until the no-association control group was tested for retention of the train task 2 weeks later—1 week after the demonstration, immediately before being tested for deferred imitation. To ensure that neither the physical training context nor the experimenter inadvertently served as a retrieval cue for the R-O association in Phase 2, one experimenter conducted the operant conditioning procedure and administered its long-term retention test in one room, and a different experimenter modeled the target actions and administered the deferred imitation test in a different room. (In operant and deferred imitation studies, 6-month-olds do not generalize across either rooms or experimenters (Amabile & Rovee-Collier, 1991; Hartshorn, Rovee-Collier, Gerhardstein, Bhatt, Klein, Aaron, et al., 1998a; Learmonth, Lamberth, & Rovee-Collier, 2004, 2005].) In this way, the no-association control group had no opportunity to retrieve the memory of the R-O association and associate it with the modeling event in Phase 2.

The second control group was a *pooled baseline control group,* which provided an estimate of the base rate at which 6-month-olds spontaneously produce the target behaviors on the puppet. This group contained all of the 6-month-olds who had previously participated in baseline control groups in deferred imitation studies in our lab.[3] It had no operant training and did not see the target actions modeled on the puppet; rather, the imitation test was its first and only session.

Retention measures

Operant conditioning

Infants' long-term retention of the train task was assessed with two individual measures of relative responding (Rovee-Collier, 1996). The *retention ratio* (RR) reflects the extent to which an infant continues to exhibit his or her final level of learning after a delay. It expresses the infant's rate of responding during the immediate retention test (IRT) as a fraction of the same infant's rate of responding during the long-term retention test (LRT): RR = IRT/LRT. If a group's responding during the IRT did not decline over the retention interval, then its mean RR would not be significantly below 1.00 (H_0: no forgetting); if its responding did decline significantly over the delay, however, then its mean RR would be significantly below 1.00 (H_1: forgetting).

Although a mean RR significantly below 1.00 indicates that a group exhibited forgetting, it does not indicate whether the group's forgetting was complete or partial. That conclusion depends on whether the group had responded at operant level or not, respectively, during the LRT. Qualifying the RR, however, presents a problem common to all operant research—individual differences in operant level. For two individuals with an identical final level of learning (e.g., 20 responses/min) but different initial operant levels (e.g., 5 versus 10 responses/min), for example, long-term retention at operant level would be indexed by two different RRs (0.25 versus 0.50, respectively). Animal researchers have solved this problem by including a subject's operant level in either the numerator or denominator of an individual pre-post measure of response change (for review, see Church, 1973).

We have adopted the same solution and include each infant's operant level (baseline or BASE) as the denominator and the same infant's rate of responding during the LRT as the numerator of a *baseline ratio* (BR): BR = LRT/BASE. We then use a group's *M* BR to qualify its *M* RR: If a group's *M* BR did not significantly exceed 1.00 (H_0: no retention), then its forgetting was complete. If a group's *M* BR significantly exceeded 1.00 (H_1: retention), then its forgetting was partial. If a group's *M* BR did not significantly exceed 1.00 (H_0), however, then it exhibited no retention, even when its *M* RR was not significantly below 1.00. Noncontingent-reinforcement control groups, for example, typically have *M* RRs of 1.00 because they continue to respond at operant level during the IRT and LRT (e.g., Hartshorn & Rovee-Collier, 1997).

Deferred imitation

An imitation score was calculated for each infant by summing the number of target behaviors (range = 0–3: remove the mitten, shake the mitten, attempt to replace the mitten) that were produced during the test. *Deferred imitation* was operationally defined as a mean imitation score of an experimental test group that significantly exceeded the mean test score ($M = 0.13$, $SE = 0.05$) of an age-matched, spontaneous-production pooled baseline control group (H_1). Conversely, *forgetting* was operationally defined as a mean imitation test score that did not significantly exceed the mean test score of the pooled baseline control group (H_0).

Results and discussion

Operant task

Separate one-way analyses of variance (ANOVAs) indicated that the mean response rates of the experimental groups and the no-association control group did not differ during either the baseline phase, $F(3, 20) = .73$, $p = .55$, $MSe = 28.07$, *partial* $\eta^2 = .10$, or the immediate retention test, $F(3, 20) = .17$, $p = .91$, $MSe = 38.10$, *partial* $\eta^2 = .03$. These results eliminated group differences in either operant level or the final level of learning (i.e., retention after no delay), respectively, as the basis for any group differences in long-term retention.

To determine whether any group had exhibited forgetting, we used one-sample directional *t* tests to compare the *M* RR of each group with a theoretical RR of 1.00 (H_0: no forgetting). The no-association control group and the experimental groups tested 2 weeks and 5 weeks after

[3] Because the incidence of spontaneously performing the target actions in the population is low but non-zero, the mean baserate of a pooled baseline control group more closely approximates the population mean, decreasing the likelihood of Type I and Type II errors. The pooled baseline control group presently contained 45 six-month-olds (26 girls, 19 boys) who had participated in spontaneous baseline control groups in our previous deferred imitation studies with the same stimuli and parameters (Barr, Marrott, & Rovee-Collier, 2003; Barr, Rovee-Collier, & Campanella, 2005; Barr, Muentener, Garcia, Fujimoto, & Chavez, 2007; Barr et al., 2001; Barr, Vieira, & Rovee-Collier, 2002; Campanella & Rovee-Collier, 2005; Learmonth et al., 2004). Infants' mean age was 195.7 days ($SD = 8.3$). They were Caucasian ($n = 30$), Asian ($n = 6$), African American ($n = 3$), Hispanic ($n = 3$), and of mixed race ($n = 3$). Their parents' mean educational attainment was 15.6 years ($SD = 1.2$) and mean SEI was 72.26 ($SD = 18.89$).

operant training, respectively, exhibited no forgetting (i.e., mean RR not significantly below 1.00), but the experimental group tested 7 weeks afterward did (see Table 1 and Fig. 2, top panel).

To determine which groups exhibited significant retention during the long-term test, we used identical analyses to compare the *M* BR of each group with the theoretical BR of 1.00. Both the experimental group and the no-association control group that were tested 2 weeks after operant training and the experimental group that was tested 5 weeks afterward (4 weeks after its memory was retrieved) exhibited significant retention of the R-O association (i.e., *M* BRs significantly exceeding 1.00). These results confirmed that the three groups exhibited no forgetting. The experimental group that was tested 7 weeks after operant training (6 weeks after its memory was retrieved), however, exhibited no retention (i.e., *M* BR not significantly exceeding 1.00), revealing that its forgetting was complete (see Table 2).

Deferred imitation task

A trained observer scored the videotaped test sessions of all infants, and a second observer who was blind to infants'

Table 1 Mean retention ratios, standard errors (± 1 SE), *t* values, and degrees of freedom (*df*) for nine experimental groups and one control group (n = 6) in two experiments as a function of weeks since Phase 2 (formation of the association). *Note*: Add 1 week (Experiment 1) or 2 weeks (Experiment 2) for weeks since operant training

Test group (weeks since Phase 2)	Retention ratio		
	M RR	*SE*	*t(df)*
Experiment 1			
1	1.05	0.40	$t(5) = 0.14$
4	1.13	0.25	$t(5) = 0.51$
6	0.70	0.13	$t(4) = -2.29$*
1 [No-assoc control]	1.21	0.18	$t(5) = 1.14$
Experiment 2			
1	0.68	0.18	$t(5) = -1.74$
2	1.35	0.28	$t(5) = 1.24$
4	1.56	0.33	$t(4) = 1.65$
6	0.98	0.10	$t(5) < -0.15$
8	0.95	0.21	$t(5) < -0.26$
10	0.82	0.24	$t(5) < -0.74$

*$p < 0.05$, **$p < 0.01$

In both experiments, two RRs and four BRs were outliers. Each was replaced with the next highest ratio in the group, and the *df* was reduced by 1 (Tukey, 1977; see Tables 1 and 2). Group significance levels were affected by corrections of only three BRs, however, two of which were marginally significant (uncorrected *ps* = 0.055, 0.055, 0.09).

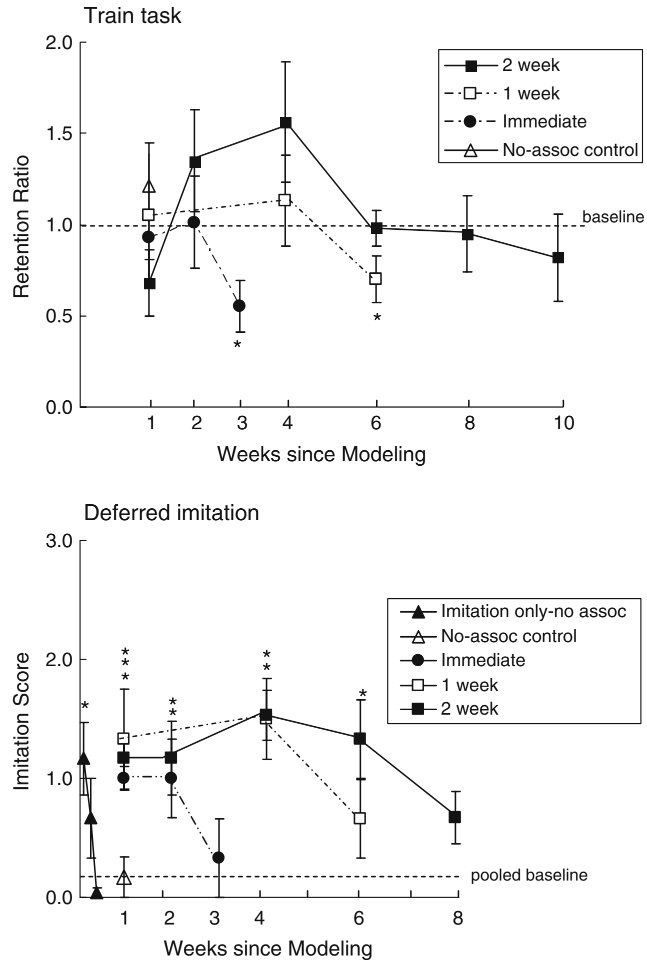

Fig. 2 *Top panel:* The mean retention ratios (± 1 *SE*) of independent groups of 6-month-old infants as a function of the time, in weeks, since the memory of the train task was retrieved and associated with the demonstration. The demonstration occurred either 1 week (*open squares*) or 2 weeks (*filled squares*) after infants had learned the train task. Also shown are data from groups whose demonstration occurred immediately after infants had learned the train task, when the central representation of the train task was still active (*filled circles*, Barr et al., 2001). For the no-association control group (*open triangle*), the demonstration occurred 1 week after infants had learned the train task, but the train set was not present. This group was tested 1 week later. An asterisk indicates that a test group exhibited significant forgetting, that is, its mean retention ratio was significantly below 1.00 (*dashed line*). *Bottom panel:* The mean imitation scores (± 1 *SE*) of independent groups of 6-month-old infants as a function of the time since modeling, in weeks. Six-month-olds without prior operant training exhibited significant deferred imitation 1 day after a 60-s demonstration of the target actions but not after 2 or 3 days (*filled triangles*; from Barr et al., 2001). Potentiation of the modeling event occurred when the demonstration occurred either immediately after the train task and was directly associated with it (*filled circles*; Barr et al., 2001) or in the presence of the memory of the train task that was associatively activated either 1 week (*open squares*) or 2 weeks (*filled squares*) after the train task and was indirectly associated with it. For the 1-week no-association control group (*open triangle*), the train box was not present when the target actions were modeled. An asterisk indicates that a test group exhibited significant deferred imitation (i.e., its mean imitation score was significantly higher than the mean test score of the pooled baseline control group [*dashed line*])

group assignments independently scored 66% of them. The interobserver reliability was 100% (*kappa* = 1.0).

During the immediate imitation test following demonstration of the target actions, the mean latencies (in s) to touch the puppet of the experimental group that was tested 1 week later (M = 47.40, SE = 14.30) and the 1-week association control group (M = 23.40, SE = 10.45) did not differ, Student's $t(8) = 1.36$, $p = .21$. Likewise, the mean immediate imitation scores of the 1-week experimental test group (M = 1.83, SE = .17) and the 1-week no-association control group (M = 1.67, SE = .33) did not differ, Student's $t(10) = .46$, $p = .66$. These results eliminated group differences in either motivation to approach the puppet or learning the modeled actions as the basis for a potential group difference in deferred imitation.

A one-way ANOVA indicated that the mean deferred imitation test scores of the three experimental and two control groups differed significantly, $F(4, 64) = 14.45$, $p < .0001$, $MSe = 4.11$, *partial* $\eta^2 = .48$. Post hoc Dunnett's t tests ($p < .05$) were used to compare the mean imitation score of each group with the mean test score of the pooled baseline control group. This test controls for Type I errors across multiple comparisons with a control group (Dunnett, 1955). These analyses indicated that the experimental group had a higher mean test score than the pooled baseline control group both 1 week and 4 weeks after the modeling event but not 6 weeks afterward (see Table 2 and Fig. 2, bottom panel).

The 1-week mean imitation score of the no-association control group also did not differ from the mean test score of the pooled baseline control group and was identical to the 3-day mean imitation score of infants in Barr et al. (2001), who had also failed to exhibit deferred imitation without an association to facilitate it (see Fig. 2, bottom panel: filled triangles). The failure of the no-association control group to imitate the target actions 1 week after they were modeled contrasts sharply with the same group's excellent retention on the R-O association test only moments earlier. This result indicates that the retrieved memory of prior learning was responsible for facilitating infants' new learning and memory of the modeling event and excludes alternative explanations for the facilitation: Neither prior conditioning experience per se nor mere familiarity with the operant task was responsible for infants' improved learning and recall of the modeled actions.

Experiment 2: Mediated learning 2 weeks after operant training

Batsell, Trost, Cochran, Blankenship, and Batson (2003) reported that when additional training strengthened a taste that had previously potentiated conditioning of an odor aversion, the associated odor aversion was strengthened as well. In Experiment 2, we asked whether increasing the strength of the mediator would similarly strengthen infants' learning of the modeling event. One manipulation that increases the strength of a memory without requiring additional training is merely retrieving it, and allowing more time to elapse before retrieving the memory representation strengthens it more (Bjork, 1988; Hsu & Rovee-Collier, 2009; Rovee-Collier, 1995; Rovee-Collier et al., 1993; Schmidt & Bjork, 1992).

In Experiment 2, therefore, we attempted to increase the memory strength of the R-O association by increasing its retrieval delay from 1 week to 2 weeks—the longest duration that 6-month-olds can remember the train task.

Method

Participants

The final sample consisted of 36 full-term 6-month-old infants (21 boys, 15 girls) who were recruited as before and assigned to test groups (n = 6) as they became available for study. Their mean age was 191.4 days (SD = 6.6) on the first day of training. Participants were Hispanic (n = 5), Asian (n = 3), and Caucasian (n = 28). Their parents' mean educational attainment was 15.3 years (SD = 1.2) and mean SEI was 68.3 (SD = 14.5). Testing was discontinued on additional infants who cried during operant training (n = 5) or failed to touch the puppet (n = 1).

Procedure

The procedure was the same as in Experiment 1 with two exceptions. First, Phase 2 occurred 2 weeks after operant training. Second, at the start of Phase 2, immediately before the target actions were modeled, we administered a 2-min preliminary retention test (lever deactivated) as a memory probe to ensure that all infants had actually retrieved the R-O memory at the end of its forgetting function, 14 days after operant training. During the preliminary test,[4] every infant responded at least 1.5 times above operant level

[4] The response lever was deactivated during the 2-min preliminary test—an extinction manipulation that, if sufficiently long, would decrease the strength of the R-O association. Because preliminary tests lasting 2 and 3 min have never affected the strength of a retrieved R-O memory (Enright, Rovee-Collier, Fagen, & Caniglia, 1983; Galluccio & Rovee-Collier, 2006; Hartshorn, 2003; Rovee-Collier, Hartshorn, & DiRubbo, 1999; Shafer, 2009), however, the present 2-min preliminary test is unlikely to have affected the strength of the modeling event that was associated with the retrieved memory either.

Table 2 Mean baseline ratios (BR), mean imitation test scores, standard errors (± 1 SE), *t* values, and degrees of freedom (*df*) of independent groups (*n* = 6) of 6-month-old infants as a function of weeks since Phase 2 (formation of the association) in Experiments 1 and 2. *Note*: Add 1 week (Experiment 1) or 2 weeks (Experiment 2) for weeks since operant training

Test group (weeks since Phase 2)	Operant test			Imitation test		
	M BR	*SE*	*t*(df)	*M* Score	*SE*	*t*(df)
Experiment 1						
1	2.64	0.54	3.031 (5)*	1.33	0.42	3.80 (64)*
4	2.24	0.35	3.53 (5)**	1.50	0.34	4.36 (64)*
6	2.38	0.90	2.21 (4)	0.66	0.33	1.61 (64)
1 [No-assoc control]	3.10	0.94	2.59 (4)*	0.17	0.17	0.54 (64)
Experiment 2						
1	1.54	0.25	2.16 (4)*	1.17	0.17	3.69 (74)*
2	2.01	0.31	3.24 (4)*	1.17	0.31	3.69 (74)*
4	4.10	0.98	3.18 (5)*	1.50	0.22	4.92 (74)*
6	2.79	0.63	2.86 (5)*	1.33	0.21	4.22 (74)*
8	2.03	0.37	2.82 (5)*	0.67	0.33	1.82 (74)
10	2.41	0.86	1.64 (5)	0.50	0.22	1.23 (74)

*$p < 0.05$, **$p < 0.01$

(the original learning criterion), indicating that all had successfully retrieved the R-O memory and eliminating retrieval failure as the basis for a potential potentiation failure. Immediately after the preliminary test, the caregiver (still holding the seated infant) rotated his or her chair to the side, and the experimenter modeled the target actions on the puppet.

We began testing independent groups 1 week after the modeling event, initially doubling the test delay and then increasing it in 2-week steps. Testing was again terminated when a group exhibited no retention on both tasks. This strategy yielded six independent experimental groups that were tested 1, 2, 4, 6, 8, or 10 weeks after the demonstration (3, 4, 6, 8, 10, or 12 weeks after operant training, respectively). The pooled baseline control group again provided the base rate at which 6-month-old infants spontaneously produce the target actions. Because the no-association control group that was tested 7 days after the demonstration in Experiment 1 had a mean deferred imitation score that was identical to the mean test score of the pooled baseline control group, and the mean deferred imitation scores of prior no-association groups had failed to exhibit significant deferred imitation either 2 or 3 days after the demonstration (Barr et al., 2001; see Fig. 2, bottom panel), we decided not to test another no-association control group 7 days after the demonstration in Experiment 2.[5]

[5] Unlike adults, human infants are defined as a risk population by the National Institute of Health, which requires that researchers minimize the number of infants enrolled in their studies. As a result, we have adopted the strategy of *partial replication* in our studies: The experimental design of each new study always includes a critical replication group from a preceding study but does not include that same group in follow-up experiments within the same study.

Results and discussion

Operant task

Separate ANOVAs indicated that the mean lever presses of the six groups did not differ during either the baseline phase, $F(5, 30) = 1.92$, $p = .12$, $MSe = 24.53$, *partial* $\eta^2 = .24$, or the immediate retention test, $F(5, 30) = 1.48$, $p = .23$, $MSe = 141.43$, *partial* $\eta^2 = .20$. These results again eliminated group differences in either operant level or the final level of learning (i.e., retention after no delay), respectively, as the basis for any group differences in long-term retention.

To determine whether any group exhibited significant forgetting, we again used one-sample directional *t* tests to compare the *M* RR of each group with the theoretical RR of 1.00 (H_0: no forgetting). These analyses indicated that no group had exhibited forgetting (i.e., *M* RRs not significantly below 1.00) after any test delay (see Table 1 and Fig. 2, top panel).

To determine which groups exhibited significant retention during the long-term test, we used identical analyses to compare the *M* BR of each group with the theoretical BR of 1.00 (H_0: no retention). Independent groups that were tested 1, 2, 4, 6, and 8 weeks after Phase 2 exhibited significant retention (i.e., *M* BRs significantly exceeding 1.00), responding above operant level during the LRT and confirming the RR analyses. Despite its non-significant RR, however, the group that was tested 10 weeks after Phase 2 exhibited no retention (i.e., *M* BR not significantly exceeding 1.00), responding at operant level during the LRT (see Table 2).

Deferred imitation task

A trained observer scored all of the videotaped test sessions, and a second observer who was blind to infants' group assignments independently scored 89% of them. The interobserver reliability was 100% (*kappa* = 1.0).

During the immediate imitation test, the 1-week experimental test groups in Experiments 1 and 2 had highly similar mean latencies to touch the puppet and identical mean immediate imitation scores. Despite the questionable practice of making cross-experiment comparisons, these data encouraged us to compare the mean latency (in s) to touch the puppet (M = 52.00, SE = 23.40) and the mean immediate imitation score (M = 1.83, SE = 0.17) of the 1-week experimental test group in Experiment 2 with the mean latency (M = 23.09, SE = 23.37) and mean immediate imitation score (M = 1.67, SE = .33) of the 1-week no-association control group from Experiment 1. As before, the groups did not differ on either measure (*latency to touch*, $t(8)$ = 1.36, p = .21; *immediate imitation score:* $t(10)$ = .46, p = .66). These results lead us to exclude group differences in either motivation to approach the puppet or learning the modeled actions as the basis for a potential group difference in deferred imitation.

A one-way ANOVA indicated that the mean deferred imitation test scores of the seven groups (six experimental groups, one control group) differed significantly, $F(6, 74)$ = 16.09, $p < .0001$, MSe = 3.56, *partial* η^2 = .57. Dunnett's t tests ($p < .05$) comparing the mean imitation score of each experimental group with the mean test score of the baseline control group revealed that groups exhibited significant deferred imitation 1, 2, 4, and 6 weeks after the demonstration but not 8 or 10 weeks afterward. All experimental groups had mean imitation scores higher than the mean test score of the baseline control group except the 8- and 10-week test groups (see Table 2 and Fig. 2, bottom panel).

These results confirm the finding of Experiment 1 that prior learning of the train task mediates new learning of the modeling event. When the target actions were modeled in the presence of the train box 2 weeks after operant conditioning in Experiment 2, the retrieved memory that was associated with the modeling event was stronger than when it had been retrieved after a delay only half as long (1 week) in Experiment 1. As a result, infants' prior learning of the train task also potentiated retention of the modeling event longer—for 6 weeks instead of 4 weeks.

We note that retention of the conditioned association increased *logarithmically* over test delays (2, 4, 8 weeks) in Experiments 1 and 2, which is an instantiation of the *ratio rule* (Bjork, 2001). We have obtained the same relationship in prior operant and deferred imitation studies with young infants as well (Barr, Rovee-Collier, & Campanella, 2005; Galluccio & Rovee-Collier, 2006; Hartshorn, Wilk, Muller, & Rovee-Collier, 1998c; Hildreth & Hill, 2003). Although retention of the associated modeling event only increased *additively* (2, 4, 6 weeks) over the same test delays, this disparity was based solely on the final data point and must be replicated.

General discussion

The finding that prior learning facilitates new learning is not novel. For more than a century, transfer of learning has been obtained in hundreds of studies using a variety of different methods with both human and nonhuman adults and infants. What makes the present finding special and distinguishes it from prior findings is the extraordinary magnitude of the facilitation and the facility with which it occurred. In our original study of potentiation with preverbal infants, we had found that prior learning of an R-O (response-outcome) association, which 6-month-old infants remember for 2 weeks, facilitated their learning of a modeling event, which infants typically remember for only 1 day. In that study, the final operant training session and the demonstration were associated when they occurred in rapid succession, and infants subsequently recalled the modeled actions for 2 weeks too (Barr et al., 2001).

In the current study, we examined the similarity between potentiation and the prior knowledge effect. Kole and Healy (2007) had reported that adults' prior knowledge could be used to mediate new learning. Our primary research question, therefore, was whether infants' prior learning of an R-O association could similarly be used to mediate and strengthen their new learning of the modeling event and extend its recall. The answer was "yes." In Experiment 1, when the target actions were modeled 1 week after operant training in the presence of a retrieval cue for the conditioned association, infants remembered both the target actions and the train task for 4 weeks. In Experiment 2, when the target actions were modeled 2 weeks after operant training in the presence of the same retrieval cue, infants remembered them for 6 weeks and the operant task for 8 weeks.

The similarity between potentiated learning and retention in infants and the prior knowledge effect in adults is striking. In both instances, new information is learned better when it is associated with prior learning than when it is learned alone; the potentiation of new learning can be either direct or indirect (mediated); and potentiation occurs whether or not the prior learning and new learning are perceptually or conceptually related. Potentiation in infants and the prior knowledge effect in adults also respond similarly to manipulations of the same two independent variables. Barr et al. (2001), for example, originally found that when the train task and the modeling event were *directly* associated, 6-month-olds' prior learning potentiated their learning and recall of the modeling event. Presently, we demonstrated in Experiment 1 that when the retrieved memory of the train task was *indirectly* associated with the modeling event, the activated memory representation of prior learning mediated infants' new learning of the modeling event and potentiated its recall. Kole and Healy (2007) had similarly found that when adults' prior knowledge was *indirectly* associated with the to-be-learned information, it mediated the new learning. Further, we demonstrated In Experiment 2 that increasing the magnitude (memory strength) of the activated representation of prior learning improved infants' learning and recall of the modeling event even more. Similarly, when Kole and Healy (2007) had varied the strength of adults' prior knowledge (Low Knowledge, Mediated Knowledge, High Knowledge conditions), they had found that the High Knowledge condition yielded the best learning and retention.

Finally, potentiation in infants, like the prior knowledge effect in adults, is an *encoding* phenomenon. We recently found that a prior association between two hand puppets facilitated 6-month-olds' new learning and retention of the train task (Mitchell, Chakraborty, Hsu-Yang, Giles, & Rovee-Collier, 2010). A paired experimental group was simultaneously exposed to two puppets (S1 and S2) twice on the same day for 30 min on each occasion. On this exposure regimen, 6-month-olds form an S1-S2 association and remember it for 4 weeks (Giles, 2010). An unpaired (no-association) control group was exposed to S1 and S2 separately on the same regimen. Immediately after their second 30-min exposure to the puppets, all infants learned the operant train task for one session, which they typically remember for only 5 days (Hsu & Rovee-Collier, 2009), *in the presence* of the two puppets and were tested with the train *in the absenc*e of the puppets.

For the paired experimental group, the presence of the associated puppets during operant training facilitated its learning and potentiated its retention of the train task from 5 days to 4 weeks—the same duration that 6-month-olds remember the S1-S2 association (Giles, 2010). The fact that the associated puppets were absent during the LRT demonstrates that potentiation is an encoding rather than a retrieval phenomenon. For the unpaired control group, however, the presence of the puppets during operant training had no effect on learning and retention of the train task: The unpaired control group exhibited no retention 2 weeks after operant training.

Kole and Healy (2007) had argued that a mental model account of the prior knowledge effect offered the best explanation of their data and of data from a prior study (Van Overschelde & Healy, 2001). In both studies, adults learned a large number of new facts with a minimum of interference. According to this account, new information is integrated into preexisting concepts, thereby preserving its distinctiveness and buffering it from proactive interference by information already in memory. Although it is premature to seek a formal account of potentiation in young infants at this point, Kole and Healy's rationale for selecting a mental model account of the prior knowledge effect in adults does not apply to young infants. Not only are 6-month-olds' memories highly specific to the details of an original encoding episode, but also they are not susceptible to proactive interference.

Adults have built up massive amounts of prior knowledge over a lifetime, whereas 6-month-olds' knowledge base is just being formed. Yet, despite profound differences in task, learning content, experimental methods, and linguistic competence (to name a few), studies of the prior knowledge effect with adults and our studies of potentiated learning and memory with very young infants have yielded remarkably similar findings. This similarity has led us to conclude that the origin of the prior knowledge effect can be traced to early infancy.

The findings of the present study have far-reaching implications for early cognitive development. Because infants formed a new and relatively enduring association between an associatively activated memory representation and a very brief (60 s) physically present event so rapidly and effortlessly—even when their attention was not explicitly directed to the retrieval cue, it seems highly likely that young infants form numerous associations in the same way every day. Over the weeks and months that prior associations remain latent, they can be linked to other preexisting associations in a mnemonic network without being expressed. Further, the more new associations infants form, the more rapidly the network will expand, and the more complex and interconnected it will become (Cuevas, Rovee-Collier, & Learmonth, 2006; Timmons, 1994; Townsend, 2007). Finally, because associations are behaviorally silent and only a small fraction may ever be expressed—either directly or indirectly, the full extent of their contribution to the early knowledge base will never be known.

Acknowledgments This research was funded by Grant Numbers HD043047 from the National Institute of Child Health and Human Development to Rachel Barr and MH32307 from the National Institute of Mental Health to Carolyn Rovee-Collier.

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