Published in final edited form as:

Dev Psychobiol. 2015 May ; 57(4): 497–505. doi:10.1002/dev.21298.

Deconstructing the Reactivation of Imitation in Young Infants

Amy E. Learmonth¹, Kimberly Cuevas², and Carolyn Rovee-Collier^{3,†}

¹Department of Psychology, William Paterson University

²Department of Psychology, University of Connecticut

³Department of Psychology, Rutgers University

Abstract

Reactivation is an automatic, perceptual process in which exposure to components of a forgotten event alleviates forgetting. Most research on infant memory reactivation has used conditioning paradigms. We used the puppet imitation task to systematically examine which stimuli could retrieve 6-month-olds' forgotten memory of the modeled actions. Infants watched an adult model a sequence of actions on a puppet, imitated the actions, and were exposed to reactivation cues 24 hr before a 7-day (Experiment 1) or 14-day (Experiment 2) retention test. Exposure to any component of the original event reactivated the memory during the 7-day test, but two of the same components failed to alleviate forgetting during the 14-day test. Increasing the number of retrieval cues facilitated 14-day test performance. These findings reveal that the principles of reactivation are the same for conditioning and imitation paradigms: The necessary and sufficient conditions for memory reactivation are directly related to memory accessibility.

Keywords

retrieval failure; automatic processing; reactivation; infants; memory attributes; imitation

Underwood (1969) described a memory as a collection of attributes that are noticed about an event when it occurs. Only attributes that are represented in the original memory can cue its retrieval—familiar cues that were not part of the original event cannot. Hasher and Griffin (1978) elaborated Underwood's model, proposing that memory attributes are independent and forgotten at different rates, thus becoming differentially accessible to retrieval over time. This notion has since been documented in studies with infants—both animal (Riccio, Richardson, & Ebner, 1984) and human (Bhatt & Rovee-Collier, 1996; Borovsky & Rovee-Collier, 1990). Further, Hasher and Zacks (1979) proposed that memory processes are either automatic or effortful. Any attribute of an event that is the brief focus of attention enters long-term memory automatically, without awareness, and without affecting other ongoing cognitive processes. If an individual's eyes casually pass over the visual landscape, there is

Correspondence concerning this article should be addressed to Kimberly Cuevas, Department of Psychology, University of Connecticut. kimberly.cuevas@uconn.edu.

[†]This manuscript was submitted after the death of CRC. Her contributions to our field were staggering and the other authors are honored to have worked with her.

no focus of attention; rather, attention must briefly rest on an attribute for some minimum duration. The same automatic process occurs during memory reactivation.

Memory reactivation is an automatic, perceptual process in which exposure to components of a forgotten event alleviates forgetting. This phenomenon indicates a distinction between the availability and accessibility of information in memory. Memories can remain available in memory storage despite being temporarily inaccessible at the time of retrieval (Rovee-Collier, 1997; Rovee-Collier, Sullivan, Enright, Lucas, & Fagen, 1980; for review of neural evidence, see Li, Callaghan, & Richardson, 2014). Spear (1978) proposed that memory reactivation facilitates retrieval of the latent memory by increasing the accessibility of its attributes.

Jacoby (1983) viewed reactivation in terms of perceptual enhancement. Perceptual enhancement increases the salience of retrieval cues for whole prior processing episodes. These retrieval cues make veridical contact with the attributes that were perceptually processed in the original event. Hasher and Griffin (1978) also proposed that the rate of perceptual processing at a given age determines the minimum exposure required for automatic processing of a reactivation cue. Perceptual processing is slower during early infancy because of the immaturity of the central nervous system. Prior operant studies of reactivation found that the minimum duration of an effective prime decreases sharply between 3 and 12 months of age (Hsu, Rovee-Collier, Hill, Grodkiewicz, & Joh, 2005). However, after a prior prime at 3 months of age, the minimum duration of an effective second prime is the same as that of 12-month-olds who have been primed only once (Bearce & Rovee-Collier, 2006). Thus, maturational changes are unlikely to be the sole account for age-related differences in reactivation (see also Hayne, Gross, Hildreth, & Rovee-Collier, 2000).

The majority of research on infant memory reactivation has used operant conditioning paradigms (Rovee-Collier et al., 1980; for review, see Rovee-Collier, Hayne, & Colombo, 2001); however, much of what very young infants learn is acquired by merely observing their environmental surround and what other people do (e.g., Barr, Dowden, & Hayne, 1996; Campanella & Rovee-Collier, 2005; Cuevas, Rovee-Collier, & Learmonth, 2006). Although substantial research has used imitation paradigms to examine infant memory development, little is known about corresponding memory reactivation. Specifying the necessary and sufficient conditions for memory reactivation enhances our understanding of the possible long-lasting effects of early observational learning while also potentially revealing universal properties of infant memory reactivation that are not paradigm specific.

To this end, Hayne, Barr, and Herbert (2003) examined whether cues from the puppet imitation task could retrieve 18-month-olds' forgotten memory of the modeled actions. After a 6-week delay, 30 s of exposure to the moving puppet was an effective prime--infants imitated the target actions 24 hr later. This prime, however, was only effective if 18-month-olds had imitated the target actions immediately after modeling. Because immediate imitation is a requisite for subsequent reactivation of the forgotten memory at 18 months of age, then it is most likely also a criterion for reactivation at younger ages. The minimal conditions for memory reactivation using an imitation paradigm have not been investigated,

and it is unknown whether fewer retrieval cues (or shorter exposure to the puppet) could have also been effective memory primes.

The purpose of the current study was to extend previous research on the minimum duration of an effective prime from operant conditioning to imitation. To this end, we provide a downward extension of Hayne et al.'s (2003) memory reactivation work in imitation by determining which stimuli would serve as effective memory primes at 6 months of age. Previous research with the puppet imitation task has revealed that 6-month-olds imitate the modeled actions 24 but not 48 hr later (Barr et al., 1996; Barr, Vieira, & Rovee-Collier, 2001). Therefore, in two experiments, 6-month-olds watched an adult model a sequence of actions on a puppet, imitated the actions, and were exposed to reactivation cues 24 hr before a 7-day (Experiment 1) or 14-day (Experiment 2) retention test.

Experiment 1

At 6 months of age, the minimum effective duration of a reactivation treatment is 7.5 s for operant tasks (Sweeney & Rovee-Collier, 2001). Previous reactivation studies with the puppet imitation task have used primes of 30 s or longer (e.g., Barr, Vieira, & Rovee-Collier, 2002; Hayne et al., 2003). In Experiment 1, 6-month-olds were primed approximately 1 week after forgetting—the same delay after which a 7.5-s prime is effective for operant tasks (Sweeney & Rovee-Collier, 2001). Whether a 7.5-s prime would also be effective for an imitation task is unknown. To this end, the duration of our initial prime was 7.5 s, and the duration of successive primes was approximately halved or doubled until the minimum duration of priming with the puppet was determined.

In more recent work, we found that all aspects of the context in which the event occurs are represented in infants' memory of the modeling event (Learmonth, Lamberth, & Rovee-Collier, 2004, 2005). Although the training context alone effectively reactivates the forgotten memory of an operant task (Hayne & Findlay, 1995; Rovee-Collier, Griesler, & Earley, 1985), it is unknown whether contextual cues can also retrieve the forgotten memory of a modeled event. Thus, we examined whether presenting the experimenter alone (i.e., with no additional cues) would be an effective memory prime.

Method

Participants—Forty-two 6-month olds (20 boys, 22 girls) were recruited from commercial mailing lists, birth announcements, and by word of mouth. Their mean age was 191.4 days ($SD = 7.9$). Participants were African-American ($n = 2$), Asian ($n = 9$), Caucasian ($n = 24$), Hispanic ($n = 4$), and of mixed race ($n = 3$). Their parents' mean educational attainment, as reported by 95.2% of the sample, was 15.5 years ($SD = 1.3$), and their mean rank of socioeconomic status (SEI¹; Nakao & Treas, 1992), reported by 81% of the sample, was 64.40 ($SD = 20.99$). Testing was discontinued on additional infants due to scheduling

¹All human studies funded by NIMH are required to report information pertaining to the race, ethnicity, and socioeconomic status of participants. Educational attainment, occupational status, and annual income are the three major components of socioeconomic status. The socioeconomic index (SEI), published by Nakao and Treas (1992), is the recommended source for occupational status. In the SEI, ranks of occupations range from 1 to 100, with higher-paying occupations (e.g., physician and lawyer) being assigned higher ranks.

difficulties ($n = 3$), illness ($n = 2$), refusal to touch the demonstration puppet ($n = 3$), and experimenter error ($n = 3$).

Stimuli—Two hand puppets (a black-and-white cow, a yellow duck) were constructed for this research and not commercially available (see Figure 1). Puppets were counterbalanced within groups. Both puppets were 30 cm tall and made of soft, acrylic fur. Each puppet wore a removable felt mitten (8×9 cm) on its right hand. A large jingle bell was pinned inside the mitten during the demonstration, but was removed during testing. A VHS-C camcorder on a tripod set at right angles to the infant was used to videotape all sessions for future scoring.

Procedure—Infants were studied in their own homes at a time of day when they were likely to be playful. This time varied across infants but remained fairly constant across all sessions for a given infant. All sessions occurred within the same room.

Demonstration session (Session 1)—The experimenter began the demonstration session by interacting with the infant for 5 min or until she elicited a smile. The infant sat on the caregiver's lap or at her feet, while the experimenter knelt in front of the infant with the puppet on her right hand. The experimenter positioned the puppet at the infant's eye level and approximately 80 cm from the infant's chest (out of the infant's reach), and modeled a sequence of three target actions: (1) remove the mitten from the puppet's right hand; (2) shake the mitten to ring the bell inside; and (3) replace the mitten on the puppet's right hand. This sequence of target actions lasted 10 s and was repeated five more times for a total demonstration time of 60 s. Immediately after the demonstration, infants were allowed three opportunities to reproduce the target actions.

Imitation test session (Session 3)—The imitation test session occurred 7 days after the modeling event. The experimenter held the puppet as before but within the infant's reach (i.e., approximately 30 cm in front of the infant's chest). The bell was removed from the mitten. The infant was allowed 120 s from the time he or she first touched the puppet in which to imitate the previously modeled actions.

Reactivation procedure (Session 2)—The reactivation procedure occurred 24 hr prior to the imitation test session. For three experimental groups, a brief exposure (7.5 s, 4 s, or 2 s) to the puppet was the memory prime. The experimenter held the puppet at the infant's eye level and shook it gently to ring the bell attached to the puppet's back. Because the experimenter was present during the modeling event, she was also part of the original memory. Thus, for the fourth experimental group, the experimenter alone—no puppet—was presented as a reactivation cue for approximately 5 min (i.e., approximately the same duration the experimenter was present in the other experimental groups).

Control group procedure—In all studies of reactivation, two standard control groups are essential: (1) a forgetting control group (no reactivation), to ensure that the memory had been forgotten by the time of testing—this group was tested 2 days after the modeling event; (2) a reactivation control group, to ensure that no new learning took place during the reactivation procedure—this group received a 7.5-s puppet prime but saw no modeling event. In addition, a pooled baseline control group provided the baserate at which 6-month-

olds spontaneously produce the target actions in their first and only session.² Finally, unique to this experiment was the question of whether a pre-familiarized experimenter who was not present during the demonstration would reactivate the memory. According to Underwood's (1969) model of memory only attributes of the original memory event can "act as retrieval mechanisms for a target memory" (p. 559). For the experimenter specificity group, a second adult interacted with the infant for 5 min 1 day before the demonstration and was exposed for 5 min as the reactivation cue.

Results

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 on the puppet's right hand) that were produced during the test. One observer scored the videotapes of all test sessions; a second observer, who was blind to infants' group assignments, independently scored 24% of them. The interobserver reliability was 95% ($kappa = .89$). When the two raters differed, the primary rater's score was assigned.

A one-way analysis of variance (ANOVA) indicated that the mean test scores of the four experimental groups and four control groups differed, $F(7, 64) = 8.69, p < .001, \eta_p^2 = .49$. Post hoc tests (Fisher's LSD, $p < .05$) revealed that the mean imitation scores of the four experimental groups were significantly higher than the mean imitation scores of the four control groups. The mean imitation scores of the four experimental groups did not differ, nor did the mean test scores of the four control groups.

Although the ANOVA indicates whether or not the groups differed, it does not indicate which group, if any, exhibited significant evidence of retention during the test. To determine this, we used Dunnett's t tests ($p < .05$) to compare the test score of each group against the baserate (0.13) provided by the pooled baseline control group. These analyses showed that the mean imitation score of each experimental group was higher than the mean test score of the pooled baseline control group, but the mean test score of each of the remaining three control groups was not (see Figure 2).

The present results were unequivocal. When the initial reactivation cue duration of 7.5 s was successively halved until it failed to promote memory retrieval, 6-month-olds only required exposure to the experimenter (i.e., no puppet) in order for their latent memory to be retrieved 1 week after it had been forgotten. The effectiveness of a reactivation cue lasting only 2 s was surprising, particularly given that healthy adults cannot automatically process frequency information at exposure durations less than 2 s (Hasher, Zacks, Rose, & Sanft, 1987). We conclude that this finding resulted from the compounding of the 2-s exposure and the presence of the experimenter, who alone was an effective memory prime.

²The pooled baseline control group at 6 months of age contained the 30 infants (12 boys, 18 girls) who were in spontaneous baseline control groups in all of our previous studies with the same stimuli and procedure since 2005 (Barr, Muentener, & Garcia, 2007; Barr, Rovee-Collier, & Campanella, 2005; Campanella & Rovee-Collier, 2005; Learmonth et al., 2005). Infants' mean age was 197.9 days ($SD = 9.5$). They were African-American ($n = 2$), Asian ($n = 3$), Caucasian ($n = 16$), Hispanic ($n = 1$), of mixed race ($n = 3$), and not reported ($n = 5$). Their mean parental educational attainment was 15.7 years ($SD = 1.2$) and mean SEI was 71.61 ($SD = 21.35$). For this group, the test session was their first and only session. This group provided a mean baserate of 0.13 for spontaneously produced target actions at 6 months.

In contrast to operant work with 6-month-olds (Sweeney & Rovee-Collier, 2001), our findings indicated that less than 7.5 s of exposure to the focal cue was sufficient for priming 1 week after forgetting. We attribute this discrepancy to the relative role of the experimenter in each paradigm. In operant tasks, the experimenter interacts very little with the infants and remains out of the infants' direct line of sight. In imitation tasks, however, the experimenter interacts extensively with the infants both when the target actions are modeled and when they are tested (e.g., the puppet is “an extension” of the experimenter's arm). Moreover, the results of Experiment 1 showed that the memory of an event that infants imitate is reactivated in the same manner as forgotten operant memories.

Experiment 2

In operant studies with 3-month-olds, the minimum duration of an effective reactivation treatment increases with the time since the original event. At 3 months, for example, an effective reactivation stimulus had to be exposed two times longer after 2 weeks than after 1 week and three times longer after 3 weeks (Joh, Sweeney & Rovee-Collier, 2002). Spear (1978) proposed that memories that are forgotten longer are more difficult to retrieve. Our second research question asked whether the recovery of the forgotten memory of a modeled event similarly requires stronger or a greater number of reactivation cues after a longer delay. To answer it, we repeated the modeling event procedure but doubled the test delay from 7 to 14 days and again examined what constituted an effective reactivation cue after the longer test delay.

In anticipation that our 7-day minimum effective prime (i.e., experimenter only exposure) would not be effective after 14 days, we considered additional contextual cues that might facilitate memory retrieval in the absence of the focal cue (i.e., puppet). Previous infant research using operant and imitation paradigms has added novel proximal contextual cues to the environment by using colorful cloth mats or crib liners (e.g., Learmonth et al., 2004; Rovee-Collier et al., 1985). This work has revealed that contextual cues are represented in infants' memories, and that by 3 months of age, exposure to the training context alone (i.e., crib liner) is an effective memory prime for an operant task (Hayne & Findlay, 1995; Rovee-Collier et al., 1985). To examine whether additional retrieval cues could enhance the effectiveness of the experimenter (in the absence of the puppet) as a prime after a 14-day delay, an additional group was trained, primed, and tested in the presence of the distinctive cloth mat.

Method

Participants—Participants were thirty 6-month-olds (11 boys, 19 girls) with a mean age of 194.4 days ($SD = 8.6$). They were Asian ($n = 1$), Caucasian ($n = 24$), Hispanic ($n = 1$), Native American ($n = 1$), of mixed race ($n = 2$), and not reported ($n = 1$). Their parents' mean educational attainment, reported by 83.3% of the sample, was 15.7 years ($SD = 0.9$) and mean SEI, reported by 80% of the sample, was 66.62 ($SD = 14.99$). They were recruited as before and randomly assigned to one of five groups ($n = 6$) as they became available for study. Testing was discontinued on additional infants due to scheduling difficulties ($n = 2$), refusing to touch the puppet ($n = 1$), or crying ($n = 3$).

Stimuli—The apparatus was the same as in Experiment 1 except that a second experimenter only reactivation group sat on a distinctive floor mat during modeling, reactivation, and testing. One mat was blue with pink felt circles (5 cm diam.) arranged in a grid pattern, while the other was green with yellow felt stripes (2.5 cm wide). The floor mats were counterbalanced.

Reactivation procedure (Session 2)—The procedure was the same as before except that all groups were exposed to the memory prime 13 days after the demonstration session—1 day before the imitation test. One reactivation group was identical to the 2-s puppet exposure group in Experiment 1. The second reactivation group was exposed to the puppet for 10 s. The third reactivation group viewed a 30-s demonstration³ of the modeling event. The experimenter only reactivation group was identical to its counterpart in Experiment 1. Finally, the fifth reactivation group was exposed to the experimenter only while sitting on the same floor mat that had been present during all sessions⁴.

Results

Test scores were calculated as before by summing the number of each infant's target actions. One observer scored all of the videotapes; a second observer, who was blind to infants' group assignments, independently scored 21% of them. The interobserver reliability was 90% ($kappa = .8$). When the two raters differed, the primary rater's score was assigned.

A one-way ANOVA was conducted over the mean imitation test scores of the five reactivation groups in Experiment 2, the original forgetting control group and reactivation control group from Experiment 1, and the pooled baseline control group. The ANOVA indicated that the mean test scores of the eight groups differed, $F(7, 64) = 4.55, p < .001, \eta_p^2 = .33$. Post hoc tests (Fisher's LSD, $p < .05$) revealed that the mean imitation scores of the 30-s demonstration and 10-s puppet reactivation groups were higher than that of the forgetting and reactivation control groups, but the imitation test scores of the remaining experimental groups were not.

To determine if any reactivation group had exhibited significant imitation during the 14-day test, Dunnett's t tests ($p < .05$) were used to compare the test score of each group with the baserate (0.13) provided by the pooled baseline control group. These analyses revealed that the mean imitation scores of the 30-s demonstration group, the 10-s puppet reactivation group, and the experimenter only-floor mat reactivation group were each higher than the mean test score of the pooled baseline control group. However, the mean imitation score of the 2-s puppet reactivation group was not, nor was the mean imitation score of the experimenter only reactivation group (see Figure 2).

These analyses provide an answer to the primary research question in Experiment 2: Does the recovery of the forgotten memory of a modeled event require more or stronger reactivation cues after a longer delay? The answer is “yes”. Consistent with operant work

³Barr et al. (1996) found a 30-s demonstration is sufficient for immediate, but not 24-hr, imitation at 6 months of age.

⁴Six-month-olds also encode the features of the physical environment in which the target actions are modeled, including a colorful floor mat (Learmonth et al., 2004).

with young infants (Joh et al., 2002), the minimum effective duration of a reactivation treatment is affected by when the prime occurs in relation to when the memory was forgotten. Longer retention intervals require longer exposure to the reactivation stimulus and/or additional retrieval cues for the prime to be effective. When the memory of the target actions had been forgotten for only 1 week, a 2-s exposure to the puppet or visit from the experimenter alone were sufficient to recover it. However, when the memory had been forgotten for 2 weeks, a 10-s exposure to the puppet or visit from the experimenter with a distinctive contextual cue (i.e., floor mat) was necessary to alleviate forgetting.

General Discussion

The present study demonstrates that the general principles of reactivation are independent of the content of the memory being reactivated and whether infants encoded the original event via conditioning or imitation. The necessary and sufficient conditions for memory reactivation are directly related to memory accessibility. One week after forgetting the modeled actions, exposure to any component of the original event reactivated 6-month-olds' imitation memory; however, 2 weeks after forgetting, two of the same components failed to alleviate forgetting. Increasing the number of retrieval cues facilitated memory retrieval after a longer retention interval. Reactivation requires no special account: Forgetting and failures to alleviate it are often problems of memory retrieval. The present results are predicted by well-established principles of memory and cognition.

The findings of this study are consistent with Underwood's (1969) model of memory as a collection of attributes that are noticed about an event when it occurs. Only attributes that are represented in the original memory can cue its retrieval—familiar cues that were not part of the original event cannot (as demonstrated here by the experimenter specificity control group). Hasher and Griffin (1978) argued that these memory attributes are independent and forgotten at different rates, thus becoming differentially accessible to retrieval over time. Previously, their assertion was documented in studies using conditioning paradigms with infants (Bhatt & Rovee-Collier, 1996; Borovsky & Rovee-Collier, 1990; Riccio et al., 1984). Presently, data from Experiment 2 confirmed their proposal as well. Some of the same memory attributes that were effective reactivation cues in Experiment 1 were forgotten faster than others and were no longer effective reactivation cues after the longer retention interval in Experiment 2.

Hasher and Zacks (1979) proposed that memory processes are either automatic or effortful. Any attribute that is noticed when an event occurs enters long-term memory automatically and without awareness. The same automatic process occurs during reactivation. Jacoby (1983) viewed reactivation in terms of an automatic perceptual process that enhances the salience of retrieval cues for the whole prior processing episode. Only if these retrieval cues make veridical contact with the memory attributes that were perceptually processed and represented in the memory of the original event will they retrieve it. In short, the rules of automatic processing of memory attributes, as explicated above, are invariant.

Spear (1978) proposed that memory reactivation increases the accessibility of the prior memory. He argued that memories that have been forgotten longer are less accessible, hence

more difficult to retrieve, and require a longer exposure duration or a greater number of retrieval cues. His proposal essentially reflects Hasher and Griffin's conclusion that memory attributes are forgotten and retrieved at different rates. Increasing the difficulty of memory retrieval by doubling the retention interval yielded data consistent with this conclusion (see also Hildreth & Hill, 2003). This conclusion is also consistent with findings from operant studies with 3- and 6-month-olds that the minimum duration of an effective reactivation treatment increases as the time since forgetting increases (DeFrancisco & Rovee-Collier, 2008; Joh et al., 2002; Hsu et al., 2005; Sweeney & Rovee-Collier, 2001). These data point to the inevitable conclusion that forgetting is often a retrieval failure.

The operant conditioning work on minimum duration priming has revealed several principles of memory reactivation that have yet to be tested with imitation paradigms. First, the minimum duration of an effective prime for an operant memory decreases sharply between 3 and 12 months of age (Hsu et al., 2005). However, prior reactivation treatments potentially reduce the minimum duration of subsequent primes. For 3-month-olds who received a prior prime, the minimum duration of an effective second prime is the same as that of 12-month-olds who have been primed only once (Bearce & Rovee-Collier, 2006). Additional operant work has revealed that memory reactivation is not an all-or-none phenomenon (Hsu et al., 2005; Sweeney & Rovee-Collier, 2001); the minimum duration prime does not appear to always reactivate the full complement of forgotten memory attributes. For instance, the persistence of the reactivated operant memory in 3- to 12-month-olds is approximately half as long following a minimum duration prime as compared to a full-length prime (Hsu et al., 2005).

Systematic analysis of reactivation using an imitation paradigm is critical to determining which of the aforementioned properties of minimum duration primes are universal to infant memory. Because of limits in manual dexterity, 6 months is the youngest age at which object-based imitation tasks are appropriate. However, the puppet imitation task is appropriate for infants between 6 and 24 months of age (Barr et al., 1996), overlapping the developmental span of operant work. To determine the persistence of a reactivated imitation memory, it is also important to test older infants because 6-month-olds remember the modeled actions for only 1 day (but see Barr et al., 2005).

We found that 1 week after 6-month-olds forgot the modeled actions, exposure to the experimenter alone was an effective reminder. Future work is necessary to determine the precise duration of exposure to the experimenter alone that would be sufficient to retrieve infants' forgotten memories. We hypothesize that these findings would parallel operant findings (Hsu et al., 2005), with the minimum duration decreasing as a function of age. Likewise, we included an experimenter only group that was trained, primed, and tested with a distinctive proximal context (i.e., floor mat as per Learmonth et al., 2004) in Experiment 2. Although this group exhibited some evidence of remembering the modeled actions (i.e., performance was significantly higher than baseline; four out of six infants imitated at least one action), group performance was not significantly higher than the forgetting and reactivation control groups. Without the distinctive proximal contextual cues, a 10-s, but not a 2-s, prime was sufficient to retrieve infants' forgotten memory of the modeled actions 2 weeks after forgetting. Additional imitation work is necessary to directly examine the impact

of contextual cues on the minimum duration of reactivation and determine whether contextual elements are less effective than other elements.

In the present study, we also ensured that 6-month-olds had encoded the target actions by providing them with the opportunity to reproduce them at the time of encoding. Hayne et al. (2003) found that immediate imitation is a requisite for subsequent reactivation of the forgotten memory at 18 months of age. Although it is highly likely that similar encoding conditions are also requisites for memory reactivation in younger infants, additional research is necessary to examine this possibility as ontogenetic change in selective attention is often linked with exuberant learning during early infancy that is not exhibited in older infants (see Rovee-Collier & Giles, 2010).

A challenge for memory researchers is to determine the extent to which a prior memory that has not been expressed behaviorally is inaccessible. That is, if a prior memory is not retrieved during the test, then it is at behavioral zero; when responding is at baseline, the important question is how far below zero is the latent memory. If successful retrieval increases the accessibility of the prior memory, then the minimum duration of exposure to a retrieval cue that leads to an above-zero behavioral expression on the retention test is a reliable index of the extent to which it was subzero before the reactivation treatment. This conclusion is theoretically important. For example, if some latent memories are further below zero, then a longer minimum exposure duration will be necessary to return them to an active (above zero) state as was the case when the retention interval was extended from 7 to 14 days in the present study (see also Joh et al., 2002). Likewise, subzero memories at all ages, regardless of content, are equally inaccessible if they require the same minimum duration of exposure to a retrieval cue in order to be behaviorally expressed (see also Hsu et al., 2005). Thus, regardless of paradigm, the minimum duration of reactivation also provides a measure of memory accessibility. In the future, animal research on the neural markers of a memory trace (see Li et al., 2014, for review) might provide an additional index of memory accessibility.

In sum, the principles of reactivation are the same regardless of memory content, whether the processing episode involved conditioning or imitation, participant age, and retrieval delay. Reactivation is an automatic, non-effortful, perceptual process that enhances the salience of components of a prior processing episode when presented after the original episode has been forgotten. Reactivation is critically dependent on the number of reactivation cues presented and the duration of exposure to those cues. The present results were predicted by well-established principles of memory and cognition. No special new accounts of memory reactivation are necessary to explain it. Forgetting is often simply a retrieval failure (Spear, 1971), as is the inefficacy of a reactivation cue. Finally, memories that are not behaviorally expressed during a retention test require a longer minimum exposure to be activated in the future. The minimum duration of exposure to a latent memory to return it to an active state is a reliable index of its inaccessibility; as such, it takes on new theoretical significance.

Acknowledgments

This research was funded by an NIH grant MH32307-37 to CRC. We thank Lynn Hasher for providing her reprints and Breege Pfenninger, who provided technical assistance, typed, and made critical suggestions to the manuscript. Finally, we thank of our participants and their families for their time and interest in our work.

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Figure 1.
The two hand puppets (a yellow duck, a black-and-white cow) used in both experiments.
Puppets were counterbalanced within groups.

Figure 2.

Experiments 1 and 2. (*left panel*) The mean 7-day imitation test score of four reactivation groups (Experiment 1). (*center panel*) The mean 14-day imitation test score of five reactivation groups (Experiment 2). (*right panel*) The mean test score of two standard control groups and an experimenter specificity control group. The dashed line indicates the baserate of the pooled baseline control group. Asterisks indicate that an individual reactivation group had a mean test score that was significantly higher than the baserate. Vertical bars indicate +1 SE.