Published in final edited form as:

Infant Behav Dev. 2011 April ; 34(2): 327–338. doi:10.1016/j.infbeh.2011.02.004.

Infant Long-Term Memory for Associations Formed during Mere Exposure

Amy Giles and Carolyn Rovee-Collier

Rutgers--The State University of New Jersey

Abstract

We previously found that young infants spontaneously associate stimuli that they merely see together. Using a sensory preconditioning paradigm with 6- and 9-month-olds, we asked how long such associations remain latent before being forgotten and what exposure conditions affect their persistence. Groups were preexposed to two puppets for 1 hr/day for 2 days, 1 hr on 1 day, or 1 hr on 1 day in two sessions; 1 to 27 days later, target actions were modeled on one puppet, and infants were tested with the other puppet 1 day later. The longest delay after which infants imitated the actions on the other puppet defined how long they remembered the association. The data revealed that the preexposure regimen determined retention. Regardless of exposure time, both ages remembered the association longer after two sessions, and younger infants remembered longer than older infants--for 4 weeks--after two 30-min sessions on 1 day.

Keywords

association; deferred imitation; human infants; long-term memory; stimulus preexposure; sensory preconditioning; session duration; session number; temporal contiguity; transfer test

1.1 Introduction

Since the time of Aristotle, associations have been a cornerstone of major theories of learning and memory. According to Aristotle, associations were formed between temporally contiguous events—a principle that has withstood the passage of time. Because associations are unobservable or latent, however, behavioral scientists developed indirect methods to study them. The sensory preconditioning (SPC) paradigm was introduced by Brogden (1939) to assess association formation in animals. It consists of three phases.

In Phase 1, a paired experimental group is simultaneously preexposed to two neutral stimuli ($S1 + S2$), and an unpaired control group is preexposed to the same stimuli equally long but separately. For both groups, Phases 2 and 3 are identical. In Phase 2, subjects are trained to produce a distinctive response to one of the stimuli ($S1 \rightarrow R1$), and in Phase 3, they are given a transfer test with the untrained stimulus ($S2 \rightarrow ?$). If the paired experimental group produces the learned response to the untrained stimulus ($S2 \rightarrow R1$), but the unpaired control group does not, then it can be inferred that an association was formed between $S1$ and $S2$.

Address correspondence to: Carolyn Rovee-Collier, 87 Pine Hill Rd., Stockton, NJ 08559-1112 USA, Fax: (732) 445-2263, Phone: (908) 996-2291, rovee@rci.rutgers.edu. Address questions or correspondence to Amy Bullman Giles (bullman@rci.rutgers.edu).

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

when they were initially paired. The association later enabled the learned response to transfer from one stimulus to the other.

Researchers have long believed that very young human infants were incapable of associating stimuli or events that they merely saw together, with no explicit reinforcement for doing so. Recent studies, however, have demonstrated that this belief is incorrect (for reviews, see Rovee-Collier and Cuevas, 2009, and Rovee-Collier and Giles, 2009). In fact, very young infants, both human and nonhuman, are particularly adept at associating two stimuli or events that occur simultaneously.

Boller (1997) was the first to adapt the SPC paradigm for use with human infants. She preexposed 6-month-olds to two distinctive cloth liners (i.e., contexts) that were either paired or unpaired. Later, she trained them to kick to move a mobile in one context and then tested their retention with the training mobile in the other context 1 day later. Although 6-month-olds fail to exhibit retention if their training and test contexts differ (Borovsky and Rovee-Collier, 1990), Boller found that the paired preexposure group exhibited significant retention in the untrained context, but the unpaired preexposure group still did not. She concluded that the paired group had associated the two contexts when they were preexposed together in Phase 1 and that the association had mediated the transfer of learned responding from one context to the other during the retention test.

Barr, Marrott, and Rovee-Collier (2003) adapted Boller's basic procedure to examine SPC using cues instead of contexts, a modeling event instead of operant conditioning, and a deferred imitation recall test instead of a conditioning recognition test. They preexposed 6-month-olds to two hand puppets (S1, S2) that were either paired (the experimental group) or unpaired (the control group). Later, they modeled a series of target actions on one of the puppets (S1) and gave infants a deferred imitation transfer test with the other puppet (S2) 1 day later. An age-matched baseline control group that had seen neither the puppets nor the modeling event was tested with S2. This group provided the baserate at which 6-month-olds spontaneously perform the target actions.

As expected, the paired preexposure group imitated the modeled actions on S2, but the unpaired control group did not, confirming that the paired group had associated the two puppets in Phase 1. Barr et al. (2003) also tested another paired preexposure group with a novel puppet (S3) to assess the specificity of the association. This group failed to imitate the modeled actions on S3, confirming that the association was specific to the puppets that were paired in Phase 1.

Young infants are notorious for their rapid forgetting of associations that have been explicitly reinforced, and the younger they are, the more rapidly they forget (Hartshorn, Rovee-Collier, Gerhardstein, Bhatt, Wondoloski, Klein, Gilch, Wurtzel, and Campos-de-Carvalho, 1998). How long young infants can remember associations that were formed during mere exposure, without being explicitly reinforced, however, is unknown. Because young infants spend so much of their waking time visually examining their surround, especially before they are able to locomote, it seems likely that a large portion of what they learn during this time results from merely noticing co-occurring stimuli or events rather than from explicitly and repeatedly being reinforced for performing a particular response. An important question, then, becomes, —How long can young infants' associations that are formed spontaneously, by contiguity, remain latent yet later be retrieved and used?

Because new associations can be linked with both existing associations (Cuevas, Rovee-Collier, and Learmonth, 2006; Townsend, 2007) and new events (Barr, Vieira, and Rovee-Collier, 2001, 2002), the answer to this question would define the period during which a spontaneously formed association could be incorporated into the infant's expanding network

of associations. Further, even though a particular association might not be directly expressed, it may link other concepts that are (Townsend, 2007). Defining this “window of opportunity” at 6 and 9 months of age, when young infants are quite adept at forming simultaneous associations in the SPC paradigm (Cuevas, 2009), could offer new insight into how the early knowledge base is formed and expanded. The present study was designed to answer this question.

All experiments used the SPC paradigm. In Experiment 1, 6- and 9-month-olds were preexposed to paired puppets for 1 hr on each of 2 consecutive days. In Experiment 2, the preexposure phase was reduced to 1 hr on 1 day, and experimental groups received either one continuous 1-hr preexposure period (Experiment 2a) or two discrete preexposure periods lasting 30 min each (Experiment 2b). In Experiment 3, the specificity of 6-month-olds’ memory of the association was assessed after the longest delays that they had successfully recalled it in Experiments 1 and 2.

1.2 Experiment 1: Two Daily 1-hr Preexposure Sessions

In an initial study, Reynolds, Learmonth, and Rovee-Collier (2005) had simultaneously preexposed 6-, 9-, and 12-month-olds to puppets S1 and S2 for 2 consecutive days (Phase 1), modeled the target actions 1, 7, 14, or 21 days later on S1 (Phase 2), and tested infants with S2 1 day later (Phase 3). They expected that older infants would remember the association longer, but this did not happen. Although 6- and 9-month-olds imitated the actions on S2 after 14 but not 21 days, 12-month-olds failed to imitate on S2 after any delay—long or short. They concluded that 12-month-olds had not formed the S1–S2 association in the first place—a conclusion that has been confirmed (Cuevas, 2009; Muentener, 2004).

Experiment 1 was designed to repeat the preceding study with 6- and 9-month olds with two major changes: A precise imitation response period was instituted, and the preexposure time was confined to a continuous period instead of being accumulated throughout the day. Independent groups at each age were simultaneously preexposed to puppets S1 and S2 for 1 hr on each of 2 consecutive days (Phase 1). After a designated delay had elapsed, the target actions were modeled on S1 (Phase 2), and infants received a deferred imitation transfer test with S2 (Phase 3) 24 hr later. Imitating the modeled actions on S2 would be taken as evidence that infants had not only formed the S1–S2 association in Phase 1 but also still remembered it in Phase 3, despite the intervening delay.

1.2.1 Method

Participants—The final sample consisted of 36 six-month-olds (15 boys, 21 girls) with a mean age of 191.1 days ($SD = 8.6$) and 27 nine-month-olds (14 boys, 13 girls) with a mean age of 277.6 days ($SD = 5.3$) who were recruited from public birth announcements, commercial mailing lists, and by word of mouth. Infants were assigned to groups ($n = 9$) as they became available for study. They were African American ($n = 1$), Asian ($n = 5$), Caucasian ($n = 47$), Hispanic ($n = 2$), and of mixed race ($n = 8$). Their parents’ mean educational attainment was 15.1 years ($SD = 0.7$) at 6 months and 15.8 years ($SD = 0.6$) at 9 months, and their mean socioeconomic index (SEI¹; Nakao and Treas, 1992) was 69.6 ($SD = 14.2$) and 56.8 ($SD = 19.9$) at each age, respectively. Testing was discontinued on additional infants because of crying ($n = 2$), refusal to touch the puppet ($n = 5$), caregiver interference ($n = 7$), or videotape failure ($n = 7$).

¹In 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.

Stimuli—Two hand puppets, randomly drawn for each infant from a pool of six hand puppets (a pink mouse, a gray rabbit, a black-and-white cow, a yellow duck, a pink rabbit, and a gray mouse), were used in all experiments. Infants do not spontaneously generalize between any of these puppets before 18 months of age (Hayne, MacDonald, and Barr, 1997; Learmonth, Lamberth, and Rovee-Collier, 2004, 2005). The puppets were constructed for our laboratory and are not commercially available. They were 30 cm tall and made of soft, acrylic fur. A removable felt mitten (8 cm × 9 cm) in a matching color covered each puppet's right hand. A jingle bell was pinned inside the mitten during the demonstration but was removed during the test. Puppets were preexposed on a two-post wooden stand. A camcorder on a tripod was used to videotape all demonstration and test sessions for later scoring.

Procedure—Infants were studied in their homes at a time of day when they were likely to be playful. This time varied across infants but remained fairly constant for all sessions of a given infant. All sessions with the same infant took place in the same room. The SPC procedure was the same as that used by Barr et al. (2003).

Phase 1: Preexposure to S1+S2 (Association Formation)—Infants were simultaneously exposed to two puppets (S1, S2) for 1 hr on each of 2 consecutive days by their caregiver. The puppets were displayed side-by-side on a two-post stand in the infant's full view but out of the infant's reach. The caregiver was encouraged to schedule the preexposure while the infant was restrained in a high chair. During the preexposure period, the infant was free to eat a meal or snacks and/or play with toys; the caregiver could interact freely with the infant but could not to direct the infant's attention to the puppets. At the end of each preexposure period, the caregiver removed the puppets and put them out of sight in a bag provided by the experimenter.

To maintain caregivers' personal involvement and interest, the experimenter gave them a diary in which to record the location, the date and time that an exposure began and ended, and the infant's activities throughout the preexposure period. An infant whose caregiver did not return a completed form was excluded from the final sample.

Phase 2: Modeling the Target Actions (R1) on S1—Phase 2 occurred 6 or more days after Phase 1. Prior to the demonstration, the experimenter interacted with the infant for 5 min or until she elicited a smile, and the infant was then seated on the caregiver's knees. The experimenter knelt in front of the infant and held S1 at the infant's eye level, approximately 80 cm from the infant's chest (out of the infant's reach). The experimenter removed the mitten from the puppet's right hand, shook it three times to ring the jingle bell that was pinned inside, and replaced it on the puppet's hand. This sequence lasted 10 s and was repeated five more times at 6 months for a total of 60 s and two more times at 9 months for a total of 30 s. These modeling durations yield 24-hr retention at 6 and 9 months of age (Barr, Dowden, and Hayne, 1996; Learmonth et al., 2005).

Phase 3: Deferred Imitation Transfer Test with S2—Phase 3 occurred 24 hr after Phase 2. During the transfer test, the experimenter held S2 within the infant's reach, approximately 30 cm in front of the infant's chest (see Figure 1b). Infants were allowed 90 s (9-month-olds) or 120 s (6-month-olds) to imitate the modeled actions from the time they first touched the puppet.

The independent variable was the time that elapsed between Phase 1 and Phase 2. Retention of the S1–S2 association over that interval was measured 24 hr later during the deferred imitation transfer test with S2 (Phase 3). The experimental strategy was to begin testing 7 days after the final preexposure session and thereafter to either double or halve the Phase 1–

Phase 2 interval for each succeeding test group, depending on whether the current test group exhibited retention or forgetting, respectively, 24 hr later. Testing was discontinued after the longest S1–S2 interval that yielded 24-hr retention was found. This strategy yielded four independent test groups at 6 months (Phase 1–Phase 2 delays = 6, 9, 13, and 15 days) and three independent test groups at 9 months (Phase 1–Phase 2 delays = 6, 13, and 17 days). Two age-matched pooled baseline control groups² provided the baserate at which 6-month-olds ($M = 0.13$, $SE = 0.05$) and 9-month-olds ($M = 0.25$, $SE = 0.12$) spontaneously perform the target actions.

Although the Phase 1–Phase 2 interval was the independent variable, retention was not expressed until the Phase-3 transfer test 1 day later. Therefore, all data are reported and discussed in terms of the Phase 1–Phase 3 interval. (In Experiment 1, for example, data are reported for test delays of 7, 10, 14, and 16 days at 6 months of age and 7, 14, and 18 days at 9 months of age.)

1.2.2 Results and Discussion

An imitation score was calculated by summing the total number of target actions (remove the mitten, shake the mitten, attempt to replace the mitten on the puppet's right hand) that each infant produced in the response period (range = 0–3). (Infants younger than 18 months rarely attempt to replace the mitten.) One observer coded 100% of the videotapes, and a second observer, who was blind to infants' test groups, independently coded 20% of the videotapes. Their interobserver reliability, based on the number of exact agreements, was 96% ($kappa = .92$). When the two observers differed, the primary observer's score was assigned.

At each age, the mean imitation scores of the experimental test groups and the age-matched baseline control group were subjected to a one-way analysis of variance (ANOVA). Directional Dunnett's t tests were used to determine whether the mean imitation score of any experimental group significantly exceeded the mean test score of the age-matched baseline control group. This test controls for Type I errors across multiple comparisons with a control group. The alpha level was set at $p < .05$ for both analyses.

At 6 months, the ANOVA indicated that the mean imitation scores of the four experimental groups and baseline control group differed, $F(4, 65) = 6.80$, $p < .001$. The Dunnett's t tests revealed that the experimental groups had higher mean test scores than the baseline control group after 7 and 10 days but not 14 or 16 days. At 9 months, the ANOVA indicated that the mean imitation scores of the three experimental groups and baseline control group also differed, $F(3, 50) = 5.67$, $p < .001$. The Dunnett's t tests revealed that the experimental groups had higher mean test scores than the baseline control group after 7 and 14 days but not 18 days (see Figure 2).

These findings reveal that very young infants can retrieve and express an association that had continued to remain latent for a substantial period of time after they formed it. The S1–S2 association that infants formed when they were merely preexposed to two puppets simultaneously for 1 hr on each of 2 days was remembered for 10 days at 6 months of age

²At 6 months, the pooled baseline control group contained 45 infants (19 boys, 26 girls) with a mean age of 195.7 days ($SD = 8.30$). 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 ($SD = 1.20$) and mean SEI was 72.26 ($SD = 18.89$). At 9 months, the pooled baseline control group contained 24 infants (14 boys, 10 girls) with a mean age of 280 days ($SD = 6.74$). They were Caucasian ($n = 20$), Asian ($n = 2$), Hispanic ($n = 1$), and of mixed race ($n = 1$). Their parents' mean educational attainment was 15.9 years ($SD = .40$) and mean SEI was 74.89 ($SD = 12.03$). All infants had participated in spontaneous baseline control groups in all of our previous deferred imitation studies with the same test procedure and stimuli (Barr et al., 2001, 2002, 2003, 2005; Barr, Muentener, Garcia, Fujimoto, and Chavez, 2007; Campanella and Rovee-Collier, 2005; Learmonth et al., 2004).

and 14 days at 9 months of age. The length of the interval for which infants remembered an association that they had formed by merely seeing the puppets together was unexpected: Infants of these ages who see a series of target actions modeled on a puppet multiple times remember them for only 1 day (Barr et al., 1996, 2001; Learmonth et al., 2004).

It seemed likely that infants' relatively long retention of the association was due to the fact that they had received two preexposure sessions 24 hr apart. We previously found, for example, that giving 6-month-olds a second (partial) demonstration session 24 hr after the first one increased their retention of the target actions from 1 to 7 days (Barr, Rovee-Collier, and Campanella, 2005). Although the number of demonstration sessions affects how long infants remember a modeling event, the effect of the number of preexposure sessions on how long infants remember an association formed in the SPC paradigm is unknown. In Experiment 2, therefore, we answered this question.

1.3 Experiment 2a: A Single 1-hr Preexposure Session

In Experiment 1, infants were simultaneously preexposed to S1 and S2 for 1 hr on 2 consecutive days. Barr et al. (2005) found that doubling the number of sessions in which the target actions were modeled on a puppet extended infants' deferred imitation from 1 to 7 days at 6 months of age. Similarly, Hsu (in press; Hsu and Rovee-Collier, 2009) found that 6- and 9-month-olds remember an operant contingency twice as long after two sessions as after one. In Experiment 2a, therefore, we determined how long infants could remember the S1–S2 association after only one 1-hr preexposure session instead of two.

1.3.1 Method

Participants—The final sample consisted of 27 six-month-olds (10 boys, 17 girls) with a mean age of 187.8 days ($SD = 4.9$) and 18 nine-month-olds (11 boys, 7 girls) with a mean age of 281.7 days ($SD = 5.5$). Infants were recruited as before and assigned to groups ($n = 9$) as they became available for study. They were African American ($n = 6$), Asian ($n = 2$), Caucasian ($n = 32$), Hispanic ($n = 2$), of mixed race ($n = 3$), or were not reported ($n = 2$). Their parents' mean educational attainment was 15.6 years ($SD = 0.8$) at 6 months and 15.7 years ($SD = 1.0$) at 9 months, and their mean SEI was 61.6 ($SD = 19.1$) and 63.7 ($SD = 15.8$) at each age, respectively. Testing was discontinued on additional infants because of refusal to touch the puppet ($n = 3$), caregiver interference ($n = 3$), or videotape failure ($n = 5$).

Procedure—The procedure was the same as before except for the timing of the preexposure. Our experimental strategy was to begin testing 2 days after the preexposure session and increase the test delay to 3 days and, if infants remembered, to 7 days (these test delays corresponded to Phase 1–Phase 2 intervals of 1, 2, and 6 days, respectively). This strategy yielded three independent test groups at 6 months who were tested after delays of 2, 3, and 7 days and two independent test groups at 9 months who were tested after delays of 2 and 3 days. The two age-matched baseline control groups were also included in the analysis.

1.3.2 Results and Discussion

At 6 months, the ANOVA indicated that the mean imitation scores of the three experimental groups and baseline control group differed, $F(3, 56) = 7.70, p < .01$. The Dunnett's t tests revealed that the experimental groups had higher mean test scores than the baseline control group after 2 and 3 days but not 7 days. At 9 months, the ANOVA indicated that the mean imitation scores of the two experimental groups and baseline control group also differed, $F(2, 41) = 4.98, p < .001$. The Dunnett's t tests revealed that the experimental group had a higher mean test score than the baseline control group after a test delay of 2 but not 3 days (see Figure 3).

These results revealed that although the S1–S2 association could be formed in one 1-hr preexposure session, infants remembered it less than half as long as when they had received two 1-hr sessions on consecutive days in Experiment 1. The basis of their poorer retention, however, was unclear: In Experiment 2a, the variables of total preexposure time and total number of sessions were confounded. One possibility is that infants' poorer retention in Experiment 2a resulted from halving the preexposure duration; alternatively, it could have resulted from halving the number of preexposure sessions. Individuals given two widely separated preexposure sessions are afforded an opportunity to retrieve the inactive memory of the association at the outset of the second session—an opportunity obviously not provided by a single session.

Experiment 2b, therefore, was designed to deconfound the effects of total preexposure time and number of preexposure sessions on retention of the S1–S2 association.

1.4 Experiment 2b: Two 30-min Preexposure Sessions on 1 Day

In Experiment 1, infants received two 1-hr preexposure sessions on consecutive days, whereas in Experiment 2a, they had received one 1-hr preexposure session on 1 day. The briefer retention of the S1–S2 association in Experiment 2a could have resulted from a decrease in session number, preexposure time, or both. In Experiment 2b, therefore, we gave infants two preexposure sessions, as in Experiment 1, but maintained a total preexposure time of 1 hr, as in Experiment 2a. We set the minimum interval between the two preexposure sessions at 5 hr so that no residual activation produced by preexposure to the paired puppets during the first session would be present when the second preexposure session occurred. In this way, we ensured that the S1–S2 association would be retrieved (activated) from long-term memory (Hall, 2003; Lee, Gomberg, Cuevas, Hsu, and Rovee-Collier, 2008).

1.4.1 Method

Participants—The final sample consisted of 36 six-month-olds (18 boys, 18 girls) with a mean age of 187.0 days ($SD = 5.1$) and 36 nine-month-olds (24 boys, 12 girls) with a mean age of 280.0 days ($SD = 4.4$). Infants were recruited as before and assigned to groups ($n = 9$) as they became available for study. They were African-American ($n = 1$), Asian ($n = 6$), Caucasian ($n = 52$), Hispanic ($n = 4$), and of mixed race ($n = 7$). Their parents' mean educational attainment was 15.4 years ($SD = 1.5$) at 6 months and 15.4 years ($SD = 1.3$) at 9 months, and their mean SEI was 69.4 ($SD = 21.9$) and 69.4 ($SD = 17.9$) at each age, respectively. Testing was discontinued on additional infants because of refusal to touch the puppet ($n = 2$), caregiver interference ($n = 3$), or videotape failure ($n = 2$).

Procedure—The procedure was the same as in Experiment 2a with the exception that infants received two 30-min preexposure sessions that were separated by a minimum of 5 hr. Again, our experimental strategy was to begin testing 7 days after the final preexposure session and thereafter to either increase or decrease the Phase 1–Phase 2 interval for a succeeding test group, depending on whether the current group exhibited retention or forgetting, respectively, 24 hr later. This strategy yielded four independent experimental groups that were tested after delays of 7, 14, 21, or 28 days (i.e., Phase 1–Phase 2 intervals of 6, 13, 20, or 27 days, respectively) at both 6 and 9 months of age.

1.4.2 Results and Discussion

At 6 months, the ANOVA indicated that the mean imitation scores of the four experimental groups and baseline control group differed, $F(4, 64) = 10.70$, $p < .001$. Dunnett's t tests revealed that the experimental groups had higher mean test scores than the baseline control

group after all test delays--7, 14, 21, and 28 days. At 9 months, the ANOVA indicated that the mean imitation scores of the two experimental groups and baseline control group also differed, $F(4, 59) = 3.19, p < .025$. Dunnett's t tests revealed that the experimental groups had higher mean test scores than the baseline control group after 7 and 14 days but not 21 or 28 days (see Figure 4).

Finally, a Univariate Analysis of Variance was performed over the mean imitation scores across the preceding experiments for the factors of Group (i.e., preexposure regimen), Age, and Delay to answer three basic questions: (1) Did the preexposure regimen (or "Group") significantly affect infants' mean imitation test scores, and did this effect vary with Age or Delay? (2) Did either Delay or Age significantly affect the mean imitation scores? and (3) Did Group, Age, and Delay interact to significantly affect infants' mean imitation scores? The answers were straightforward. There were only significant main effects of Group, $F(2, 233) = 3.71, p < .026$, and Delay, $F(8, 233) = 2.85, p < .005$. The main effect of Age, $F(1, 233) < 1$, was not significant, and there were no significant interactions (Group $\times$ Age: $F(1, 233) = 3.24, p < .073$; Group $\times$ Delay: $F(1, 233) < 1$; Age $\times$ Delay: $F(4, 233) < 1$; Age $\times$ Group $\times$ Delay: $F(1, 233) < 1$).

Although total preexposure time was identical in Experiments 2a and 2b, the S1–S2 association was remembered at least *nine times longer* in Experiment 2b at 6 months (28 days versus 3 days) and *seven times longer* at 9 months (14 days versus 2 days). At 9 months, however, the absolute duration of retention in Experiments 1 and 2b was identical, even though the total duration of preexposure was twice as long in Experiment 1 (two 1-hr preexposure sessions) than in Experiment 2b (two 30-min preexposure sessions). This result provides clear evidence that the *number of sessions* outweighs the retention benefit of longer exposure time and is the critical determinant of how long infants remember an association that they spontaneously formed between two temporally contiguous, real-world stimuli. We attribute infants' longer retention after two sessions than after one session of equal duration to their opportunity to retrieve the memory of the first preexposure session at the outset of the second one.

Finally, we observe that 6-month-olds who are explicitly reinforced for lever pressing to move a toy train in two 8-min sessions over 2 consecutive days can remember that association only half as long (14 days; e.g., Hartshorn et al., 1998) as they presently remembered an S1–S2 association that they formed spontaneously during mere exposure to two, temporally contiguous stimuli. This result reveals that relatively long retention in young infants is not unique to operant conditioning studies that entail an active motor response and reward.

1.5 Experiment 3: Specificity of the Memory for the Association at 6 Months

A final question that should be raised about memories of simultaneous associations formed during a mere exposure concerns their specificity. In operant studies, the memories of young infants are highly specific to the stimuli that were present during the original event shortly after training, but they become increasingly fuzzy after longer delays and result in generalization to novel test stimuli (Bhatt and Rovee-Collier, 1996; Borovsky and Rovee-Collier, 1990; Hartshorn et al., 1998; Rovee-Collier and Sullivan, 1980).

Experiment 3 was designed to determine if the memory of the association that infants formed between S1 and S2 in the preceding experiments remained specific to those puppets after longer test delays. Infants were tested with a novel puppet (S3) after the longest test delay that they had remembered the S1–S2 association in Experiment 1, Experiment 2a, and Experiment 2b. After these delays, infants are most likely to have forgotten the specific details of the associated puppet (S2) and generalize to a novel one. Because there were no

age differences between delays or groups in the preceding experiments and no generalization differences between these ages (Learmonth et al., 2005), only 6-month-olds were included in Experiment 3.

1.5.1 Method

Participants—The final sample consisted of twenty-seven 6-month-olds (15 boys, 12 girls) with a mean age of 186.7 days ($SD = 4.8$) who were recruited and assigned to groups ($n = 9$) as before. They were African American ($n = 2$), Asian ($n = 2$), Caucasian ($n = 19$), Hispanic ($n = 1$), of mixed race ($n = 2$), or were not reported ($n = 1$). Their parents' mean educational attainment was 13.4 years ($SD = 1.6$) and mean SEI was 56.9 ($SD = 9.3$). Testing was discontinued on additional infants for refusal to touch the puppet ($n = 1$) and parental interference ($n = 2$).

Procedure—Three groups were tested with a novel puppet (S3) after the longest delay that the corresponding group in each of the preceding experiments had exhibited significant imitation when tested with S2. Group 1 received the same preexposure regimen as infants in Experiment 1 (1 hr on 2 consecutive days) and was tested with S3 after 10 days; group 2 received the same preexposure regimen as infants in Experiment 2a (1 hr on 1 day) and was tested with S3 after 3 days; and group 3 received the same preexposure regimen as infants in Experiment 2b (two 30-min sessions on 1 day) and was tested with S3 after 21 days.³ Analyses included the three generalization groups that were tested with S3, their counterparts from Experiments 1, 2a, and 2b that were tested with S2, and the baseline control group.

1.5.2 Results and Discussion

A one-way ANOVA indicated that the mean test scores of group 1, its corresponding 10-day group from Experiment 1, and the baseline control group differed significantly, $F(2, 47) = 18.58, p < .001$. Dunnett's t tests indicated that the two experimental groups had higher mean test scores than the baseline control group. An identical ANOVA indicated that the mean test scores of group 2, its corresponding 3-day group from Experiment 2a, and the baseline control group also differed, $F(2, 47) = 16.16, p < .001$. Dunnett's t tests again indicated that the two experimental groups had higher mean test scores than the baseline control group. Finally, a one-way ANOVA indicated that the mean test scores of group 3, the corresponding 21-day group from Experiment 2b, and the baseline control group differed, $F(2, 47) = 22.32, p < .001$. As before, Dunnett's t tests indicated that the two experimental groups had higher mean test scores than the baseline control group.

These data reveal that infants' memory of the S1–S2 association, which is highly specific after 24 hr (Barr et al., 2003), is generalized after the longest delay that they still remember it, irrespective of the preexposure regimen. These results indicate that infants had forgotten the specific details of the puppet over time but still remembered its general features. Had they forgotten the association altogether, they would have discriminated the test puppet (S3) from the puppet (S1), on which the target actions were modeled 24 hr earlier, and failed to imitate on it, just as infants without an S1–S2 association (Barr et al., 2003) or who saw the demonstration puppet for the first time (Learmonth et al., 2004) do not imitate on a novel test puppet 24 hr later.

³The generalization group was tested after 21 days because the original 28-day test group had shown significant forgetting after that delay, and we wanted to ensure that an infant's failure to generalize after that delay would not be due to a failure to remember the association.

The finding that infants forget the specific details of a stimulus or event before they forget its general features has also been obtained in numerous studies of both SPC and operant learning (Barr et al., 2005; Bhatt and Rovee-Collier, 1996; Borovsky and Rovee-Collier, 1990; Campanella and Rovee-Collier, 2005; Hartshorn et al., 1998; Hitchcock and Rovee-Collier, 1996; Rovee-Collier and Sullivan, 1980) and is widely accepted as a general fact of memory that holds for individuals of all ages.

1.6. General Discussion

Research using an SPC paradigm with young infants has found that they form associations between two stimuli on the basis of contiguity, without being explicitly reinforced for doing so (for review, see Rovee-Collier and Giles, 2010). The maximum period for which these associations can remain latent before being retrieved and potentially expressed is unknown. This information is important because it describes the period during which these associations can enter into other new associations, offering insight into how the early knowledge base is formed and expanded. Barr, Rovee-Collier, and Learmonth (in press) found that new associations formed in this way can be linked with subsequent events. In addition, Cuevas et al. (2006) and Townsend (2007) found that new associations are linked with existing associations.

The present findings demonstrated that the duration for which a spontaneously formed association can remain latent without being forgotten was determined by the preexposure regimen in the initial phase of SPC. Here, after two 1-hr preexposure sessions, 6- and 9-month-old infants remembered the association for 10 and 14 days, respectively. After a single 1-hr preexposure session, infants of both ages remembered the association for only 2 and 3 days. After two 30-min preexposure sessions on 1 day, however, 6-month-olds remembered the association for 28 days, while 9-month-olds remembered it for only half as long--14 days--the same as when their two preexposure sessions were on consecutive days. The longevity of young infants' memory of an association that was formed spontaneously during mere simultaneous exposure to two real-world objects, particularly at 6 months of age, is at odds with the conclusion that infants' brains are too immature to encode and maintain memories over the long term until late in the first year of life (for review, see Bauer, 2009).

Why did two 30-min preexposure sessions afford such a huge retention benefit relative to one 60-min session at both ages, particularly when the total preexposure time was the same in both conditions? What retention advantage did the second session provide? The retention advantage apparently resulted from the retrieval opportunity that was afforded at the outset of the second session. Research with both human and nonhuman adults and infants, for example, has found that a memory is strengthened simply by retrieving it (Barr et al., in press; Bjork, 1988, 2001; Hsu and Rovee-Collier, 2009; Rovee-Collier, 1995; Schmidt and Bjork, 1992). Conceivably, this finding could lie at the heart of the well-known superiority of distributed relative to massed training (Cohen, 1985; Crowder, 1976; Leaton, 1976; Spear, 1978).

This account, however, raises an additional question: Why did 6-month-olds remember more than two times longer after two 30-min preexposure sessions on 1 day than after two 1-hr sessions on 2 consecutive days, yet 9-month-olds remembered for the same duration in both instances? Infants of all species usually remember longer when they are older (Hartshorn et al., 1998). In research on session spacing, younger infants also exhibit a greater relative retention benefit than older infants when their training sessions are most widely separated. Hsu (in press), for example, found that 3- and 6-month-olds remembered two to three times longer when the second training session was at the end of their respective forgetting

functions than at the beginning. In contrast, 9-month-olds exhibited no relative retention benefit from greater session spacing at all, and 12- to 18-month-olds' retention was actually poorer when their two training sessions were widely separated.

Considered jointly, these sets of data are consistent with evidence that young human infants undergo a special "period of exuberant learning" that ends late in the first year of life (Rovee-Collier and Giles, 2010). Younger infants' learning and memory ability is superior to that of older infants during this period, but their precocious ability disappears when the period ends. In light of the preceding data, it is not surprising that 9 months is the age at which this transition occurs (Cuevas, 2009).

Finally, although infants remembered the association for a surprisingly long time, what did they remember? The answer to this question was provided by 6-month-olds in Experiment 3, who generalized imitation to a novel test puppet after the longest interval that they remembered the association, regardless of preexposure regimen. Their data indicated that infants had forgotten the specific details of S2 over time but still remembered its general features. Had they forgotten the association altogether, they would have discriminated the test puppet (S3) from the puppet that was used during the demonstration 24 hr earlier (S1) and failed to imitate on it.

The present findings are at odds with the widely accepted assumption that very early in life, infants' learning is mediated by a primitive implicit memory system that supports the learning of only simple procedures, perceptual or motor skills, and habits that are established gradually by explicit reinforcement. The implicit memory system, however, does not accommodate either the variety and rapidity of young infants' learning or the duration for which they remember it. Rather, our findings support the ecological model of memory development (Spear, 1984), which has increasingly garnered support from research with animal and human infants (e.g., Barr et al., in press; Brookes, Slater, Quinn, Lewkowicz, Hayes, and Brown, 2001; Chen, Lariviere, Heyser, Spear, and Spear, 1991; Cheslock, Varlinskaya, High, and Spear, 2003; Cuevas, 2009; Delaunay-El Allam, Soussignan, Patris, Marlier, and Schaal, 2010; Hannon & Trehub, 2005; Hsu, in press; Pascalis, de Haan, and Nelson, 2002; Scott, Pascalis, and Nelson, 2007; Shionoya, Moriceau, Lunday, Miner, Roth, and Sullivan, 2006; Townsend, 2007; Werker and Lalonde, 1988; for reviews, see Rovee-Collier and Cuevas, 2009; Rovee-Collier and Giles, 2010).

According to the ecological model, the developmental period that is commonly thought to be dominated by the implicit memory system is actually an evolutionarily selected period in which the young of all species rapidly and nonselectively form numerous associations between temporally contiguous stimuli or events in their environment which, in turn, facilitate adaptation to the ecological challenges posed by each of their changing ecological niches. Because niches change more rapidly when infants are more immature and developing more rapidly, they must learn the relationships in each niche more rapidly too. Contrary to current thinking, immature infants learn *better* than older infants during this early period; after it ends, however, their special disposition for rapid and exuberant learning disappears. In both animal and human infants, this period of rapid learning ends at the same age that the explicit memory system presumably matures (Bauer, DeBoer, and Lukowski, 2007; Carver and Bauer, 2001; Carver, Bauer, Wiebe, Waters, and Nelson, 2003; Chen et al., 1991; Cuevas, 2009; Jones and Herbert, 2006; Richmond and Nelson, 2007; Spear, 1984).

The present findings reveal that during the period of exuberant learning, manipulations that increase the memory strength of associations provide a powerful benefit for early cognitive development. Expanding the interval in which a reoccurring association can be integrated or

associated with other event representations in the future offsets the otherwise rapid forgetting of very young infants and further expands their rapidly growing knowledge base. Transfer tasks in general, and the SPC paradigm in particular, offer an opportunity to observe what otherwise would remain the hidden learning of young infants.

Acknowledgments

This research was conducted by the first author as a master's thesis under the direction of the second author. It was supported by Grant No. MH32307 from the National Institute of Mental Health to Carolyn Rovee-Collier. We thank the members of the thesis committee, Louis Matzel and David Vicario, for suggestions that improved the final manuscript and Jennifer Bausmith for statistical assistance. Funding by NIMH does not constitute or imply endorsement of its content.

References

- Barr R, Dowden A, Hayne H. Developmental changes in deferred imitation by 6- to 24-month-old infants. *Infant Behavior & Development*. 1996; 19:159–170.
- Barr R, Marrott H, Rovee-Collier C. The role of sensory preconditioning in memory retrieval by preverbal infants. *Learning & Behavior*. 2003; 31:111–123. [PubMed: 12882370]
- Barr R, Rovee-Collier C, Campanella J. Retrieval protracts deferred imitation by 6-month-olds. *Infancy*. 2005; 7:263–283.
- Barr R, Rovee-Collier C, Learmonth AE. Potentiation of deferred imitation in young infants: The origin of the prior knowledge effect? *Memory & Cognition*. (in press).
- Barr R, Vieira A, Rovee-Collier C. Mediated imitation at 6 months of age: Remembering by association. *Journal of Experimental Child Psychology*. 2001; 79:229–252. [PubMed: 11394928]
- Barr R, Vieira A, Rovee-Collier C. Bidirectional priming in infants. *Memory & Cognition*. 2002; 30:246–255.
- Bauer, PJ. Learning and memory; Like a horse and carriage. In: Woodward, A.; Needham, A., editors. *Learning and the infant mind*. New York: Oxford University Press; 2009. p. 3-28.
- Bauer, PJ.; DeBoer, T.; Lukowski, AF. In the language of multiple memory systems, defining and describing developments in long-term explicit memory. In: Oakes, L.; Bauer, P., editors. *Short- and long-term memory in infancy and early childhood: Taking the first steps towards remembering*. New York: Oxford University Press; 2007. p. 240-270.
- Bhatt RS, Rovee-Collier C. Infants' forgetting of correlated attributes and object recognition. *Child Development*. 1996; 67:172–187. [PubMed: 8605826]
- Bjork, RA. Retrieval practice and the maintenance of knowledge. In: Gruneberg, M.; Morris, P.; Sykes, R., editors. *Practical aspects of memory: Current research and issues*. Chichester, UK: Wiley; 1988. p. 296-401.
- Bjork, RA. Recency and recovery in human memory. In: Roediger, HL., III; Nairne, JS.; Neath, I.; Surprenant, AM., editors. *The nature of remembering: Essays in honor of Robert G. Crowder*. Washington, D.C.: American Psychological Association; 2001. p. 211-232.
- Boller K. Preexposure effects on infant learning and memory. *Developmental Psychobiology*. 1997; 31:93–105. [PubMed: 9298635]
- Borovsky D, Rovee-Collier C. Contextual constraints on memory retrieval at six months. *Child Development*. 1990; 61:1569–1583. [PubMed: 2245747]
- Brogden WJ. Sensory pre-conditioning. *Journal of Experimental Psychology*. 1939; 25:323–332.
- Brookes H, Slater A, Quinn P, Lewkowicz D, Hayes & Brown E. Three-month-old infants learn arbitrary auditory–visual pairings between voices and faces. *Infant and Child Development*. 2001; 10:75–82.
- Campanella J, Rovee-Collier C. Latent learning and deferred imitation at 3 months. *Infancy*. 2005; 7:243–262.
- Carver LJ, Bauer PJ. The dawning of a past: The emergence of long-term explicit memory in infancy. *Journal of Experimental Psychology*. 2001; 130:726–745. [PubMed: 11757877]

- Carver LJ, Bauer PJ, Wiebe SA, Waters JM, Nelson CA. Developments in long-term explicit memory late in the first year of life: Behavioral and electrophysiological indices. *Psychological Science*. 2003; 14:629–635. [PubMed: 14629697]
- Chen W, Lariviere NA, Heyser CJ, Spear LP, Spear NE. Age-related differences in sensory conditioning in rats. *Developmental Psychobiology*. 1991; 24:307–325. [PubMed: 1752352]
- Cheslock SJ, Varlinskaya EI, High JM, Spear NE. Higher order conditioning in the newborn rat: Effects of temporal disparity imply infantile encoding of simultaneous events. *Infancy*. 2003; 4:157–176.
- Cohen, RL. On the generality of the laws of memory. In: Nilsson, L.-C.; Archer, T., editors. *Perspectives on learning and memory*. Hillsdale, NJ: Erlbaum; 1985. p. 247–277.
- Coppock WJ. Pre-extinction in sensory preconditioning. *Journal of Experimental Psychology*. 1958; 47:355–357.
- Crowder, RG. *Principles of learning and memory*. Hillsdale, NJ: Erlbaum; 1976.
- Cuevas, K. Unpublished doctoral dissertation. Department of Psychology, Rutgers University; New Brunswick, NJ: 2009. Transitions in the temporal parameters of sensory preconditioning during infancy.
- Cuevas, K.; Rovee-Collier, C.; Bullman, A. Timing shifts in sensory preconditioning over the first year. Paper presented at the meeting of the Eastern Psychological Association; Baltimore, MD. 2006 March.
- Cuevas K, Rovee-Collier C, Learmonth AE. Infants form associations between memory representations of stimuli that are absent. *Psychological Science*. 2006; 17:543–549. [PubMed: 16771806]
- Delaunay-El Allam M, Soussignan R, Patris B, Marlier L, Schaal B. Long-lasting memory for an odor acquired at the mother's breast. *Developmental Science*. 2010.1111/j.1467-7687.2009.00941
- Hall G. Learned changes in the sensitivity of stimulus representations: Associative and nonassociative mechanisms. *Quarterly Journal of Experimental Psychology*. 2003; 56B:43–55. [PubMed: 12623536]
- Hannon EE, Trehub SE. Tuning in to musical rhythms: Infants learn more readily than adults. *Proceedings of the National Academy of Sciences (USA)*. 2005; 102:12639–12643.
- Hartshorn K, Rovee-Collier C, Gerhardstein P, Bhatt RS, Wondoloski TL, Klein PJ, Gilch J, Wurtzel N, Campos-de-Carvalho M. The ontogeny of long-term memory over the first year-and-a-half of life. *Developmental Psychobiology*. 1998; 32:69–89. [PubMed: 9526683]
- Hayne H, MacDonald S, Barr R. Developmental changes in the specificity of memory over the second year of life. *Infant Behavior & Development*. 1997; 20:233–245.
- Hitchcock DFA, Rovee-Collier C. The effect of repeated reactivations on memory specificity in infancy. *Journal of Experimental Child Psychology*. 1996; 62:378–400. [PubMed: 8691119]
- Hsu VC. Time windows in retention over the first year-and-a-half of life: Spacing effects. *Developmental Psychobiology*. (in press).
- Hsu, VC.; Rovee-Collier, C. The time window construct in early memory development. In: Columbo, F., editor. *New directions in developmental psychobiology*. New York, NY: Nova Science Publishers; 2009. p. 1–22.
- Jones EJH, Herbert JS. Exploring memory in infancy: Deferred imitation and the development of declarative memory. *Infant and Child Development*. 2006; 15:195–205.
- Learmonth AE, Lamberth R, Rovee-Collier C. Generalization of deferred imitation in the first year of life. *Journal of Experimental Child Psychology*. 2004; 88:297–318. [PubMed: 15265678]
- Learmonth AE, Lamberth R, Rovee-Collier C. The social context of imitation in infancy. *Journal of Experimental Child Psychology*. 2005; 91:297–314. [PubMed: 16042966]
- Leaton RN. Long-term retention of the habituation of lick suppression and startle response produced by a single auditory stimulus. *Journal of Experimental Psychology: Animal Behavior Processes*. 1976; 2:248–259. [PubMed: 939952]
- Lee, S.; Gomberg, J.; Cuevas, K.; Hsu, VC.; Rovee-Collier, C. Retroactive interference measures encoding speed in multiple tasks at 6 months. Poster presented at the meeting of the International Society for Developmental Psychobiology; Washington, D.C. 2008 November.

- Muentener, P. Unpublished undergraduate honors thesis. Department of Psychology, Georgetown University; Washington, D.C: 2004. The role of sensory preconditioning in the associative learning of older infants.
- Nakao, K.; Treas, J. General Social Survey Methodological Reports No. 74. Chicago: NORC; 1992. The 1989 Socioeconomic Index of Occupations: Construction from the 1989 Occupational Prestige Scores.
- Pascalis O, de Haan M, Nelson CA. Is face processing species-specific during the first year of life? *Science*. 2002; 296:321–1323. [PubMed: 11951038]
- Reynolds, B.; Learmonth, AE.; Rovee-Collier, C. Retention of latent associations and deferred imitation in the second half-year of life. Paper presented at the meeting of the Eastern Psychological Association; Boston, MA. 2005 March.
- Richmond J, Nelson CA. Accounting for change in declarative memory: A cognitive neuroscience perspective. *Developmental Review*. 2007; 27:349–373. [PubMed: 18769510]
- Rovee-Collier C. Time windows in cognitive development. *Developmental Psychology*. 1995; 31:147–169.
- Rovee-Collier C, Cuevas K. Multiple memory systems are unnecessary to account for infant memory development: An ecological model. *Developmental Psychology*. 2009; 45:160–174. [PubMed: 19209999]
- Rovee-Collier C, Giles A. Why a neuromaturational model of memory fails: Exuberant learning in early infancy. *Behavioural Processes*. 2010; 83:197–206. [PubMed: 19945516]
- Rovee-Collier, C.; Hayne, H. Memory in infancy and early childhood. In: Tulving, E.; Craik, FIM., editors. *The Oxford handbook of memory*. 2. New York: Oxford University Press; 2005. p. 267-282.
- Rovee-Collier C, Sullivan MW. Organization of infant memory. *Journal of Experimental Psychology: Human Learning and Memory*. 1980; 6:798–807. [PubMed: 7441191]
- Schmidt RA, Bjork RA. New conceptualizations of practice; Common principles in three paradigms suggest new concepts for training. *Psychological Science*. 1992; 3:207–217.
- Scott LS, Pascalis O, Nelson CA. A domain-general theory of perceptual development. *Current Directions in Psychological Science*. 2007; 16:197–201. [PubMed: 21132090]
- Seidel RJ. A review of sensory preconditioning. *Psychological Bulletin*. 1959; 46:58–73. [PubMed: 13623960]
- Shionoya K, Moriceau S, Lunday L, Miner C, Roth TL, Sullivan RM. Developmental switch in neural circuitry underlying odor-malaise learning. *Learning and Memory*. 2006; 13:801–808. [PubMed: 17101877]
- Spear, NE. Ecologically determined dispositions control the ontogeny of learning and memory. In: Kail, R.; Spear, NE., editors. *Comparative perspectives on the development of memory*. Hillsdale, NJ: Erlbaum; 1984. p. 225-258.
- Spear, NE. *The processing of memories: Forgetting and retention*. Hillsdale, NJ: Erlbaum; 1978.
- Townsend, DA. Unpublished doctoral dissertation. Rutgers University; New Brunswick, NJ: 2007. The transitivity of preconditioned infantile associative memories during deferred imitation.
- Vander Linde E, Morrongiello BA, Rovee-Collier C. Determinants of retention in 8-week-old infants. *Developmental Psychology*. 1985; 21:601–613.
- Werker JF, Lalonde CE. Cross-language speech perception: Initial capabilities and developmental change. *Developmental Psychology*. 1988; 24:672–683.

Figure 1.

The experimental arrangement during the preexposure phase (Phase 1, *left panel*) and the deferred imitation transfer test (Phase 3, *right panel*), shown here with a 6-month-old. Here, the infant forms an association between the pink rabbit (S1) and yellow duck (S2) when he sees them together (*left panel*). In Phase 2 (*not shown*), the infant sees three target actions modeled on the rabbit (S1). In Phase 3, 24 hr after Phase 2, the infant is tested with the duck (S2) for imitation of the modeled actions (*right panel*). If the infant remembers the S1–S2 association, then he will imitate them on S2.

Figure 2.

The mean imitation transfer test scores of independent groups of 6-month-olds (*top panel*) and 9-month-olds (*bottom panel*) in Experiment 1. Groups received a daily 1-hr preexposure session to S1+S2 for 2 days, saw the target actions modeled on S1 after different delays, and received the imitation transfer test 24 hr later with S2. The *dashed line* indicates the mean test score of the age-matched pooled baseline control group. An asterisk indicates that a test group exhibited significant retention of the S1–S2 association; vertical lines indicate $\pm 1 SE$.

Figure 3.

The mean imitation transfer test scores of independent groups of 6-month-olds (*top panel*) and 9-month-olds (*bottom panel*) in Experiment 2a. Groups received one 1-hr preexposure session to S1+S2, saw the target actions modeled on S1 after different delays, and received the imitation transfer test 24 hr later with S2. The *dashed line* indicates the mean test score of the age-matched pooled baseline control group. An asterisk indicates that a test group exhibited significant retention of the S1–S2 association; vertical lines indicate +1 *SE*.

Figure 4.

The mean imitation transfer test scores of independent groups of 6-month-olds (*top panel*) and 9-month-olds (*bottom panel*) in Experiment 2b. Groups received two 30-min preexposure sessions to S1+S2 on a single day, saw the target actions modeled on S1 after different delays, and received the imitation transfer test 24 hr later with S2. The *dashed line* indicates the mean test score of the age-matched pooled baseline control group. An asterisk indicates that a test group exhibited significant retention of the S1–S2 association; vertical lines indicate +1 *SE*.

Figure 5.

The mean imitation transfer test scores of generalization groups of 6-month-olds in Experiment 3 (*black bars*) that were tested with a novel puppet (S3) and of the corresponding preexposure groups in Experiments 1 (*left panel*), 2a (*center panel*), and 2b (*left panel*) that were tested with the associated paired puppet (S2) after the same delay (*white bars*). The *dashed line* indicates the mean test score of the pooled baseline control group. Asterisks indicate that all groups exhibited significant imitation. Vertical lines indicate +1 *SE*.