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A Dissociation Between Recognition and Reactivation: The Renewal Effect at 3 Months of Age

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Abstract

Extinction allows organisms to adapt to an ever-changing environment. Despite its theoretical and applied significance, extinction has never been systematically studied with human infants. Using the operant mobile task, we examined whether 3-month-olds would exhibit evidence of original learning following extinction. In a recognition paradigm, infants exhibited renewal when tested in the acquisition context (ABA renewal) or a neutral context (ABC and AAB renewal) 1 day following extinction (Experiment 1a) and spontaneous recovery 3 days following extinction (Experiment 1b). In Experiments 2a-2b, we used a reminder paradigm to examine whether the extinguished response could be reinstated after the operant response had been forgotten. We failed, however, to find reinstatement of extinguished responding after spontaneous forgetting, regardless of the reminder and test contexts. We attributed this retention failure to competing responses at test. Although extinguished responding is recovered during infancy, this effect is elusive after the response has been forgotten.

Keywords

context; human infants; long-term retention; memory; extinction; operant conditioning; recognition; reminding; renewal effect; spontaneous recovery; reinstatement

For many years, the role of the environmental surround, or context, was not considered in theories of learning. Current models of conditioning typically treat the context in which learning occurs as an additional conditioned stimulus (CS) that enters into direct associations with the unconditioned stimulus (US) (Pearce & Hall, 1980; Rescorla & Wagner, 1972; Wagner, 1981; Wagner & Brandon, 2001). However, research on the contextual determinants of behavior has found that under some circumstances, the context influences conditioned responding without entering into association with the US (e.g., occasion setting; Holland, 1983). The renewal effect is one example in which the context

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plays a vital role in retention, giving meaning to ambiguous cues and providing nonverbal subjects with environmental “instructions” about what to do (Bouton, 1984, 1993; Bouton & King, 1983).

Bouton and Bolles (1979) initially reported that rats given conditioning trials in one context and extinction trials in another context exhibited conditioned responding when they were returned to the acquisition context during testing. They termed the recovery of acquisition performance the “renewal effect.” Subsequent work revealed that testing rats in a neutral (novel) context also produced a renewal effect (e.g., Bouton & Ricker, 1994). These findings suggest that the renewal effect is not simply the product of re-encountering the retrieval cues associated with the excitatory context in which the response was acquired. The renewal effect apparently reflects a retrieval failure that results when the contextual cues associated with extinction are absent during testing (Bouton, 2007).

The renewal effect has considerable theoretical and applied significance. Pavlov (1927) viewed conditioned associations as permanent and considered the phenomenon of spontaneous recovery following extinction as supporting evidence. The renewal effect is evidence that original learning survives extinction as well. Because many behavioral treatments of phobias and addictions (e.g., cue exposure therapy) in applied settings are based on the principles of extinction, understanding the characteristics and parameters of the renewal effect is essential for extending the generality of effective treatments beyond the clinic. For instance, extinction in multiple contexts attenuates renewal in both rats and humans (e.g., Gunther, Denniston, & Miller, 1998; Neumann, 2006; but see Bouton, García-Gutiérrez, Zilski, & Moody, 2006; Neumann, Lipp, & Cory, 2007).

Only relatively recently has the renewal effect been examined with human adults, and it has yet to be examined with human infants. To a large extent, this neglect reflects the widespread and long-held assumption that the brains of young infants are too immature to encode and store environmental information about the context in which learning occurs (e.g., Nadel, Willner, & Kurz, 1985; Nelson, 1995; see Revillo, Cotella, Paglini, & Arias, 2015, for review). Evidence from developing rat pups has generally supported this assumption. Rat pups typically fail to exhibit contextual learning before postnatal day (PND) 16-17 (e.g., Brasser & Spear, 2004; Carew & Rudy, 1991; Richardson, Riccio, & Axiotis, 1986) and do not exhibit a renewal effect until PND 24 when trained in an appetitive classical conditioning paradigm (Carew & Rudy, 1991). Likewise, standard-reared pups trained in a fear conditioning paradigm fail to exhibit a renewal effect before PND 23 (Callaghan & Richardson, 2011; Cowan, Callaghan & Richardson, 2013; Kim & Richardson, 2007b; Yap & Richardson, 2007). However, recent evidence of renewal at PND 18 (acquisition PND 14-15; extinction PND 16-17) within a taste aversion paradigm suggests that the contextual control of responding may emerge earlier for some types of memories (Revillo, Castello, Paglini, & Arias, 2014a).

Operant studies with human infants have repeatedly found that 3-month-olds encode numerous aspects of the incidental training context, including its location in the home (Hayne, Rovee-Collier, & Borza, 1991), ambient odors (Rubin, Fagen, & Carroll, 1998), background music (Fagen et al., 1997), and the proximal visual surround (Hayne & Findlay,

1995; Rovee-Collier, Griesler, & Earley, 1985). At 3 months, for example, infants trained in the mobile conjugate reinforcement procedure recognize the original mobile after a test delay of 1 day whether the proximal visual context (a distinctive colored-and-patterned cloth draped over the sides of the crib) is the same or different. After test delays of 3 days and longer, however, 3-month-olds generalize to a novel test mobile unless they are tested in the original training context (Butler & Rovee-Collier, 1989). The data suggest that the distinctive training context disambiguates whether the test mobile is novel or not after infants have forgotten the specific details of the original training mobile, which occurs 3 days after training.

Although this finding reveals that the environmental context is represented in very young infants' memory of an event and controls its subsequent retrieval, whether such young infants are able to associate different contexts with different outcomes is unknown. In studies of the renewal effect, different contexts are explicitly associated with different experimental contingencies and function as environmental instructions that "tell" the subject what contingency is in effect. Very little is also known about extinction *per se* in infants. Shafer (2008) found that 3-month-olds' conditioned kicking failed to decrease significantly during the actual extinction manipulation, yet they exhibited a strong extinction effect 24 hr later when trained and tested without a distinctive context. Although numerous studies have confirmed that adults exhibit evidence of original learning following extinction (e.g., spontaneous recovery, renewal, reinstatement), relatively little is known about the persistence of learning following extinction during infancy.

The present study examined whether human infants would exhibit evidence of original learning following extinction. Despite its practical implications for the elimination of undesirable responses, the renewal effect has not been studied in human infants. In Experiment 1a, we used a delayed recognition paradigm to examine whether 3-month-old infants would exhibit a renewal effect. To this end, we operantly trained independent groups of infants in the mobile conjugate reinforcement task in a distinctive context, administered an extinction procedure in another distinctive context, and then measured their retention in one of these two contexts or a novel one. Experiment 1b used the same procedure without changing the context to determine whether the effects of extinction would dissipate after 3 days (i.e., spontaneous recovery). Finally, in Experiments 2a and 2b, we used a reminder paradigm to examine the long-term retention of the renewal effect. Specifically, once an extinguished conditioned response has been forgotten, can the presentation of a reminder reinstate conditioned responding?

Experiment 1a: The Renewal Effect

In Experiment 1a, we examined whether 3-month-old infants might exhibit a renewal effect. The particular colored-and-patterned cloth panel that was draped over the crib rails during each experimental phase defined the environmental context. Infants learned to kick to move the mobile in a distinctive context (Context A) and received an extinction manipulation (kicking did not produce mobile movement) with the training mobile in a different context (Context B). One day later, infants were tested with the original mobile in the acquisition context (Context A; Group A/B/A), the extinction context (Context B; Group A/B/B), or a

neutral context (Context C; Group A/B/C). An additional spontaneous recovery control group was trained, extinguished, and tested in the same context (Group A/A/A). A renewal effect would be seen if 3-month-olds tested outside the extinction context (Groups A/B/A, A/B/C) were to exhibit significant retention, while infants tested in the extinction context (Groups A/A/A, A/B/B) did not. Because Bouton and Ricker (1994) had also found a renewal effect in a neutral test context, we predicted that if infants exhibited a renewal effect in the acquisition test context (Context A), then they would do so in a neutral test context (Context C) as well. It is possible, however, that renewal in a novel context does not emerge until later in development. Yap and Richardson (2007) found that although PND 25 rats exhibit ABA renewal, they failed to exhibit AAB renewal. Thus, we also examined whether 3-month-olds would exhibit renewal when acquisition and extinction occur in the same context, and testing occurs in a neutral context (Group A/A/B).

Method

Participants.—The final sample consisted of sixty 3-month-olds (40 boys, 20 girls) who were recruited through published local birth announcements, a mailing list service, and by word of mouth. They were randomly assigned to groups ($n = 12$) as they became available for study. Infants' mean age was 96.9 days ($SD = 7.1$) on the first day of training. Participants were African-American ($n = 3$), Asian ($n = 6$), Caucasian ($n = 39$), Other ($n = 1$), of mixed race ($n = 9$), and not reported ($n = 2$). Their parents' mean educational attainment was 15.8 years ($SD = 0.6$), and their mean rank of socioeconomic status (Socioeconomic Index, *SEI*; Nakao & Treas, 1992) was 72.22 ($SD = 13.04$). Additional infants were not included in the final sample due to excessive crying ($n = 12$), experimenter error ($n = 3$), failure to meet original learning criterion ($n = 14$), a scheduling conflict ($n = 1$), an excessively high baseline rate ($n = 1$), illness ($n = 1$), failing to remain supine ($n = 1$), or falling asleep ($n = 2$).

Apparatus.—The operant apparatus was one of two training mobiles, counterbalanced within groups. Each mobile consisted of five, highly detailed, painted wooden figures and jingle bells that were suspended from plastic cross bars (Nursery Plastics, Models 801 and 809). The mobiles were not commercially available. Throughout each session, the mobile was hung from an aluminum L-shaped stand (BCS Machine Co., South Plainfield, NJ) that was clamped to the crib rail nearest the experimenter, and an identical "empty" stand was clamped to the opposite rail. One end of a satin ribbon was connected without slack to the infant's ankle, while the other end was attached to one of the two stands. During reinforcement phases (*acquisition*), the ribbon was attached to the same stand as the mobile; during nonreinforcement phases (*baseline*, *extinction*, *long-term retention test*), it was attached to the empty stand.

During each session, a distinctive colored-and-patterned cloth panel was draped over the front and sides of the crib (the context). For a given group, different contexts served as the acquisition context (Context A), the extinction context (Context A or B), and when appropriate, the neutral test context (Context B or C). The panels were bright yellow with green squares, blue with red stripes, or pink with black Ts and were counterbalanced within groups.

Procedure.—All sessions took place in the infant's home crib at a time when the infant was alert and playful. This time varied across infants but remained relatively constant across all sessions for a given infant. Infants received two training sessions that were separated by 1 day and a long-term retention test 1 day later.

Baseline phase (Session 1).: Session 1 began with a 4-min nonreinforcement phase during which the mobile was hung over the infant, and the ankle ribbon was connected to an empty stand. This arrangement allowed the mobile to be in view, but infants could not move it by kicking. Infants' kicks/min (operant level) were recorded for 2 min in two different contexts, ensuring that all groups had baseline data for both the acquisition (for learning criterion calculations) and test contexts (for baseline ratio calculations). The first 2 min occurred in the extinction (Context B: Group A/B/A), extinction/test (Context B: Groups A/B/B), test (Context B: A/A/B; Context C: Group A/B/C), or neutral (Context B/C: Group A/A/A) context. For all infants, the second 2 min occurred in the acquisition context (Context A); thus, context order was not counterbalanced during the baseline phase.¹

Acquisition phase (Sessions 1 and 2).: The baseline phase was followed immediately by a 9-min reinforcement phase during which the ankle ribbon was attached to the same stand as the mobile, so that kicks moved the mobile with an intensity commensurate with their rate and vigor ("conjugate reinforcement"). Twenty-four hours later, Session 2 began with a 9-min reinforcement phase in Context A. To proceed to the extinction phase, infants were required to meet an initial learning criterion (i.e., kicking 1.5 times above operant level in the acquisition context for 2 of 3 consecutive min).

Extinction phase (Session 2).: The extinction phase was a 9-min nonreinforcement phase immediately following the end of acquisition in Session 2. All infants remained in the crib, and extinction occurred in either the same context as acquisition (Context A) or in a different context (Context B).

Long-term retention test (Session 3).: The long-term retention test was a 2-min nonreinforcement period that occurred 1 day after Session 2 in Context A (Groups A/B/A, A/A/A), Context B (Groups A/B/B, A/A/B), or Context C (Group A/B/C). In the group labels, the first letter indicates the acquisition context, the second letter indicates the extinction context, and the third letter indicates the test context. Following the long-term retention test, reacquisition was introduced as a motivational control procedure to insure that infants who had responded poorly during the test were not ill, tired, or unmotivated on that particular day.

A kick was defined as any horizontal or vertical movement of the leg that at least partially retraces its original path in a smooth, continuous motion (Rovee & Rovee, 1969). During all sessions, the experimenter stood out of the infant's direct line of sight and recorded the number of kicks/min of the foot with the ribbon attached. A second observer, naïve with

¹Liner order was not counterbalanced during baseline in order to avoid changing the context between the baseline and acquisition phases. A preliminary analysis revealed that infants' baseline kick rates were not systematically affected by the fixed order of the cloth liners, $t(59) < 1$.

respect to infants' group assignments, independently recorded the kicks/min of 12 infants during 26 randomly selected sessions in Experiments 1a-1b. A Pearson product-moment correlation, computed over 367 pairs of their joint response counts/min, yielded an interobserver reliability coefficient of 0.96.

Results and Discussion

Baseline (Session 1).—A one-way analysis of variance (ANOVA) over the mean kick rates of the five groups during the baseline phase in the test context confirmed that they did not differ before training, $F(4, 55) = 1.84, p = .13$ (Table 1). This analysis ruled out the possibility that group differences during the long-term retention test might be due to initial group differences in unlearned activity.

Extinction (Session 2).—A $5(\text{Group}) \times 9(\text{Minute})^2$ ANOVA with repeated measures over minute for mean kick rates during the extinction phase yielded no significant main effects [group: $F(4, 26) < 1$; minute: $F(8, 208) = 1.19, p = .31$] or interaction, $F(32, 208) < 1$ (See Figure 1). Previous research has found that although 3-month-olds fail to exhibit an overall decrease in responding during the extinction manipulation, they do not respond above baseline when tested 24 hr later (Shafer, 2008).

Long-term retention (Session 3).—Retention was defined in terms of an individual measure of relative responding, the *baseline ratio*, that we have used in all previous studies of infant long-term memory (Rovee-Collier, 1996). The baseline ratio (LRT/BASE: kick rate during the long-term retention test/kick rate during the baseline phase in the test context) is an all or none ratio that expresses the extent to which an infant's response rate during the long-term retention test (LRT) exceeds that same infant's response rate during the baseline phase (BASE). If the group's mean baseline ratio is significantly greater than 1.00 (H_0 : no retention), then it has displayed significant retention. A one-way ANOVA over the mean baseline ratios indicated that the groups differed significantly, $F(4, 55) = 4.33, p = .004, \eta_p^2 = .24$ (Figure 2).

Although an ANOVA indicates whether the groups were the same or different, it does not answer our primary question, namely, whether particular groups exhibited renewal. All may have responded significantly above operant level, or none may have. To answer this question, we first used directional one-sample t tests to compare the mean baseline ratio (LRT/BASE) of each group against a theoretical population baseline ratio of 1.00 (H_0 : no retention, no renewal). A group mean baseline ratio significantly greater than a theoretical population baseline ratio of 1.00 signifies significant retention (H_1 : retention, renewal). Next, to confirm the presence of a renewal effect, we used directional Fisher LSD post-hoc tests to examine whether the mean baseline ratios of the groups that exhibited significant

²In Experiments 1a-1b, not all infants completed the 9-min extinction period (due to excessive crying), but all completed at least 6 (Experiment 1a) or 7 min (Experiment 1b). Secondary analyses were limited to the number of minutes in which data from all infants were available. For Experiment 1a, a $5(\text{Group}) \times 6(\text{Minute})$ ANOVA yielded no significant main effects [group: $F(4, 54) < 1$; minute: $F(5, 270) = 2.07, p = .07$] or interaction, $F(20, 270) < 1$. For Experiment 1b, a $2(\text{Group}) \times 7(\text{Minute})$ ANOVA yielded a significant main effect of minute, $F(6, 60) = 2.82, p = .02, \eta_p^2 = .22$, but no main effect of group, $F(1, 10) < 1$, and no interaction, $F(6, 60) = 1.26, p = .29$. An examination of mean kick rates revealed an increase in infants' kicking from the first ($M = 13.42, SE = 1.79$) to seventh minute ($M = 19.92, SE = 4.10$) of extinction.

retention were significantly higher than the mean baseline ratios of the renewal control groups (Groups A/A/A, A/B/B).

The results of these analyses were consistent with a renewal effect (Figure 2). When the extinction manipulation was in one context and the retention test was in another, groups that were tested in either the original acquisition context, Group A/B/A: $t(11) = 5.11$, $p < .001$, $d = 1.47$, or in a neutral context, Group A/B/C: $t(11) = 4.11$, $p < .001$, $d = 1.19$, and Group A/A/B: $t(11) = 2.31$, $p = .02$, $d = 0.67$, exhibited significant retention (i.e., baseline ratios > 1.00). As hypothesized, groups that were tested in the extinction context exhibited no retention, Group A/B/B: $t(11) = 1.40$, $p = .09$, and Group A/A/A: $t(11) < 1$ (i.e., baseline ratios not > 1.00). The poor test performance of Groups A/A/A and A/B/B confirms that renewed responding by Groups A/B/A, A/B/C, and A/A/B was not due to spontaneous recovery after a 1-day delay. Furthermore, post-hoc analyses confirmed the presence of the renewal effect; Groups A/B/A, A/B/C, and A/A/B had mean baseline ratios that were significantly higher than Group A/A/A ($p = .001$, $p < .001$, $p = .008$, respectively). However, only Groups A/B/A and A/B/C had mean baseline ratios significantly higher than Group A/B/B ($p = .036$ and $p = .015$, respectively). Thus, the renewal effect is a reliable and robust phenomenon in early infancy.

The finding that 3-month-old infants exhibited a renewal effect indicates that very young infants not only can encode information about their environmental surround but can also use that information to guide their subsequent behavior. Additionally, this finding reveals that original learning is preserved through extinction in early infancy—a finding consistent with Pavlov's (1927) conclusion that extinction is not unlearning. Our findings are consistent with an early study on the extinction of high-rate operant crying of two institutionalized infants (a 6-week-old and 20-week-old) that hinted of a renewal effect (Etzel & Gewirtz, 1967). Practically speaking, when considered together, these findings suggest that the elimination of an undesirable behavior such as excessive crying or tantrums is context-specific. When extinguished in one context, they are likely to reappear when the context is changed (i.e., ABA, ABC, and AAB renewal). This is the first evidence of AAB renewal in infants of any species; 25 PND rat pups trained in a Pavlovian fear-conditioning paradigm exhibit ABA but not AAB renewal (Yap & Richardson, 2007).

Experiment 1b: Dissipation of Extinction

Spontaneous recovery also provides evidence that extinction does not destroy original learning (Pavlov, 1927). Although multiple explanations of spontaneous recovery have been proposed (see Rescorla, 2004, for review), Bouton's (1993, 2004) view of spontaneous recovery as a form of the renewal effect is both straightforward and intriguing. Bouton has proposed that the temporal context of an event is an integral part of the training context; when the retention interval between training and testing is greater, the context change is greater as well. He has argued that spontaneous recovery—the reappearance of conditioned responding following extinction with the passage of time—is actually a special case of the renewal effect in a changed temporal context (see also Urcelay, Wheeler, & Miller, 2009). Accordingly, we asked if 3-month-olds would renew responding when there was only a change in the temporal context.

At 3 months of age, infants remember the mobile task for only 5 days (Hartshorn et al., 1998; Hayne, 1990) but still respond robustly after a 3-day retention interval whether they were trained and tested in a highly distinctive context (Butler & Rovee-Collier, 1989) or not (Rovee-Collier, Adler, & Borza, 1994; Rovee-Collier & Sullivan, 1980). In these studies, infants received no extinction training. In two more recent studies, however, infants given both acquisition and extinction training in the familiar, non-highly distinctive context of the home crib exhibited a significant extinction effect when tested 1 day later (Kuhn-McKearin, Cuevas, Shafer, & Rovee-Collier, 2007; Shafer, 2008). Similarly, in Experiment 1a, the spontaneous recovery control group that was given both acquisition and extinction training in the same highly distinctive context also exhibited an extinction effect when tested in the same context 1 day later.

In Experiment 1b, we trained and tested infants in a highly distinctive context or in the absence of a highly distinctive context and in both instances extended the retention interval to 3 days (i.e., approximately halfway through the forgetting function of the conditioned response). We asked whether either group would exhibit spontaneous recovery after the longer test delay, when the difference in the temporal context of training and testing was greater and the effects of extinction might dissipate.

Method

Participants.—Participants were twelve 3-month-olds (5 boys, 7 girls) with a mean age of 98.8 days ($SD = 4.3$) on the first day of the study. They were randomly assigned to groups ($n = 6$) as they became available for study. They were Asian ($n = 1$), Caucasian ($n = 9$), of mixed race ($n = 1$), and not reported ($n = 1$). Their parents' mean educational attainment was 15.8 years ($SD = 0.6$) and mean SEI was 69.13 ($SD = 16.72$). Additional infants were not included in the final sample due to excessive crying ($n = 7$), failure to meet original learning criterion ($n = 4$), failing to remain supine ($n = 2$), or an excessively high baseline rate ($n = 1$).

Procedure.—The procedure was the same as before except that the retention interval was increased to 3 days. Two spontaneous recovery groups were tested. Group A/A/A-3 received acquisition, extinction, and testing in a highly distinctive physical context, whereas Group x/x/x-3 received acquisition, extinction, and testing in the familiar, non-highly distinctive context of the home crib.

Results and Discussion

Baseline (Session 1).—An independent t -test indicated that the mean kick rates of the two groups did not differ during the baseline phase in the test context, $t(10) = 1.39$, $p = .19$ (Table 1).

Extinction (Session 2).—A $2(\text{Group}) \times 9(\text{Minute})^2$ ANOVA with repeated measures over minute yielded no significant main effects [group: $F(1, 7) < 1$; minute: $F(8, 56) = 1.47$, $p = .19$] or interaction, $F(8, 56) < 1$.

Long-term retention (Session 3).—An independent t -test revealed that the mean baseline ratios of the two groups did not differ during the long-term retention test, $t(10) < 1$. Directional one-sample t tests revealed that 3-month-olds in both groups exhibited spontaneous recovery 3 days after the extinction manipulation. Groups A/A/A-3 and x/x/x-3 had mean baseline ratios that were significantly above 1.00, $t(5) = 2.31$, $p = .034$, $d = 0.94$ and $t(5) = 2.22$, $p = .039$, $d = 0.91$, respectively (Figure 3). Further, directional independent t -tests indicated that the mean baseline ratio of Groups A/A/A-3 and x/x/x-3 were both significantly higher than the mean baseline ratio of the spontaneous recovery control group (Group A/A/A) from Experiment 1a that was tested 1 day after the extinction manipulation, $t(16) = 3.20$, $p = .003$, $d = 1.36$, and $t(16) = 2.83$, $p = .006$, $d = 1.27$, respectively.

Given that 3-month-olds who received acquisition and extinction in the same physical context—whether highly distinctive or not—had exhibited an extinction effect after a 1-day retention interval (Experiment 1a; Kuhn-McKearin et al., 2007; Shafer, 2008), the finding that corresponding groups exhibited spontaneous recovery after a 3-day retention interval confirms that original learning is relatively permanent during infancy. Our findings are consistent with recent evidence that preweanling rat pups exhibit spontaneous recovery of a conditioned fear response following extinction (Revillo, Paglini, & Arias, 2014b). Thus, it appears that during infancy, the effects of extinction dissipate with the passage of time. Practically speaking, this result means that the elimination of an undesirable behavior may be relatively transient: As time passes, previously extinguished behaviors are likely to reappear. According to Bouton's (2004) interpretation of spontaneous recovery, renewal in human infants occurs in an altered temporal as well as physical context (but see Shafer, 2008). The data are also consistent with the familiar pattern of a recency effect (i.e., extinction) after a shorter retention interval and a primacy effect (i.e., acquisition) after a longer one (Cornell & Bergstrom, 1983; Wright, Santiago, Sands, Kendrick, & Cook, 1985).

Experiment 2a: Reinstatement of Conditioned Responding After Forgetting

The finding that 3-month-olds renewed conditioned responding after a change in either the temporal or physical context (Experiments 1a-1b) ensured that original learning was not eliminated by extinction during early infancy. In Experiment 2a, we used a reminder paradigm to examine whether the extinguished operant response could be reinstated after the operant response had been forgotten. Although numerous studies have examined the reinstatement of an extinguished conditioned response (i.e., presentation of the US alone following extinction renews conditioned responding to the CS; e.g., Bouton & Bolles, 1979; Rescorla & Heth, 1975), none have examined the effects of reinstatement after the extinguished conditioned response has been forgotten. Reminders are particularly important for long-term retention early in ontogeny when forgetting occurs rapidly (see Campbell & Spear, 1972; Rovee-Collier & Cuevas, 2008, for review). Many conditioned responses are forgotten at some point in ontogeny, and the potential life-long effects of extinction on conditioned responding are unknown.

Three-month-olds are most amenable for examining the retrieval of a forgotten conditioned response; their retention of the mobile task is relatively brief (i.e., 5 days). In addition, the presence of the renewal effect 1 day after extinction and spontaneous recovery 3 days after

extinction confirms that extinction does not erase original learning. We can thus separate the effects of extinction training on conditioned responding before and after the conditioned response has been forgotten. Whether or how the memory of extinction might influence the recovery of the forgotten training memory in a reminder paradigm is unknown.

At 3 months of age, infants remember the mobile task for 5 days, but their memory can be reactivated after it was forgotten by exposure to a reminder 1 day prior to the long-term retention test (Rovee-Collier, Sullivan, Enright, Lucas, & Fagen, 1980). Previous studies have found that exposure to the moving mobile, to the acquisition context alone (no mobile present), or the acquisition context with the moving mobile are all effective reminders (e.g., Galluccio & Rovee-Collier, 1999; Hayne & Findlay, 1995; Rovee-Collier et al., 1980, 1985). At all ages, a reminder restores learned performance to the same level that it was at the end of acquisition.

Although a reminder is an isolated component of the original training event, it recovers the memory of the entire event. Fagen, Yengo, Rovee-Collier, and Enright (1981) found that a moving mobile was an effective reminder for the forgotten discrimination memory of 3-month-olds who had originally learned that kicking to one mobile (S^+) was reinforced, but kicking to a second mobile (S^-) was not. Because we had never attempted to retrieve a forgotten memory following an explicit extinction manipulation, we were unsure as to which particular reminder to use. Therefore, we used a variety of different reminders that had been effective in the past.

Finally, because infants exhibited a robust renewal effect when tested with a recognition paradigm (Experiment 1a), we also used a renewal effect design to test for the reinstatement of extinguished responding with a reminder paradigm. To this end, infants received a 3-min reminder 13 days after acquisition/extinction (Session 2) and were tested 24 hr later. The retrieval of ABA renewal was examined in independent groups of infants who were reminded with either the context alone (i.e., acquisition or extinction) or a moving mobile in the acquisition context (i.e., reactivation reminder or reinstatement reminder³). We also asked whether extinguished responding would be reinstated if Groups A/A/A and A/B/C were reminded with a moving mobile in the acquisition context. The forgetting control group (Group A/A/xA) received no reminder (x) before the long-term retention test.

Method

Participants.—The final sample consisted of forty-three 3-month-olds (23 boys, 20 girls) with a mean age of 97.0 days ($SD = 5.3$). They were African-American ($n = 3$), Asian ($n = 5$), Caucasian ($n = 29$), Hispanic ($n = 3$), and of mixed race ($n = 3$). Their parents' mean educational attainment was 15.8 years ($SD = 0.8$) and mean SEI was 73.27 ($SD = 12.33$). Additional infants were not included in the final sample due to excessive crying in any session ($n = 18$), failure to meet learning criterion ($n = 30$), an excessively low baseline rate

³Reactivation and reinstatement reminders have been used with infants to recover memories of earlier experiences (see Rovee-Collier & Cuevas, 2008 for review). In infancy research, a "reinstatement reminder" refers to a partial training trial in which the response-reinforcement contingency is briefly reintroduced (i.e., contingent moving mobile) and a "reactivation reminder" refers to the presentation of an isolated component of the event (i.e., noncontingent moving mobile)

($n = 1$), an excessively high baseline rate ($n = 3$), illness ($n = 1$), experimenter error ($n = 1$), falling asleep ($n = 1$), a scheduling conflict ($n = 2$), or failing to remain supine ($n = 1$).

Procedure.—Sessions 1 (acquisition), 2 (acquisition and extinction), and 3 (the long-term retention test) were the same as for Groups A/A/A, A/B/A, and A/B/C in Experiment 1a except that the extinction manipulation was 6 min, and 14 days intervened between Sessions 2 and 3. Infants received a 3-min reminder 24 hr prior to the 14-day test, 13 days after the conclusion of training. They were exposed to the acquisition context alone (a), the extinction context alone (b), a noncontingent moving mobile (a^+) in the acquisition context, a contingent moving mobile (a_{rein}) in the acquisition context, or no reminder (x).

The forgetting control group (Group A/A/xA) received no reminder (x). During the 3-min context alone reminder, infants were returned to the crib that was draped with the same experimental context that had been present during acquisition (Group A/B/aA) or extinction (Group A/B/bA); no mobile was present. When the 3 min elapsed, the caregiver lifted the infant from the crib, and the reminder treatment was over. The reinstatement reminder group (Group A/B/ a_{rein} A) received a 3-min reminder treatment that was procedurally identical to a reinforcement period during training in the acquisition context.

The reactivation reminder procedure was identical to that originally used by Rovee-Collier et al. (1980). The reactivation reminder groups (Groups A/A/ a^+ A, A/B/ a^+ A, A/B/ a^+ C) were reminded in the acquisition context in the same crib they were trained but were situated in a sling seat (Summer Bounce n' Play, Model 1404) to minimize leg movement. The ribbon connected to the mobile was not attached to the infant's ankle but was held by the experimenter, who drew and released it to move the mobile for 3 min at the same rate each infant had kicked during the last 3 min of acquisition in Session 2.

A second observer, naïve with respect to an infant's group assignment, independently recorded the kicks/min of 11 infants during 21 randomly selected sessions for Experiments 2a-2b. A Pearson product-moment correlation, computed over 235 joint response counts per minute, yielded an interobserver reliability coefficient of 0.94.

Results and Discussion

Baseline (Session 1).—A one-way ANOVA over the mean kick rates of the seven groups during the baseline phase in the test context, $F(6, 36) < 1$, confirmed that they did not differ before training (Table 2).

Extinction (Session 2).—A 7 (Group) $\times$ 6 (Minute) ANOVA with repeated measures over minute, yielded a significant main effect of group, $F(6, 33) = 3.47$, $p = .009$, $\eta_p^2 = .39$, but no main effect of minute, $F(5, 165) < 1$, and no interaction, $F(30, 165) < 1$. Because there were no a priori hypotheses regarding group differences in kick rates during extinction, we completed Bonferroni post-hoc analyses to control for multiple comparisons. These analyses revealed that Group A/B/bA kicked ($M = 22.93$, $SE = 3.00$) significantly ($p < .05$) more during extinction than Groups A/B/ a^+ C ($M = 6.89$, $SE = 2.74$) and A/B/ a^+ A ($M = 9.24$, $SE = 2.54$).

Long-term retention (Session 3).—A one-way ANOVA indicated that the mean baseline ratios of the seven groups were not significantly different, $F(6, 36) < 1$ (Figure 4). Directional one-sample t tests comparing the mean baseline ratio of each group against 1.00 revealed that none of the groups exhibited significant retention during the 14-day test [Groups A/A/xA, A/A/a⁺A, and A/B/a_{rein}A: $t(5) < 1$; Group A/B/aA: $t(5) = 1.16$, $p = .15$; Group A/B/bA: $t(5) = 1.18$, $p = .15$; Group A/B/a⁺A: $t(6) = 1.14$, $p = .15$; Group A/B/a⁺C: $t(5) = 1.07$, $p = .17$].

The failure of the acquisition context to prime the forgotten acquisition memory (i.e., reinstate extinguished responding) was perplexing because it had been an effective prime in previous studies (Hayne & Findlay, 1995; Rovee-Collier et al., 1985). In those studies, however, infants had not experienced an extinction manipulation prior to reminding. Infants' failure to exhibit the renewal effect after reminding was not due to an insufficient number of cues during reminding (context alone vs. context plus mobile) or to testing in an ambiguous context (Context A vs. Context C). We were surprised that introducing additional cues during reminding provided no benefit. Because a moving mobile was an effective reminder in the past when infants had acquired competing responses to the same cue (Fagen et al., 1981), we are confident that infants were effectively reminded and attribute their failure to exhibit context-specific retention to competition between conflicting memories during the test. Presently, we propose that the reminder successfully reactivated the memories of acquisition and extinction, and these conflicting memories (kicking→mobile movement, kicking→no mobile movement) competed at the time of retrieval. However, if the extinction memory was retrieved at the time of testing (a recency effect), then it would have been impossible to distinguish between expression of the extinction memory and ineffective reminding. These possibilities were addressed in Experiments 2b.

Experiment 2b: Temporally Discrete Extinction

We have found that a reminder reactivates not only the original memory but also memories that are associated with it by virtue of sharing a common context or cue (Gulya, Galluccio, Wilk, & Rovee-Collier, 2001; Shields & Rovee-Collier, 1992; Timmons, 1994). Although acquisition and extinction had occurred in two different physical contexts in Experiment 2a, these two manipulations had also occurred in the same temporal context (Bouton, 1993). That is, the end of acquisition in Session 2 was always followed immediately by the extinction manipulation. If acquisition and extinction were also to occur in different temporal contexts, then perhaps their memories would be more distinctive, facilitating retrieval of the acquisition memory during the long-term test.

To test this possibility, infants in Experiment 2b received either one or two extinction sessions (total extinction time remained constant) 24 hr after the final acquisition session (Session 2). We administered two extinction sessions in order to examine whether retrieving the more recent memory of extinction at the outset of the second extinction session might strengthen it and enhance the distinctiveness of its temporal context.

Method

Participants.—The final sample consisted of thirteen 3-month-olds (5 boys, 8 girls), with a mean age of 100.0 days ($SD = 5.1$) on the first day of training. They were Asian ($n = 1$), Caucasian ($n = 9$), Hispanic ($n = 1$), and of mixed race ($n = 2$). Their parents' mean educational attainment was 15.8 years ($SD = 0.6$) and mean SEI was 67.09 ($SD = 16.34$). Additional infants were not included in the final sample due to excessive crying ($n = 1$), failure to meet original learning criterion ($n = 1$), or an excessively high baseline rate ($n = 1$).

Procedure.—The procedure was the same as in Experiment 2a, except that acquisition and extinction occurred in separate sessions. One day after acquisition ended (Day 3), Group A/_B/a⁺A, received one 6-min extinction session, and Group A/_BB/a⁺A received two 3-min extinction sessions 4 hr apart. Thus, total extinction time was constant across groups, but session number differed. (In the group labels, the “_” indicates the 24-hr gap between acquisition and extinction.) The 4-hr intersession interval ensured that the memory of the first session was no longer active when the second session occurred but would have to be retrieved from long-term memory (Rossi-George & Rovee-Collier, 1999). Thirteen days after the end of acquisition in Session 2, infants were passively exposed for 3 min to the moving mobile in the acquisition context, and they were tested in the acquisition context 24 hr later.

Results and Discussion

Baseline (Session 1).—An independent t -test indicated that the mean kick rates of the two groups did not differ during the baseline phase in the test context, $t(11) < 1$ (Table 2).

Extinction (Session 2).—A 2 (Group) $\times$ 6 (Minute) ANOVA with repeated measures over minute, yielded no significant main effects [group: $F(1, 11) < 1$; minute: $F(5, 55) < 1$], and a significant Group $\times$ Minute interaction, $F(5, 55) = 5.76$, $p < .001$, $\eta_p^2 = .34$. Separate repeated measures ANOVAs for each group revealed significant main effects of minute [Group A/_B/a⁺A: $F(5, 25) = 4.38$, $p = .005$, $\eta_p^2 = .47$; Group A/_BB/a⁺A: $F(5, 30) = 2.65$, $p = .043$, $\eta_p^2 = .31$]. For Group A/_B/a⁺A, an examination of mean kick rates reveals an increase in infants' kicking from the first ($M = 6.33$, $SE = 1.56$) to sixth minute ($M = 20.50$, $SE = 6.02$) of extinction. In contrast, infants in Group A/_BB/a⁺A exhibited a decrease in kicking from the first ($M = 17.71$, $SE = 5.08$) to sixth minute ($M = 8.71$, $SE = 2.56$) of extinction.

Long-term retention (Session 3).—An independent t -test revealed that the mean baseline ratios of the two groups did not differ during the long-term retention test, $t(11) = 1.22$, $p = .25$ (Figure 5). Directional one-sample t tests comparing the mean baseline ratio of each group against 1.00 revealed that neither group exhibited retention regardless of whether extinction was distributed into one or two discrete sessions [$t(5) < 1$; $t(6) = 1.43$, $p = .10$, respectively].

In Experiment 2b, we found that presenting acquisition and extinction in different temporal contexts did not facilitate retention after priming. Because retrieval of the acquisition memory is unaffected by a context change 24 hr after the end of acquisition (Butler &

Rovee-Collier, 1989), we can safely conclude that the acquisition memory was also retrieved in the extinction context 24 hr later. Apparently, however, the ensuing extinction manipulation was presently insufficient to offset the strengthening effect of retrieving the acquisition memory—particularly in the extinction context. As a result of this retrieval, the conflict between the acquisition and extinction memories at the time of either reminding or testing persisted and precluded significant renewal in the acquisition context 24 hr later.

Finally, if infants had been effectively reminded of extinction only, which is behaviorally indistinguishable from no retention, they would also have failed to exhibit renewal. This scenario is unlikely, however, because effective reminders recover associated memories that share a common cue, as did the acquisition memory. Instead, it is more likely that infants' failure to exhibit renewal resulted from response competition to the common retrieval cue. This conclusion is potentially supported by the pattern of individual differences during the 24-hr test following priming. Half of the individuals in each of four reactivation groups in Experiments 2a-2b (Groups A/B/a⁺A and A/_BB/a⁺A: $n = 4$; Groups A/B/aA and A/B/bA: $n = 3$) exhibited renewal (i.e., baseline ratios at or above 1.5; the learning criterion), and half did not.

General Discussion

The renewal effect is a reliable and robust phenomenon in 3-month-old human infants. On recognition tests 24 hr after extinction (Experiments 1a), infants exhibited renewal when tested in either the acquisition context (ABA) or a neutral context (ABC, AAB). In addition, on a 72-hr recognition test (Experiment 1b), a change in only the temporal context resulted in spontaneous recovery. We failed, however, to find reinstatement of extinguished responding after the response had been forgotten, regardless of the reminder and test contexts (Experiments 2a-2b). Although extinguished responding is recovered during infancy, this effect is elusive after the response has been forgotten. These findings have both theoretical and applied significance.

From a basic learning perspective, the data reveal that original learning remains intact following extinction in early infancy (i.e., original learning is relatively permanent). Pavlov (1927) concluded that extinction entails the acquisition of a new association rather than unlearning of the original one. He took the phenomenon of spontaneous recovery as evidence that original learning was preserved through extinction. Contemporary researchers also view the phenomena of reinstatement and the renewal effect as additional evidence that original learning survives extinction. Our report of spontaneous recovery and renewal in young human infants is consistent with recent research suggesting that extinction does not result “unlearning” in preweanling rat pups; they exhibit reinstatement and ABA renewal of conditioned taste aversion (Revillo et al., 2014a) as well as spontaneous recovery of conditioned fear (Revillo et al., 2014b).

Other work, however, has revealed developmental dissociations in the recovery of extinguished responding. In contrast to postweanling rats, preweanling rat pups fail to exhibit ABA renewal in both appetitive and fear conditioning paradigms (e.g., Carew & Rudy, 1991; Yap & Richardson, 2007) with the exception of pups that experience maternal

deprivation (Callaghan & Richardson, 2011; Cowan et al., 2014) or chronic corticosterone treatment (Callaghan & Richardson, 2014). Similar developmental patterns have been found when examining the reinstatement of a conditioned fear response following extinction (Kim & Richardson, 2007a). Subsequent pharmacological, inactivation, and immunohistochemistry studies indicate that there are differences in the neurotransmitters and neural structures of conditioned fear extinction in preweanling and postweanling rats (see Kim & Richardson, 2010, for review). Accordingly, Kim and Richardson (2010) characterize extinction in preweanling rats as inflexible and propose that preweanling rats either store a CS-no US extinction memory in the amygdala (as compared to non-localized storage in adult rats) or exhibit a form of extinction that "...involves unlearning of the original CS-US association...due to the lack of involvement of the hippocampus and the vmPFC [ventromedial prefrontal cortex]." (p. 301). Recently, it has been hypothesized that both unlearning and learning are potentially involved in extinction with the proportion of each type of learning changing across development (Ganella & Kim, 2014; Ganella, Thangaraju Lawrence, & Kim, in press).

Thus, it appears that under some circumstances, such as conditioned fear, extinction potentially disrupts infants' original learning via unlearning (but see Revillo et al., 2014b). Recent evidence from conditioned taste aversion studies with preweanling rats (Revillo et al., 2014a) and appetitive operant conditioning studies with 3-month-old human infants (Experiments 1a-1b) suggest that in other situations, original learning persists following extinction. This dissociation in early extinction as a function of memory type could be interpreted from the perspective of an ecological model of memory development (Rovee-Collier & Cuevas, 2009; Spear, 1984), which states that "...at every point in development, organisms are perfectly adapted to meet the ecological challenges posed by their changing niche. As ecological demands change, so do their adaptive strategies and the physiological mechanisms that evolved to support them." (Rovee-Collier & Cuevas, 2009, p. 171). This would mean that there are potential adaptive advantages for infants to exhibit "unlearning" following extinction of some types of associations (i.e., conditioned fear), but not others.

It is also important to note, however, that there are differences in how rat pups and human infants respond during the extinction manipulation. Although preweanling rats exhibit a decrease in conditioned responding during extinction training (e.g., Yap & Richardson, 2007), 3-month-old human infants do not (see also Shafer, 2008). Despite persistent responding during the extinction manipulation, 3-month-olds exhibit an extinction effect when tested the next day (i.e., Groups A/A/A and A/B/B respond at baseline levels) or when reminded and tested after 2 weeks. Therefore, infants had actually acquired the extinction contingency during the extinction phase, but they were unable to express it at the time of extinction training.

We attribute persistent responding during the extinction manipulation to human infants' behavioral and emotional arousal. Consistent with this interpretation, work focused on 4- to 5-month-olds' emotional reactivity during extinction has found increases in anger expressions and persistence in operant arm pulling during 2- or 3-min extinction sessions (Crossman, Sullivan, Hitchcock, & Lewis, 2009; Sullivan & Lewis, 2003). Human infants also exhibit behavioral persistence in a variety of other situations, including object search

tasks (Cuevas & Bell, 2010; Diamond et al., 1994), behavioral contrast paradigms (Fagen, 1979; Fagen et al., 1981), and inhibitory instrumental control tasks (Kalnins & Bruner, 1973), with the broader developmental literature indicating protracted development of emotional and behavioral regulation throughout infancy and early childhood (e.g., Rothbart, Sheese, Rueda, & Posner, 2011). Thus, the persistence in young human infants' responding during the extinction manipulation likely reflects their general lack of ability to regulate their emotions and behaviors through inhibition. As noted by Shafer (2008, p. 10), "There may be an evolutionary advantage of the persistence of many survival-related behaviors (e.g. crying which increases the proximity to the mother) as well as for the selective extinction of others when conditions change."

Maturation and methodological factors potentially contribute to the aforementioned differences between preweanling rats and human infants in conditioned responding during the extinction manipulation. Although preweanling rat pups have traditionally been classified as "infants," accumulating evidence has led some researchers to propose that PND 12-21 preweanling rats are more accurately classified as juveniles (i.e., early childhood in humans; Madsen & Kim, in press). Cognitively speaking, 3-month-old human infants are potentially not as mature as PND 15-17 rats (i.e., age of rats in the aforementioned extinction studies) that are close to weaning and independence. It is unclear, however, whether maturational processes play as large a role in cross-species differences in behavioral responding during extinction as compared to differences in methodology.

In our procedure, extinction and acquisition occurred within the same session, with the extinction phase immediately following acquisition for all groups except those in Experiment 2b. In the corresponding work with rat pups, on the other hand, the extinction session(s) occurred the following day(s) (e.g., Revillo et al., 2014a; Yap & Richardson, 2007). It is plausible that the temporal separation of extinction and acquisition phases might attenuate the effects of behavioral and emotional arousal on infants' responding. For instance, slightly younger human infants exhibited decreases in instrumental responding (i.e., sucking for clarity of film) when the switch from positive to negative instrumental control occurred on separate days (Kalnins & Bruner, 1973). In the present study, the only group that exhibited a decrease in responding during the extinction manipulation had two 3-min extinction sessions that occurred the day following acquisition training (Experiment 2b: Group A/_BB/a⁺A); infants who received a single 6-min extinction session the day after extinction training (Group A/_B/a⁺A) exhibited an increase in responding during the extinction phase. Additional work examining the parameters of the extinction manipulation itself in both species is essential to uncovering the underlying mechanisms of behavioral differences in responding during extinction.

Systematic investigation of the behavioral and neural markers of extinction by Richardson and colleagues has provided insight into the mechanisms underlying the extinction of conditioned fear in rat pups (see Kim & Richardson, 2010, for review). Due to ethical constraints on research involving human infants, there are limitations to providing the ideal cross-species comparison for fear conditioning; although aversive eyeblink conditioning paradigms may be a potential candidate because this paradigm can be used throughout development (e.g., Herbert, Eckerman, & Stanton, 2003). In order to develop a

comprehensive understanding of ontogenetic changes in extinction as well as the underlying mechanisms, additional systematic research on extinction of other types of memory is necessary. In the context of our operant conditioning findings with 3-month-old human infants, future research should examine (1) if extinction in younger infants is mediated by an “unlearning” mechanism (i.e., Will younger infants exhibit renewal and spontaneous recovery?), and (2) if an extinguished response can be reinstated after spontaneous forgetting by older infants.

In Experiments 2a-2b, of eight different reminder groups, all failed to exhibit renewal 24 hr after reminding. Because 3-month-olds exhibited renewal and spontaneous recovery in Experiments 1a-1b, we do not believe that the failure to exhibit reinstatement of conditioned responding after spontaneous forgetting is the result of unlearning during extinction. Further, the reminders from Experiments 2a-2b have been effective in previous work with 3-month-olds (e.g., Rovee-Collier et al., 1980, 1985), including when infants had acquired competing responses to the same cue (Fagen et al., 1981); thus, we are confident that infants were effectively reminded. We interpret these findings as the result of the reminder successfully reactivating the memories of acquisition and extinction, with response competition between these conflicting memories occurring at the time of retrieval. Our interpretation is in line with Laborda and Miller’s (2012) view that behavioral expression following an extinction manipulation depends on competing reactivated memories from acquisition and extinction. Although their interference account of extinction and response recovery is not based on the retrieval of forgotten memories, the hypothesized processes are the same. Likewise, the within-group inconsistency during our priming tests is intriguing and raises questions regarding whether renewal might be more likely after a shorter reactivation delay and less likely after a longer one. Because there have been no parallel investigations in studies with animals or human adults, the generality of findings for other ages and species from the present reactivation experiments is unknown. The dissociation in renewal on recognition and reminding tests may be unique to infants who are undergoing periods of rapid change and for whom the contingencies in their physical environment may change as well, particularly after long delays.

From a developmental perspective, these data reveal that infants not only encode information about their environmental surround, but they also use this information to guide their subsequent behavior. In other words, 3-month-olds respond or do not respond in a context-appropriate manner. This finding is in stark contrast to the long held belief that “Virtually all learning during infancy is...independent of context” (Nadel et al., 1985, p. 398). Previous work with the mobile paradigm has revealed that 3-month-olds also encode information regarding more distal aspects of the context, such as the room in their home (Hayne et al., 1991); thus, infants likely also use distal “place” information to disambiguate the meaning of ambiguous cues, as seen in the renewal effect. Carew and Rudy (1991) suggested that the ability to disambiguate ambiguous cues is mediated by a common relational representation system that is also involved in place learning. It has been argued that the hippocampal formation is involved in the storage and use of relational representations (e.g., Sutherland & Rudy, 1989) and that the prefrontal cortex is critically involved in instrumental extinction (see Todd, Vurbic, & Bouton, 2014, for review). Both brain regions exhibit protracted development, and it is unknown whether 3-month-olds’ performance is mediated by these or

alternate structures (e.g., amygdala; see Kim & Richardson, 2010, for review of the neural underpinnings of classically conditioned fear extinction in rat pups).

In applied settings, many behavioral treatments of phobias and addictions (e.g., cue exposure therapy) are based on the principles of extinction. The present studies show that understanding the contextual constraints on extinction is essential for extending the generality of effective treatments beyond the clinic. Specifically, a previously extinguished behavior may resurface if the extinction context is changed. Evidence that extinction is context-specific even in early infancy underscores the significant role of context in the elimination of undesirable behaviors. From a practical perspective, although similar research has not been performed with infants of any species, multiple extinction contexts have been shown to reduce renewal in human adults (e.g., Neumann, 2006; but see Neumann et al., 2007) and may be an important factor to consider when attempting to eliminate undesirable behaviors during infancy.

In sum, extinction allows organisms to adapt to an ever-changing environment throughout development. Three-month-old human infants exhibited evidence of original learning following extinction regardless of whether there was a change in the environmental (i.e., renewal effect; Experiment 1a) or temporal context (i.e., spontaneous recovery; Experiment 1b). After the response has been forgotten, however, a reminder treatment was ineffective at reinstating the extinguished response regardless of the training and testing contexts. We attributed this retention failure to competing responses at the time of retrieval. Taken together, these findings suggest that extinction does not result in unlearning of the original association in 3-month-old human infants.

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Figure 1.

Mean number of kicks over 2- or 3-min blocks for five independent groups in Experiment 1a. The experimental phases included baseline (*Base*), acquisition (*Acq*), extinction (*Ext*), long-term retention test (*Test*), and reacquisition (*Reacq*). Infants' baselines were recorded in the extinction [Context B: Group A/B/A (*gray opened triangles*)], test [Context B: Groups A/B/B (*gray filled circles*) and A/A/B (*black asterisks*); Context C: Group A/B/C (*gray opened diamonds*)], or neutral [Context C: Group A/A/A (*black filled squares*)] context and then in the acquisition context (Context A). In the group labels, the first letter designates the acquisition context, the second letter designates the extinction context, and the third letter designates the test context.

Figure 2.

Mean baseline ratios of five independent groups in Experiment 1a. In the group labels, the letters designate the acquisition, extinction, and test contexts, respectively. Groups A/B/A, A/B/C, and A/A/B exhibited renewal. The dashed line indicates baseline (“no retention”). Asterisks indicate significant renewal (i.e., M baseline ratio significantly > 1.00); vertical bars indicate ± 1 *SE*.

Figure 3.

Mean baseline ratios of two independent groups in Experiment 1b. In the group labels, uppercase letters designate the training, extinction, and test contexts, respectively. Group A/A/A-3 received all phases in a highly distinctive physical context, whereas Group x/x/x-3 received all phases in the familiar context of the home crib. Both groups exhibited spontaneous recovery 3 days after the extinction phase. The dashed line indicates baseline (“no retention”). Asterisks indicate significant retention (i.e., M baseline ratio significantly > 1.00); vertical bars indicate ± 1 *SE*.

Figure 4.

Mean baseline ratios of seven independent groups in Experiment 2a. In the group labels, uppercase letters designate the acquisition, extinction, and test contexts, respectively; the lowercase letter designates the reminder context: the + designates the additional presence of the noncontingent moving mobile: *rein* indicates a reinstatement of the contingently moving mobile. *Left panel:* Context-only reminder groups were placed in either the acquisition (Group A/B/aA) or extinction context alone (Group A/B/bA) 13 days after training and were tested 1 day later. A no-reminder control group (Group A/A/xA) received no reminder and was tested 14 days after training. None of the groups exhibited significant retention. *Right panel:* Noncontingent (Group A/A/a+A, Group A/B/a+A, Group A/B/a+C) and contingent (Group A/B/a_{rein}A) moving mobile reminder groups received a 3-min reminder treatment 13 days after training and were tested 1 day later. None of the reminder groups exhibited significant retention. The dashed line indicated baseline (“no retention”); vertical bars indicate +1 *SE*.

Figure 5.

Mean baseline ratios of two independent groups in Experiment 2b. In the group labels, uppercase letters designate the acquisition, extinction, and test contexts, respectively; the “_” indicates the 24-hr gap between acquisition and extinction; the lowercase letter designates the reminder context; and the + designates the presence of the noncontingent moving mobile. Group A/_B/a⁺A, received one 6-min extinction session, and Group A/_BB/a⁺A received two 3-min extinction sessions 4 hr apart. Both groups received a 3-min reminder treatment 13 days after acquisition training and were tested 1 day later. Neither group exhibited significant retention. The dashed line indicated baseline (“no retention”); vertical bars indicate +1 *SE*.

Table 1.

Mean Baseline (Base) and Long-term Retention Test (LRT) Rates of 7 Independent Groups ($n = 12$ or 6, respectively) in Experiments 1a and 1b. Parentheses contain 1 SE.

Test Group	Base	LRT
	<i>M</i> (<i>SE</i>)	<i>M</i> (<i>SE</i>)
Experiment 1a		
A/A/A	10.92 (2.35)	8.38 (2.27)
A/A/B	8.00 (1.24)	12.69 (2.53)
A/B/B	6.58 (0.85)	8.17 (1.45)
A/B/A	8.29 (1.39)	15.51 (2.50)
A/B/C	5.63 (1.12)	10.04 (1.38)
Experiment 1b		
A/A/A-3	7.03 (1.85)	12.53 (2.49)
x/x/x-3	11.46 (2.59)	19.92 (3.75)

Table 2.

Mean Baseline (Base) and Long-term Retention Test (LRT) Rates of 9 Independent Groups ($n = 6$) in Experiments 2a and 2b. Parentheses contain 1 SE.

Test Group	Base <i>M (SE)</i>	LRT <i>M (SE)</i>
Experiment 2a		
A/A/xA	6.54 (1.00)	5.75 (0.69)
A/B/aA	4.45 (1.56)	4.50 (0.86)
A/B/bA	12.56 (4.02)	12.95 (3.78)
A/A/a ⁺ A	6.00 (1.51)	4.92 (1.18)
A/B/a ⁺ A ^b	7.93 (2.83)	7.00 (1.28)
A/B/a _{rein} A	9.00 (2.61)	10.17 (3.13)
A/B/a ⁺ C	6.96 (3.12)	7.56 (1.98)
Experiment 2b		
A/_B/a ⁺ A	10.08 (2.62)	6.75 (1.51)
A/_BB/a ⁺ A ^b	10.48 (3.01)	12.00 (3.65)

^b
 $n = 7$