A SYSTEMATIC ANALYSIS OF EXTINCTION AT 3 MONTHS OF AGE

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ABSTRACT OF THE THESIS

A Systematic Analysis of Extinction at 3 Months of Age

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In operant conditioning, “extinction” refers to a procedure in which reinforcement is consistently withheld after conditioned responding. The “extinction effect” is observed when learned responding declines to its baserate, or extinguishes. Evidence suggests that the original association is preserved through extinction because conditioned responding can be restored. A hallmark of extinction is that it dissipates with time, and as subjects again exhibit the conditioned response. This phenomenon, spontaneous recovery, led Pavlov (1927) to conclude that learning is permanent. Extinction manipulations have been used in research with infants to eliminate undesirable behavior, to study emotion, and as test periods in instrumental learning preparations. However, it is unknown whether the properties of extinction are the same for human infants as for human adults and nonhuman animals.

In order to systematically characterize the extinction process early in ontogeny, 3-month-olds were first trained using the mobile conjugate reinforcement paradigm to kick to move an overhead mobile. Once the response was acquired, the extinction was presented and spontaneous recovery was assessed over the course of the normal retention

interval for the task. The duration and temporal placement of the extinction phase were manipulated.

Infants did not reduce ongoing responding during the extinction manipulation, but the extinction effect was evident during subsequent testing. More than three minutes of nonreinforcement immediately following acquisition was effective at decreasing conditioned responding during subsequent long-term retention test. Paradoxically, when the extinction session was separated from acquisition by at least one day, 3 min was sufficient to cause a reduction in conditioned responding, while 6 min enhanced retention. No evidence of spontaneous recovery was observed in this study.

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This thesis is dedicated in loving memory of Carl Keith Shafer, Jr. (June 8, 1942-December 30, 2006).

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Introduction

Once a behavior has been acquired, can it be eliminated or altered? What conditions are necessary to remove or decrease a previously learned response? Is the resulting change permanent or transient? An entire body of experimental research has been devoted to answering such questions as they pertain to humans and nonhuman subjects alike. *Extinction* is an experimental manipulation in classical and operant conditioning preparations that produces response decrements following the removal of reinforcement that previously followed stimuli or responses. When it is effective, extinction results in the same behavioral outcome as if the original memory had been erased: responding returns to its baseline. Upon closer examination, extinction appears to involve multiple functionally distinct processes. The mechanisms of extinction are relevant to our theoretical understanding of the way memories are formed and stored as well as upon practical concerns about permanence of conditioned responses. For example, extinction procedures have been studied for their clinical application to problems such as anxiety and post-traumatic stress disorder (Alvarez, Johnson, & Grillon, 2007). Furthermore, the procedure has merit as an established instructional tool for individuals with autism (Hagopian, Fisher, Sullivan, Acquisto, & LeBlanc, 1998).

There is little known, however, about the effectiveness of extinction procedures early in human development. The problem of removing an undesirable behavior from the infant's repertoire is of importance to their caregivers, medical practitioners and researchers. If the process is the same in infants and adults, then infants should show an initial response increase during the extinction treatment, followed by a decline in responding. One of the hallmarks of the extinction phenomenon occurs after a period of

baseline responding, when conditioned responding reappears with the mere passage of time (Rescorla 2004a, 2004b). *Spontaneous recovery*, as this phenomenon is known, has been taken as evidence that the original memory is preserved through extinction (Pavlov, 1927). There is growing evidence to indicate that ontogenetic as well as procedural factors affect the impact of an extinction treatment on spontaneous recovery.

This series of experiments is an attempt to systematically examine the extinction process in young infants. An operant procedure was used to establish whether a reduction in conditioned responding would be exhibited in the first place. Testing was then conducted throughout the typical span of retention to determine how permanent the reduction of conditioned responding might be. Finally, different temporal configurations of acquisition training and extinction were used to identify the potential role played by procedural factors in determining the subsequent expression of the original response.

The mechanisms by which extinction and spontaneous recovery operate have been modeled exhaustively, yet no single, unifying theory has been credited to date. A primary challenge in understanding the processes of extinction and spontaneous recovery is determining where the extinction manipulation had an impact (i.e., between CS and US, and/or between CS and response systems), and how it is controlled (i.e., passage of time and/or context; Lattal, 2007). In point of fact, there may be no single account of extinction to fully answer this question.

Four predominant models have emerged to explain extinction and spontaneous recovery. *Associative loss* models (*see* Mackintosh, 1975; Rescorla & Wagner, 1972) view the outcome of extinction training as the weakening of the conditioned CS-US association. By this account, associative strength is at least partly determined by the

learning parameters particular to the specific stimuli involved. The history of reinforcement associated with a particular CS determines the strength of the association insofar as the CS reliably predicts the US. The characteristic decline in responding observed during extinction is caused simply by the weakening of the underlying association resulting from repeatedly presenting the CS alone, and spontaneous recovery indicates that the elimination of the original association was incomplete. Like associative loss models, *generalization decrement* models emphasize the role of history of reinforcement. Capaldi (1967) has argued that responding to a CS declines during extinction because of the increasing dissimilarity of the extinction and training context, which is created by the history of nonreinforcement and reinforcement, respectively. This model predicts that spontaneous recovery should not occur if the extinction context is indistinguishable from the acquisition context, because after a few nonreinforcement trials during the test, the context more closely resembles extinction (Robbins, 1990). However, it has been shown that factors such as the physical context, time itself, and internal pharmacological or emotional states may differentially cue either acquisition or extinction memories (Bouton, Westbrook, Corcoran, & Maren, 2006).

With respect to what is learned by the organism during extinction, some argue that the extinction process is modulated by inhibitory mechanisms. That is, nonreinforcement training produces *new inhibitory associations* between CS and US (Konorski, 1967; Pearce & Hall, 1980; Spear, 1971). Pearce and Hall's model posits that presenting the CS without the US produces a new "no-US" representation, which counteracts the original association rather than directly weakening it. Spontaneous recovery is observed as the new inhibitory memory fades with time, allowing the former

excitatory association to control responding. A related view holds that acquisition and extinction memories compete during the subsequent test and spontaneous recovery occurs due to the interference of the old (reinforcement) memory with the new (nonreinforcement) memory. But as Catania (1979) notes, inhibition as an explanation is constrained by the reliance on unobservable events or processes, and therefore the language of inhibition is only useful to the extent that inhibitors can be identified.

A fourth extinction account holds that each individual element of the CS-US association is lost or devalued. Some aspect of *nonassociative loss* occurs in CS processing (Pavlov, 1927), US processing (Rescorla & Cunningham, 1978), or in the response itself (Hull, 1943). According to Pavlov (1927), the experimental extinction of a conditioned reflex involves a rapid, progressive weakening of the CR to a CS which is presented repeatedly without reinforcement. Pavlov noted that extinction is influenced by internal as well as external factors, and thus fluctuates. For example, a recently established CR is more susceptible to extinction procedures than an over-trained response; the degree of extinction can range from partial to complete. Without further experimental manipulation, the extinguished CR can recover fully with time. Extinguished responses may need to be reactivated with a brief reminder to elicit the UR. Pavlov argued that this property of extinction indicates that it is better characterized as a special form of inhibition than as a destruction of the CR. In his view, the rhythmic fluctuations in the reflexes sometimes observed following an extinction treatment can be explained as a manifestation of the internal "struggle" which is taking place (Pavlov, 1927, p. 60).

If responses compete with one another during the test phase, then how might we predict response outcomes? The observation of spontaneous recovery provides evidence that extinction is a time-dependent phenomenon. Devenport's (1998) temporal weighting rule (TWR) predicts the likelihood of response elevation or suppression by weighing the relative prominence of potential responses as a function of the passage of time. The more recent an event, the greater importance it holds during subsequent testing. As time passes, the weights of prior and recent events are more evenly distributed, until ultimately, the weighted averages of these experiences converge on an unweighted stimulus average. In this way, TWR accounts for spontaneous recovery in responding following an initially observed extinction effect. This model assumes that there is permanence of both the acquisition and the extinction experiences, but the probability of retrieving either one at the test is a function of time.

Rescorla (2004a & 2004b) also emphasized the role of temporal factors in the appearance of spontaneous recovery following extinction. A standard extinction procedure involves three essential phases: reinforcement training (acquisition), nonreinforcement training (extinction), and a subsequent test. He argued that a design that exposes participants to the extinction procedure in a temporally discrete session from original learning avoids the possibility that responding during the extinction procedure may be depressed by factors other than what is learned about the contingency between the stimulus and the outcome, such as frustration (*see* Amsel, 1958, 1972, 1992). Presenting the extinction phase in a temporally discrete session from acquisition is less likely to produce response suppression due to frustration. Importantly, Rescorla added that the observation of spontaneous recovery during a delayed test does not imply that

there was no degradation at all of the original response memory, nor does it require that anything new was learned during the extinction procedure. Simply put, spontaneous recovery necessarily means that at least some of the initial learning survives extinction.

Myers, Ressler, and Davis (2006) tested the hypothesis that the behavioral mechanisms involved in extinction differ depending on the interval at which extinction training is initiated using a fear conditioning preparation with rats. The authors expected that extinction would serve to erase the original training memory when it follows acquisition after short intervals, but that it would be akin to "new learning" at longer intervals. To that end, they tested the effects of immediate versus delayed extinction on a variety of extinction-related phenomena, including reinstatement, the renewal effect, and spontaneous recovery. Reinstatement treatments typically produce response recovery and provide evidence that conditioning to the CS has survived extinction. A reinstatement procedure consists of the presentation of signaled US presentations in the training context following extinction. In the Myers et al. study (2006), rats received Pavlovian training to anticipate a foot-shock following light presentation over 15 acquisition trials, followed by 90 presentations of the CS alone at intervals of 10 min, 1 hr, 24 hr, or 72 hr. The reinstatement treatment consisted of five unsignaled foot-shocks presented 11 days after acquisition. When subjects were tested 24 hr later for retention, only animals that had received extinction 24 or 72 hr after acquisition exhibited recovery of fear to the light following reinstatement. This finding supports the notion that short and long temporal delays of the extinction procedure may recruit altogether different mechanisms, such that short delays produce resistance to reinstatement, whereas longer delays permit reinstatement to occur.

The recovery of an extinguished response can also be mediated by contextual cues. The renewal effect is observed when subjects respond robustly during testing in the context of acquisition (context A) or a novel context (C) but not in the extinction context (B) (Bouton & Bolles, 1985). In the Myers et al. study (2006), animals received acquisition as in the first experiment. Extinction was presented following the same temporal delays, but it took place either in the same context as acquisition (A) or a different context (B). Animals were tested in context A (groups AAA, ABA). Only the 72-hr extinction groups demonstrated significantly different responding in the ABA and AAA contexts. The authors concluded erasure is more likely to take place when extinction closely follows acquisition.

Myers et al. (2006) also assessed spontaneous recovery following extinction using a fear-conditioning preparation. Subjects were trained as described above, with extinction presented after 10 min, 1 hr, or 72 hr without a context shift or reinstatement procedure. Testing took place after 1 or 21 days. None of the groups exhibited recovery when tested 1 day later. Groups that received extinction 1 hr or 72 hr after acquisition exhibited robust recovery when tested 21 days later. Spontaneous recovery was facilitated by a temporal delay between acquisition and extinction training. The authors concluded that the failure to observe recovery by the short-interval extinction groups following reinstatement, renewal, and the passage of time meant that the learning that occurs during extinction is resistant to disruption when extinction follows acquisition closely in time. The pattern of results observed is consistent with the hypothesis that different mechanisms may govern the control of conditioned responding when extinction is presented immediately following acquisition or in a temporally distinct session.

Myers et al. (2006) proposed that because synaptic depotentiation is more readily induced at short intervals following the induction of long-term potentiation (LTP), but not after a delay, extinction initiated shortly after fear acquisition engages a depotentiation (or unlearning) mechanism, whereas extinction presented after a long delay recruits a different (new learning) mechanism. According to the synaptic depotentiation/unlearning account, LTP is reversed as potentiated synapses return to basal activity, accompanied by the dephosphorylation of several second messengers (Akt, MAPK, and possibly CaMKII), up-regulation of protein phosphatases (calcineurin and PP1), and dephosphorylation and internalization of AMPA receptors (Zhou & Poo, 2004).

The role of temporal factors in the extinction process remains a topic of considerable debate. Bouton (Bouton et al., 2006; Woods & Bouton, 2007) has refuted Myers et al.'s (2006) account. Woods and Bouton (2007) collected data using both aversive- and appetitive-conditioning preparations and examined the renewal effect as a function of the temporal delay of extinction. The conditioned emotional response (CER) method was used for fear conditioning. Acquisition consisted of four pairings of 60-s termination of the houselights and a brief foot-shock. Fear was indexed by suppression of ongoing lever-press response during the CS. Extinction involved 16 or 32 trials of the "light-off" stimulus alone, presented either 10 min or 24 hr following acquisition. The groups were tested in context A or B (Groups ABA and ABB). Immediate extinction produced a quicker loss of conditioned suppression during the extinction session as well as spontaneous recovery and ABA renewal during testing. Thus immediate extinction produced a more rapid adjustment of ongoing responding, but was less permanent over

time. When the procedure was replicated without the contextual shift, robust spontaneous recovery was again observed. The authors noted that a major difference between the immediate and delayed extinction procedures might be the "emotional context" of extinction, which is determined by the history of reinforcement. Independent groups of animals received fear conditioning to a second previously untrained CS (tone) either in the emotional context of extinction, before the extinction procedure, or outside of the emotional context, before the long-term retention test. Animals revealed equivalent levels of suppression of food cup entries during extinction and testing, regardless of whether or not they had received fear conditioning to the second stimulus, with no effect of the temporal placement of that treatment. The emotional context hypothesis was not confirmed by this analysis.

In order to rule out the possibility that these findings were exclusively limited to fear conditioning preparations, an appetitive conditioning procedure was used. Acquisition consisted of 40 tone CS-food pellet pairings. Extinction (20 trials of the tone alone) was presented 10 min (immediate) or 24 hr following acquisition (delayed). Testing took place 24 hr after extinction and involved eight trials of nonreinforcement. Immediate extinction yielded greater spontaneous recovery with no effect of the emotional context on test responding. The authors concluded that immediate extinction is less durable than delayed extinction and that it does not erase original learning.

The data reviewed up to this point have been derived from research conducted with adult animals. Considerable evidence suggests that learning and memory changes throughout ontogeny (Arias, Spear, Molina, Molina, & Molina, 2007; Rovee-Collier, Hayne, & Colombo, 2001, p. 115; Spear & Campbell, 1979). Interpreting ontogenetic

investigations of memory can be challenging. As Rovee-Collier and colleagues (2001) point out, differences in task performance that are typically attributed to differences in memory have been revealed through careful experimentation to reflect age differences in the task demands and motor coordination. Extinction constitutes a disruption in the original conditions of learning, which first and foremost requires that the organism detect the disruption. Extinction procedures are particularly challenging to infants because infants seem to lack the ability to regulate their behavior through inhibition. Infants have been shown to exhibit behavioral persistence in object search tasks (Diamond et al., 1994), delayed-nonmatching-to-sample tasks (Diamond, 1995), violation of expectancy tasks (Fagen, Yengo, Rovee-Collier, & Enright, 1984; Thelen, Schöner, Scheier, & Smith 2001), and under changing contingencies (Riviére, Darcheville, & Clément, 2000), suggesting an inability to inhibit ongoing behavior (Rovee-Collier, et al., 2001, p. 96). 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.

When considering learning and memory during infancy, it is necessary to take into account the infant's unique niche. For instance, long sessions are not optimal in early infancy (i.e., Dominguez, Bocco, Chotro, Spear, & Molina, 1993, as cited in Arias et al., 2007). This problem is particularly critical nonhuman subjects, who feed frequently. In an attempt to circumvent this, Arias et al. (2007) developed a cushioned apparatus to hold a 5-day-old rat pup with a touch-sensor 1 cm from the pup's forepaws. Depressing the sensor released a brief intraoral infusion of milk. Rats received either two 15-min acquisition sessions separated by 24 hr, followed by 15-min extinction, or a

single 15-min acquisition phase immediately followed by a 6-min extinction session. Both procedures elicited a response spike at the outset of extinction followed by a decrement in responding. This response pattern was attributed to increased arousal and a negative internal emotional state driven by the sudden omission of reinforcement (Amsel, 1992; Papini & Dudley, 1997, as cited in Arias et al., 2007). In the final minutes of extinction, responding had decreased to operant level. Thus, 5-day-old rat pups demonstrate extinction of conditioned responding for a highly motivating reinforcer. Previous research had failed to show extinction with animals younger than 10 or 12 days of age on a maze-running task (Amsel, Burdette, & Letz, 1976; Chen, Gross, & Amsel, 1981). Such results highlight the importance of matching task-demands with age-appropriate responses.

Extinction procedures have been used in human infant learning preparations since the late 1950s (Brackbill, 1958; Etzel & Gewirtz, 1967; Siqueland, 1968; Williams, 1959), but little attention has been paid to establishing appropriate training parameters to promote the efficacy of the treatment. Siqueland (1968) used an operant head-turning procedure with newborns in which each response was reinforced with 5 s of nonnutritive sucking on a pacifier. He demonstrated that newborns could acquire the head-turning response with 15 min of reinforcement on either a CRF or a FR-2 schedule, and that the response was extinguished after a 5-min extinction manipulation. Infants showed a greater increase during acquisition on the FR-2 than the CRF schedule. Infants were not tested after extinction was complete, but a response decrement was observed during a 5-min extinction manipulation.

Extinction has mostly been used with infants in clinical work as a means of removing undesirable behavior, especially crying and tantrums. In a case report of one 21-month-old child showing excessive crying and screaming upon parental separation at bedtime, Williams (1959) implemented an extinction procedure to quell "tyrant-like tantrum behavior." The duration of crying gradually decreased across successive sleep periods after the caretakers implemented the extinction procedure, which required them not to enter the child's room during the tantrum. Spontaneous recovery was reported when, after a week of steady decline in crying, the child screamed incessantly at bedtime. The participant received additional extinction after one caretaker intervention, until he was reported to go to sleep after nine additional extinction trials. Etzel and Gewirtz (1967) also included an extinction treatment in a differential reinforcement paradigm as a means to eliminate operant crying in a quasi-experimental investigation of two infants who were 6 and 20 weeks of age over the course of 48 and 7 days, respectively. The experimenters provided reinforcement for infants' smiles by intermittent talking to the participants or showing them an attractive toy and withheld reinforcement during crying in a lab setting. Both infants exhibited greater smiling and less crying by the end of the study. These early investigations of extinction with infants as participants provide support for the notion that very young infants are sensitive to changes in the response-reinforcer contingency and can adjust their behavior accordingly. They do not establish the optimal conditions for extinction, the permanence of original learning or the new learning that occurs during extinction, or what learning mechanisms are tapped by the procedure. This issue must be revisited and assumptions should be challenged before implementing an intervention such as extinction.

Recently, infancy researchers have used extinction manipulations in order to study emotional reactivity. Lewis and colleagues (Lewis, Sullivan, & Ramsay, 1992; Lewis, Hitchcock, & Sullivan, 2004; Sullivan & Lewis, 2003) have used an instrumental conditioning preparation to this end. Lewis et al. (1992) assessed the emotional reactions of 2- to 8-month-olds exposed to extinction after learning an arm-pulling response. All ages were trained and tested using an identical procedure. They had a 3-min training session during which their arm-pulls activated a picture of a smiling baby and a 3s clip of a song. Acquisition was followed by a 2-min extinction phase. Significant increases in anger and sadness were observed during extinction. However, little attention was given to whether or not the task had been learned, or whether the response was actually extinguished. Sullivan and Lewis (2003) compared the responses of 4- and 5-month-old infants trained with extinction, noncontingent reinforcement and partial reinforcement. The assumption was that infants exposed to these events experience frustration produced by the loss of control, the loss of stimulation, or the violation of expectancy. Infants were first trained in the same arm-pulling task described above, but this time they were trained with 4 min rather than 3 min of acquisition. Independent groups then received a 2-min "frustration period" when they received no reinforcement (extinction), partial reinforcement (FR-3), or noncontingent reinforcement. Noncontingent reinforcement produced a decline in arm-pulling accompanied by more anger expressions than the other two treatments. Partial reinforcement and extinction produced an increase in responding and moderate increases in sadness and anger expressions.

The data on the emotional reactivity accompanying extinction were subsequently linked to physiological changes during extinction with infants. Lewis et al. (2004) found

that heart rate, respiratory sinus arrhythmia (RSA), and cortisol increases accompany the transition from acquisition to extinction. Likewise, Millar and Weir (2007) observed that 5- to 10-month-old risk-classified infants showed delayed cardiac reactivity during the transition between reinforcement and nonreinforcement training. Both studies used very brief training periods followed by brief extinction. Moreover, in Millar and Weir's study, infants spanning the entire age range of 5 to 10 months were trained and tested with identical parameters and analyzed together as a homogenous group. It is worth noting that other infant learning preparations involving operant conditioning have shown that infants require more acquisition training at younger ages (*see* Hartshorn, Rovee-Collier, Gerhardstein, et al., 1998). In light of the cascade of developmental changes in learning and memory that occur during the first year of life, this element of the design must be considered to be an experimental confound too large to ignore. Experiments with such oversights do little to inform about the impact of extinction learning or retention, but they do provide some evidence that the contingency change during extinction is detectible by young infants and that the treatment could elicit a physiological alteration in regulatory processes.

However, in infant learning research research, not all nonreinforcement periods are created equal. They have frequently been included in conditioning procedures to measure learning. Investigations of learning and memory using the mobile conjugate reinforcement task with human infants, for example, have included nonreinforcement periods during long-term and short-term retention testing to allow infants to respond based upon what they have brought into the session, (Rovee-Collier, 1996). Rovee and Fagen (1976) found that 3 min of nonreinforcement immediately following acquisition

was the optimal duration to assess immediate retention of the task with 3-month-olds. It is unclear whether procedural differences between different paradigms would permit the development of a useful heuristic for using extinction treatments across preparations with infants, but it would be useful to start with a well-established paradigm to begin to identify critical procedural factors in producing extinction during infancy.

Perhaps the most glaring omission in the literature is that no models have been proposed to explain what, if anything, is learned by human infants during the extinction session, or what learning mechanisms may be engaged by an extinction procedure. For example, extinction learning by infants may be subject to the same potential mechanisms as have been described above with nonhuman animals or human adults, such that the original association is weakened or replaced by new learning. But it may be the case that the memory of the original association is still in tact.

An initial step in identifying potential mechanisms is to establish the role of post-acquisition information on the retrieval of previously conditioned responses. Research has indicated that human infants are sensitive to changes in contingency and to post-event information. Riviére et al., (2000) trained 5- to 9-month-olds to press a touch-screen to see a 20 s cartoon clip under various fixed interval schedules. They observed an increase in the post-reinforcement pause for all participants on the trials immediately following a schedule change. This adjustment was taken as evidence that infants were surprised by the change.

Rovee-Collier (Rovee-Collier, Borza, Adler, & Boller, 1993; Rovee-Collier, Adler, Borza, 1994) have demonstrated that infants encode what happens immediately after training and that this new information can interfere expression of prior training. In a

series of experiments with 3-month-olds trained in the mobile conjugate reinforcement paradigm, Rovee-Collier et al. (1993) found that a 3-min passive exposure to a stationary novel mobile at the end of the second session did not disrupt 24-hr retention of the foot-kicking response. However, if infants were exposed to a novel mobile while it was being noncontingently moved by the experimenter, then it disrupted responding to the original mobile during the subsequent test. One day after exposure, infants responded significantly above their baseline rate when they were tested with the mobile exposed or another novel mobile, but not with the original acquisition mobile, suggesting that the original training memory had been updated by the most recently exposed cue. However, when the passive exposure was presented in a separate session 24 hr after training, infants responded robustly to both mobiles. The authors concluded that information that infants encounter after an event has ended can influence subsequent retention of the original event as well as the probability that they will remember the postevent information as having been part of the original event, but only if the postevent occurs while the original event is still in working memory.

This finding was replicated and extended by Rovee-Collier, Adler, & Borza (1994) who showed that exposing the novel mobile following increasingly longer delays (24, 48, or 72 hr) produced the same effect: infants passively exposed to a previously untrained mobile respond robustly when tested 24 hr later with the novel, but not the original mobile. Thus, infants' expression of a previously learned contingency may be altered or eliminated by new information presented after the response has been acquired.

More direct evidence of the impact of extinction on young infants' memory has recently emerged from our lab. Cuevas, Rovee-Collier, and Learmonth (2008) examined

the renewal effect with 3-month-olds using the mobile conjugate reinforcement paradigm. Infants were trained for 9 min per day for 2 consecutive days. During acquisition, a colorful, patterned cloth was draped over the sides of the infant's home crib and served as a distinctive contextual cue. At the end of acquisition, infants received a 6-min extinction manipulation with the original mobile in a different context. Independent groups were tested 24 hr later in the acquisition context (group ABA), the extinction context (group ABB), or a neutral context (group ABC). Infants exhibited an extinction effect only if they were tested in the extinction context, even though they did not exhibit a significant decrease in responding during the extinction manipulation per se. These findings indicate that this effect can be modulated by contextual cues.

In the present experiment, we applied the same training and extinction procedures in the absence of distinctive contexts to determine whether infants would detect the disruption of the response-outcome contingency without the assistance of contextual cues. There were three main objectives in the present series of experiments. First, we asked if infants would demonstrate an extinction effect without distinctive acquisition and extinction contexts. We hypothesized that infants would be able to detect the change in contingency during extinction and that their conditioned responding would be reduced during subsequent testing. We made no prediction as to whether or not they would decrease responding during the extinction procedure. A second goal was to determine the relative permanence of the extinction and acquisition memories by testing over increasing delays within the normal forgetting function for the task. Three-month-olds normally retain the foot-kicking response for 5 days (Hayne, 1990). It was expected that retention testing early in this time window would yield baseline responding, but that spontaneous

recovery (responding elevated relative to baseline) would be observed at some point before the task would otherwise be forgotten. Spontaneous recovery was operationally defined as significant retention of the conditioned response that is observed during the long-term retention test after greater delays than 24 hr since the manipulation. An extinction effect must be observed in the Day 1 test, followed by a subsequent return in elevated responding at later test delays. Finally, we asked what was the optimal duration and timing of the extinction procedure. We expected that a longer nonreinforcement period would be more effective in reducing responding, over the long term and that a shorter duration might be more likely to produce spontaneous recovery.

In this way, we sought to systematically characterize the extinction process in 3-month-old human infants. In addition to affording more precise, systematic methodology for researchers, understanding the persistence of old memories, how infants detect contingencies, and ultimately the most effective way to eliminate learned responses are central to the ways in which caregivers, medical and health professionals, and researchers interact with infants and interpret their behavior.

General Method

Participants

Healthy human infants (N = 170; male, n = 93, female, n = 77), between 88 and 112 days of age (M = 98.69, SD = 5.41), were recruited from published birth announcements, a commercial mailing list, and by word of mouth. Participants were randomly assigned into groups (n = 6 or 7) as they became available for study. Infants who were born prematurely (four weeks preterm) were tested according to their due date rather than their actual date of birth in order to correct for developmental delays (n = 5).

Additional infants were excluded due to crying (n = 38), failure meet the learning criterion (n = 23; more details about the learning criteria are described in the Procedure section below), illness (n = 5), high baseline (n = 4), scheduling conflicts (n = 2), and experimenter error (n = 1). The parents' mean educational attainment, as reported by 95% of the sample, was 15.90 years (SD = 0.40), and parents' mean occupational status (Nakao & Treas, 1992[1]), as reported by 84% of the sample was 68.44 (SD = 2.80). Participants were African-American (n = 3), Asian (n = 18), Caucasian (n = 107), Hispanic/Latino (n = 16), mixed race/ethnicity, or other (n = 26).

Apparatus

Reinforcement was provided by one of two five-piece, colorful, hand-painted wooden mobiles (Nursery Plastics, Inc.). Prior to participation, none of the infants had been exposed to any of these models, which are not commercially available. The models used were counterbalanced within groups but were held constant across experimental sessions for each participant.

Inverted, L–shaped, metal mobile stands (BCS, South Plainfield, NJ) were clamped to opposite crib railings so that their overhead suspension bars protruded toward the center of the crib. A mobile was suspended from the hook closest to the experimenter, approximately 25–30 cm above the infant's chest. A white ribbon was looped around the infant's right ankle and was connected without slack to one of the overhead suspension bars. During reinforcement phases, the ribbon was connected to the suspension bar that held the mobile, with the result that each kick activated the mobile at a rate and with an intensity proportional to the rate and intensity of kicking (Figure 1). During nonreinforcement phases, the ribbon was connected to the "empty" suspension

bar; in this arrangement, the mobile remained in view, but the infants' kicks could not activate it (Figure 2).

Insert Figures 1 & 2 here

During all experimental phases a trained observer, positioned out of the infant's view, recorded the number of kicks per minute of the foot with the ribbon attachment. A kick was defined as any horizontal or vertical movement of the leg with the ribbon attachment that at least partially retraced its arc of excursion in a smooth continuous motion (Rovee & Rovee, 1969). A second observer, also stationed out of the infant's line of sight, independently recorded kicks per minute for 180 min of 12 randomly selected sessions of seven infants. A Pearson product-moment correlation computed over their joint response counts per minute yielded an interobserver reliability coefficient of 0.96. This is consistent with previously reported interobserver reliability coefficients in studies using the mobile conjugate reinforcement procedure (Fagen et al., 1981)

Procedure

The infants were trained and tested in a supine position in their home cribs at a time of day when their caregiver thought they were likely to be playful and alert. This time differed from infant to infant but remained relatively constant across sessions for a given infant. There were three visits for each participant in the first experiment and four visits in the second experiment.

All groups received operant training on 2 successive days, 24 hr apart. Session 1 was identical for all groups, and began with a 3 min nonreinforcement period, or *baseline* (BL) phase, from which the infant's unlearned activity level, or operant level, was

ascertained. Next, the ribbon was moved to the stand containing the mobile for 9 minutes of reinforcement (*acquisition*). Session 2 began with reinforcement for either 6 or 9 min, depending on the experimental condition. Each participant was required to achieve a minimum level of responding to be included in the final sample. The learning criterion was the same as used previously in research on operant learning with infants (Rovee & Rovee, 1969; Fagan, Morrongiello, Rovee-Collier, & Gekoski, 1984) Each participant was required to meet an absolute response rate of 150% operant level (1.5 times the baseline rate of kicking) for 2 out of 3 consecutive min during acquisition. Failure to meet this criterion meant that the participant was eliminated from the experiment and all subsequent analyses.

The extinction manipulation was presented either immediately following the end of acquisition or in a separate session, 1-5 days later, and lasted 2, 3, 4, or 6 min, depending on the experiment. Long-term retention of the conditioned response was assessed during a 3-min nonreinforcement period (*long-term retention test*, LRT) in a final session between 1 and 6 days following the end of acquisition.

Retention Measures

Retention was assessed at two points: during the final 3-min of acquisition (*immediate retention test*, IRT) and during a 3-min nonreinforcement period at the outset of the final session (*long-term retention test*, LRT). Test performance provides an individual assessment of each participant's memory of the training event before and after the extinction manipulation. The primary retention measure is the *baseline ratio* (BR), which expresses the response rate during the LRT relative to the BL (BR= LRT / BL; H_0 = no retention or BR = 1.00). A BR significantly > 1.00 provides evidence that the

original memory was preserved through extinction. The *retention ratio* (RR) provides an index of the extent of an infant's retention after the delay, expressed as a proportion of LRT relative to IRT (RR = LRT / IRT). A RR of 1.00 indicates that no forgetting (or extinction) has occurred from the end of acquisition to LRT; a RR significantly < 1.00 indicates that conditioned responding decreased between the end of acquisition and the LRT.

Table 1 presents descriptive statistics for each group's absolute response rates (Baseline, IRT, LRT) and Table 2 presents each group's retention measures (BR, RR) for Experiments 1a and 1b. Prior to performing all analyses, the BRs and RRs of each group were subjected to Dixon's test for outliers (Kanji, 1999, p. 45). Dixon's test for outliers is used for small sample sizes to investigate the significance of the difference between a suspected extreme value and other values in the sample. When an outlier was found, it was replaced with the next highest or lowest ratio within that group, and one degree of freedom was lost in subsequent analyses. Across all 170 participants (340 ratios altogether), eight BRs and five RRs were outliers. The resulting correction only altered the significance level of one *t* value.

Experiment 1a

Immediate Extinction, 18-min Training Procedure

In an experimental analysis of the renewal effect with 3-month-old human infants, Cuevas et al. (2008) presented an extinction manipulation in a distinctive context for 6 min immediately following an 18-min acquisition procedure identical to that used in the present experiment. The same procedure was adopted in this study, but infants were

tested in their home cribs without a distinctive experimental context during acquisition and extinction.

As described above, Session 1 was identical for all test conditions. In Experiment 1a, 3-month-olds were exposed to a 6-min extinction period immediately following acquisition. Independent groups were trained on 2 consecutive days (acquisition) and subsequently tested for long-term retention (LRT) 1, 3, 5, or 6 days after Session 2 (Figure 3).

Insert Figure 3 here

In addition, forgetting control groups received an extinction manipulation lasting only 3 min were tested after the same delays. In previous studies of infant memory, responding during a 3-min nonreinforcement phase immediately after mobile conditioning in Session 2 (the *immediate retention test*, or IRT) has reflected responding in the final 3 min of acquisition. As a result, responding during the IRT has routinely provided a measure of both the final level of learning and retention after no delay (for review, see Rovee-Collier & Fagen, 1981). In fact, after a 3-min nonreinforcement period, infants exhibit no forgetting for 3 days, and their forgetting is not complete until 6 days after training (Galluccio, 2005; Hayne, 1990). As a result, these groups enabled decreased responding due to extinction to be distinguished from decreased responding due to forgetting.

Results

In Experiment 1a, the duration of the extinction manipulation affected infants' responding during the long-term retention test (LRT). A one-way analysis of variance

(ANOVA) on the mean baseline ratios (BRs) of the eight independent test groups indicated that the groups differed significantly [$F(7, 38) = 6.79$, $p < .01$]. Bonferroni post hoc analyses indicated that the 6-min extinction groups had lower mean BRs than the 3-min extinction groups both 1 and 3 days after acquisition. These results indicate that the 3-min extinction groups exhibited significant retention of the footkicking response, but the 6-min extinction groups did not.

An identical one-way ANOVA over the mean RRs of the eight test groups revealed that they also differed significantly [$F(7, 38) = 3.00$, $p < .05$]. A Levene's test for equality of variances (Levene, 1960) indicated that the assumption of homogeneity was not met [$(7, 38) = 2.73$, $p < .05$]. A post hoc analysis with Bonferroni corrected alpha levels revealed a significant difference only between groups tested on Day 1, such that a response decrement between the end of acquisition and the long-term retention test was observed following the 6-min treatment but not after the 3-min treatment. The RR analysis, combined with the BR analysis indicated that only the 6-min extinction manipulation impaired retention of the acquisition memory 24 hr later.

These effects were confirmed by a two-way ANOVA over the group BRs with Extinction Duration (3- or 6-min) and Test Delay (1, 3, 5, or 6 days) as between-subjects factors. A main effect of Extinction Duration [$F(1, 39) = 35.74$, $p < .01$] was found. Because there were fewer than three levels of Extinction Duration, standard post hoc tests could not be completed. Pair-wise comparisons indicated that the mean BRs for groups that had received 3 min of extinction were higher than for 6-min extinction groups. No main effect of Test Delay or interaction between the variables Extinction Duration of and Test Delay was obtained. An identical two-way ANOVA over the mean RRs revealed a

significant main effect only of Extinction Duration [$F(1, 47) = 10.93$, $p < 0.05$]. Pair-wise comparisons indicated that groups that had received 6 min of extinction had lower RRs than those that had received only 3 min of extinction.

Although an ANOVA indicates whether the BRs and RRs of the test groups significantly differed; it does not indicate whether any group exhibited significant retention. Directional, one-sample *t* tests were used to compare each group's mean BR and RR against the theoretical ratio of 1.00. None of the 6-min extinction groups had a mean BR significantly greater than 1.00 (Figure 4), and all had mean RRs significantly less than 1.00 (Figure 5). Together, these two sets of results provide convergent evidence that the extinction effect persisted throughout all delays following the 6-min extinction treatment and that no spontaneous recovery was exhibited.

Insert Figures 4 & 5 here

In contrast, the 3-min forgetting control groups exhibited significant retention of the conditioned response after all test delays but the longest. One-sample, directional *t* tests using Bonferroni adjusted alpha levels of .006 per test ($p = .05/8$) indicated that forgetting control groups tested after 1 and 3 days exhibited significant retention of the conditioned response [Day 1: $t(4) = 4.13$, $p < .006$; Day 3: $t(5) = 3.42$, $p < .006$], and the Day-5 group exhibited marginally significant retention [$t(5) = 3.65$, $p = .007$]. These results are summarized in Table 2.

Identical analyses of the mean RRs indicated that the 3-min extinction test groups did not exhibit a significant response decrement with the Bonferroni correction. The nonsignificant RRs indicate that retention was complete. Taken together, the RRs

combined with the BR analysis confirm that the 3-min extinction procedure did not affect the normal forgetting function of 3-month-olds who are trained in the mobile conjugate reinforcement paradigm.

A repeated measures ANOVA was conducted over infants' absolute responses during each experimental phase (the BL, the IRT, and the LRT) as the within-subject factor and Test Delay and Extinction Duration as between-subject factors. Mauchly's test (1940) indicated that the assumption of sphericity had been violated [$_X^2$ (2) = 11.56, p < .01]; therefore the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.75$). The results indicated that there was a significant main effect of Phase [$F(1.60, 65.55) = 34.10$, $p < .01$]. The Sidak adjustment for multiple comparisons ($p = .05$) revealed that responding during the IRT was significantly higher than the BL or the LRT. Responding during the LRT was higher than the BL. Additionally, main effects were observed both for Extinction Duration [$F(1, 41) = 17.78$, $p < .01$] and Test Delay [$F(3, 41) = 3.15$, $p < .05$]. Because fewer than three Extinction Duration groups were compared, post hoc analyses were not conducted. However, pair-wise comparisons indicated that responding in the 3-min test groups was significantly higher than in the 6-min test groups. The Sidak adjustment for multiple comparisons indicated that responding in the Day-3 test group was higher than in the Day-6 group. A significant interaction between Phase and Extinction Duration was revealed [$F(1.59, 63.61) = 11.19$, $p < .01$]. The 3-min extinction groups responded significantly higher during the LRT than 6-min extinction groups.

Finally, separate repeated-measures ANOVAs over infants' absolute responses during successive minutes of the extinction manipulation indicated that infants'

responding did not change significantly, whether the extinction procedure lasted 6 min [$F(5, 100) < 1$] or 3 min [$F(2, 40) = 1.92$, *ns*]. These results constitute a major finding of the present study. Each group's extinction curve is plotted in Figure 8.

Figure 8 about here

Experiment 1b

Immediate Extinction, 15-min Training Procedure

Infants in Experiment 1a that received 6 min of nonreinforcement did not reduce responding during the manipulation but did demonstrate an extinction effect during the long-term retention test. This effect persisted throughout the normal forgetting function of the mobile conjugate reinforcement task at 3 months; no spontaneous recovery was observed. In Experiment 1b, the duration of the extinction manipulation was reduced from 6 min to 4 min in order to test the possibility that a shorter extinction session might facilitate spontaneous recovery (Figure 9). It was anticipated that the relative proportion of reinforcement in acquisition and nonreinforcement in extinction might impact later performance. In an effort to preserve the proportion between the amounts of acquisition and extinction during the second session, the duration of acquisition was also reduced from 9 min to 6 min. Thus, the total duration of acquisition over both training sessions was 15 minutes. As in Experiment 1a, independent groups of infants receiving half of the duration of extinction (2 min) were included for comparison purposes. Long-term retention testing was conducted on Day 1, 3, or 5.

Insert Figure 9 here

Results

One-way ANOVAs indicated that the mean BRs and RRs of the six test groups did not differ. One-sample, directional *t* tests with Bonferroni adjusted alpha levels of .008 per test ($p = .05/6$) revealed that 4-min groups did not exhibit significant retention after any delay. However, the Day 1 and 5 test groups exhibited RRs significantly below 1.00 [Day 1: $t(5) = 4.80$, $p < .008$; Day 5: $t(4) = 4.75$, $p < .008$; Table 2; Figure 10]. In the absence of a BR significantly above 1.00, the RR results are meaningless.

Insert Figure 10 here

The only group that had received 2 min of extinction and had a mean BR significantly greater than 1.00 was the Day 1 test group [$t(4) = 6.33$, $p < .008$]. Because the Day 1 test group also had a mean RR significantly less than 1.00 [$t(5) = 8.42$, $p < .008$], its retention of conditioned responding was only partial. The 3-day group also had an RR significantly less than 1.00 before the Bonferroni alpha level correction was applied, but after the correction, this ratio was nonsignificant, suggesting that the Bonferroni correction was too conservative (Table 2; Figure 11). Because that group did not exhibit significant retention on the primary BR measure, the null result on the RR measure is meaningless.

Insert Figure 11 here

A three-way repeated measures ANOVA was performed over mean response rates with Phase (the Baseline, the IRT, and the LRT) as the within-subjects factor and Test Delay and Extinction Duration as between-subject factors. Mauchly's test (1940)

indicated that the assumption of sphericity had been violated [$_X^2$ (2) = 10.33, $p < .01$], therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = 0.71). The results revealed significant main effects of Phase [F(1.55, 48.01) = 14.86, $p < .01$] and Extinction Duration [F(1, 31) = 10.13, $p < .01$]. Presumably, this was due to acquisition and extinction of the response because responding during the IRT (M = 15.56, SE = 1.84) was higher than during the BL (M = 8.20, SE = 0.97) and the LRT (M =9.63, SE = 1.16). The higher responding during the IRT than the BL indicates that the response was learned; higher responding during the IRT than the LRT indicates either that the conditioned response was extinguished or forgotten. The main effect of Test Delay and the three-way interaction were not significant. If the effect were due to forgetting, then the main effect of Test Delay should have been significant. Pair-wise comparisons indicated that responding was higher on average by infants who had received the 2-min extinction treatment (M = 14.61, SE = 1.53) than the 4-min treatment (M = 7.65, SE = 1.57). This result was not expected, but it may reflect individual differences in activity level across groups. Group mean responses are plotted in Figure 12 and 13.

Insert Figures 12 & 13 here

In order to determine if infants exhibited a within-session response decrement during the extinction manipulation, a repeated measures ANOVA was conducted over the number of kicks per minute during each of the 4 min of extinction (Figure 14). Group was the between-subjects factor. There was no significant decrease in responding over

successive minutes [$F(3, 45) < 1$, *ns*], meaning that an extinction effect was not observed during the manipulation.

Insert Figure 14 here

Experiment 2a

Delayed Extinction 24 hr following an 18-min Acquisition Period

Infants in Experiments 1a and 1b failed to exhibit spontaneous recovery. In Experiment 2a, a delay was inserted between acquisition and extinction to determine if presenting the extinction manipulation in a separate session might facilitate spontaneous recovery. The procedure used in Experiment 2a was identical to Experiment 1 except that the 6-min extinction session was always presented 24 hours after the end of acquisition, on Day 1 (Figure 15). Independent groups were tested for retention on Day 2, 3, 5, or 6 relative to the end of acquisition (1, 2, 4, or 5 days after the extinction procedure). In order to minimize the use of participants, 3-min forgetting control groups were tested only after the shortest (Day 2) and longest (Day 6) retention intervals. Had these groups responded differently from one another, additional groups would have been added.

Insert Figure 15 here

Results

Descriptive statistics for Experiment 2 are summarized in Table 3. A summary of *t* test values for BR and RR are presented in Table 4. One-way ANOVAs indicated that the mean BRs and RRs of the six test groups differed significantly [BRs: $F(5, 31) = 4.52$,

$p < .05$; RRs: $F(5, 31) = 11.67$, $p < .01$]. The assumption of homogeneity of variance was not met for the BR [Levene (5, 31) = 7.87, $p < .01$] or the RR measures [Levene (5, 31) = 4.71, $p < .01$]. Games-Howell post hoc analysis indicated that none of the pair-wise comparisons between BRs were significant, and only the comparison between the RRs of the Day-2 test groups (3 vs. 6 min extinction duration) differed from one another.

A two-way ANOVA over the group mean BRs for factors of Extinction Duration (3 or 6 min) and Test Delay (1, 3, or 5 days) yielded significant main effects of Extinction Duration [$F(1, 31) = 6.46$, $p < .01$] and Test Delay [$F(3, 31) = 3.98$, $p < .01$] as well as a significant interaction [$F(1, 31) = 7.68$, $p < .01$]. A post hoc analysis did not reveal significant differences between key comparison groups.

An identical two-way ANOVA over the group RRs yielded a significant main effect of Extinction Duration [$F(1, 31) = 14.29$, $p < .01$] and Test Delay [$F(3, 31) = 10.85$, $p < .01$] and a significant interaction [$F(1, 31) = 22.26$, $p < .01$]. Because fewer than three levels of Extinction Duration were analyzed, no post hoc analyses were conducted, but pair-wise comparisons revealed that responding was significantly greater overall by groups that had received 6 min of extinction. A Bonferroni post hoc analysis indicated that Day 2 groups differed significantly from the other test groups.

One-sample, directional *t* tests indicated that the 6-min extinction test groups had mean BRs significantly greater than 1.00 after the two shortest delays [Day 2: $t(5) = 2.60$, $p < .05$; Day 3: $t(5) = 2.54$, $p < .05$; Figure 16]. However, when the Bonferroni alpha level adjustment of .008 per test ($p = .05/6$) was applied, no group had a mean BR significantly above 1.00. Groups that received a 3 min extinction procedure and were tested after the shortest (2 days) or longest (6 days) delay following acquisition exhibited

significant retention; however, when the Bonferroni alpha level adjustment was applied, these effects were not significant.

Identical *t* tests indicated that all 6-min extinction groups, except the Day-2 group, had RRs significantly less than 1.00 [Day 3: $t(4) = 6.82$, $p < 0.001$; Day 5: $t(5) = 2.72$, $p < .05$; Day 6: $t\ (5) = 5.89$, $p < 0.001$] (Figure 17). When the Bonferroni alpha level adjustment of .008 for each test was applied, only groups tested on Day 3 and 6 had RRs significantly less than 1.00. Likewise, both 3-min extinction groups had RRs significantly less than 1.00 [Day 2: $t(5) = 7.12$, $p < .001$; Day 6: $t(5) = 2.12$, $p < .05$]. However, after the Bonferroni alpha level adjustment, only the Day-2 group did. Considered jointly, these results indicated that groups that had exhibited BRs greater than 1.00 only exhibited partial retention of the conditioned response; the only group to exhibit complete retention was the 6-min extinction group tested on Day 2.

Insert Figure 16 here

Insert Figure 17 here

A repeated measures ANOVA was performed over the three experimental phases (the BL, the IRT, and the LRT), with Test Delay and Extinction Duration as between-subject factors. There was a significant main effect of Phase [$F(2, 62) = 34.96$, $p < .01$] and an interaction between Phase and Test Delay [$F(6, 62) = 2.69$, $p < .05$]. A Bonferroni's post hoc analysis did not reveal significant differences between the four test delays. Pair-wise comparisons using the Sidak adjustment indicated that response rate was higher during the IRT than the BL and LRT. Each test group responded at a higher

rate during the IRT than the BL, and the groups tested on Days 3, 5, or 6 responded less during the LRT than the IRT. The infants who received a 6-min extinction treatment and were tested on Day 2 responded more during the LRT than the IRT, but, infants who received a 3-min extinction treatment responded less on Day 2 during the LRT than they had during the IRT. These results are consistent with the RR analysis. Thus, presenting the extinction manipulation for 6 min in a separate session did not impair retention of conditioned responding 24 hr later. Mean responses by experimental and forgetting control groups during each phase are plotted in Figures 18 and 19, respectively.

Insert Figure 18 here

Insert Figure 19 here

Infants' responding did not decrease during the extinction manipulation (Figure 20). A repeated measures ANOVA of infants' responses was performed over successive minutes of the delayed extinction manipulation. This analysis yielded no effect of extinction minute for infants given a 3-min extinction procedure [$F(1, 10) = 3.53$, *ns*]. For the groups that had received the 6-min extinction treatment, Mauchly's test (1940) indicated that the assumption of sphericity had been violated [$_X^2$ (14) = 30.44, $p < .01$]; therefore the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.19$). With this adjustment, a marginally significant main effect of Extinction Minute was revealed [$F(2.81, 56.09) = 2.72$, $p < 0.06$]. A Sidak adjustment for multiple pair-wise post hoc comparisons indicated that the marginal effect was solely attributable to a higher rate of responding during Mins 2 and 3 than in Min 1; no other

pair-wise comparisons differed. As before, then, infants failed to exhibit an extinction effect at the time of the extinction manipulation.

Insert Figure 20 here

Experiment 2b

Delayed Extinction 24 hr following a 15-min Acquisition Period

Infants in Experiments 1a and 2a did not demonstrate spontaneous recovery of the conditioned response. The procedure in Experiment 2b was identical to the procedure used in Experiment 1b, with two exceptions. First, the extinction procedure occurred 24 hr after acquisition in Session 2. Second, an extinction criterion was implemented. Extinction lasted at least 4 minutes but no more than 6 minutes. The extinction session was terminated when responding decreased to the individual's own operant level for at least 2 min. If an individual did not demonstrate baseline responding, extinction lasted 6 min. Four infants tested on Day 2, three infants tested on Day 3, and one infant tested on Day 6 met the 4-min extinction criterion; remaining infants received the full 6-min extinction procedure. Long-term retention testing was carried out 2, 3, or 6 days after the end of acquisition (Figure 21). If the Day-3 and Day-6 test groups were different from one another, additional intermediate groups would have been included to identify change points in retention.

Insert Figure 21 here

Results

A one-way ANOVA indicated that the mean BRs and RRs of the three 4-6-min extinction groups did not differ [BR F (2, 17) < 1, *ns*; RR F(2, 17) < 1, *ns*]. One-sample, directional t tests comparing each mean BR with 1.00 revealed that only the Day-2 test group had a BR significantly greater than 1.00 with a Bonferroni corrected alpha level of $p = .017$ ($p = .05/3$) [$t(5) = 3.58$, $p < .008$] (Figure 22). Identical one-sample, directional t tests revealed that only RRs of the Day-2 and Day-3 groups were significantly below 1.00 using the Bonferroni correction [Day 2: $t(4) = 5.05$, $p < .01$; Day 3: $t(5) = 6.26$, $p < .01$] (Figure 23). The RR analysis indicated that the Day-2 group's retention the response was only partial.

Insert Figure 22 here

Insert Figure 23 here

A three-way repeated measures ANOVA over responses during the three experimental phases (the BL, the IRT, and the LRT), with Test Delay and Extinction Duration as between-subject factors. Mauchly's test (1940) indicated that the assumption of sphericity had been violated [χ^2 (2) = 8.62, $p < .01$]; therefore, the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.46$). The resulting analysis yielded significant main effect of Phase [$F(1.30, 15.55) = 7.66$, $p < .01$], indicating that overall responses differed during the BL, IRT, and LRT. According to pairwise comparison with the Sidak adjustment for multiple comparisons, responding during the BL was lower than during the IRT but the difference between the IRT and the LRT was not significant. A Bonferroni post hoc analysis did not reveal a significant

difference between the test delay groups. No other main effects or interactions emerged from this analysis. Post hoc analyses were not conducted for the Extinction Duration variable because fewer than three levels were included. Figure 24 shows mean responding during each session.

Insert Figure 24 here

Finally, a repeated measures ANOVA of responding over successive minutes of the 4-6-min extinction manipulation indicated that responding did not decrease [$F(5, 30) < 1$, *ns*; Figure 25]. Even when only infants who had met the extinction criterion were included in the analysis, there was still no significant main effect of Extinction Minute [$F(1, 6) < 1$, *ns*]. As before, this result indicates that infants did not exhibit an extinction effect at the time of the delayed extinction manipulation. Surprisingly, the extinction criterion used in this experiment was not a good indicator of within-session response reduction. If it had been, then those infants who met the criterion early and received only 4 min of extinction would have shown a significant decline in responding during the treatment.

Insert Figure 25 here

Experiment 2c

Delayed Extinction 24 hr prior to the LRT procedure

The delayed extinction procedure in Experiments 2a and 2b did not promote spontaneous recovery. The pattern of results observed in Experiment 2a and 2b were similar, but 2b failed to produce statistical significance in the ANOVAs and *t* tests over all test groups but the shortest delay. This result, combined with the failure of forgetting control groups in Experiment 1b to exhibit significant retention 3 or 5 days after acquisition, suggests that an 18-min acquisition period with a delayed extinction procedure presented closer to the long-term retention test might be more effective at extinguishing the conditioned response, while perhaps also promoting spontaneous recovery.

In Experiment 2c, extinction was presented in a temporally discrete session 24 hr prior to the LRT over increasing delays since acquisition. The procedure in this experiment was the same as Experiment 2a, with the exception that extinction was always administered 24 hr prior to LRT. Thus, groups received the extinction procedure on Day 2 (LRT Day 3), Day 4 (LRT Day 5), or Day 5 (LRT Day 6). Groups with only 3 min of extinction were tested after the shortest and longest test delays (Figure 26).

Insert Figure 26 here

Results

Separate one-way ANOVAs over the mean BRs and RRs revealed no significant difference between the test groups [BR: $F(4, 29) < 1$, *ns*; RR: $F(4, 27) = 1.97$, *ns*]. One-sample, directional *t* tests indicated that the 6-min groups did not have BRs significantly above 1.00 when the Bonferroni alpha level correction of $p = .01$ ($p = .05/5$) was applied. Mean BRs of each group are shown in Figure 27.

An identical one-way ANOVA over the mean RRs for groups trained with the 6-min extinction procedure revealed that the Day-3 and Day-5 groups had mean RRs that were not significantly below 1.00 (i.e. no forgetting), but the mean RR of the Day-6 exhibited an RR significantly lower than 1.00 with the Bonferroni corrected alpha level of $p < .01$ [$M = 0.43$, $t\ (4) = 5.50$, $p < .01$] (Figure 28). However, because the BRs were not significantly above 1.00, the RR analyses were meaningless.

Insert Figure 27 here

Insert Figure 28 here

Directional, one-sample *t* tests comparing the mean BRs of the 3-min extinction groups with 1.00 indicated that none exhibited retention when tested 24 hr later. Both had mean BRs that were not significantly greater than 1.00. Identical analyses comparing their mean RRs with 1.00 again confirmed the Day-6 BR result. Only the Day-6 group had a mean RR significantly below 1.00 with the Bonferroni alpha level correction [Day 3, $t(5) = 2.29$, $p < .05$; Day-6, $t(4) = 12.08$, $p < .01$] but only the latter was significant using the Bonferroni alpha correction. The shorter extinction duration presented 24 hr prior to testing did not permit long-term retention of the task.

A three-way repeated measures ANOVA with Phase (the BL, the IRT, the LRT) as the within-subject factor and Test Delay and Extinction Duration as between-subject factors yielded a significant main effect of Phase [$F(2, 50) = 25.95$, $p < .01$]. Pair-wise comparisons using the Sidak adjustment indicated that responding during the IRT was significantly higher than responding during the BL or LRT. Group mean responses over

each minute by experimental and forgetting control groups are shown in Figures 29 and 30, respectively. No other main effects or interactions were significant.

Insert Figure 29 here

Insert Figure 30 here

Finally, a repeated-measures ANOVA indicated that responding over successive minutes of the extinction manipulation changed significantly [$F(5, 75) = 3.47$, $p < .01$]. Pair-wise comparisons using the Sidak adjustment showed that responding was significantly *higher* during the fifth minute of extinction than during the first (Figure 31). Rather than reducing conditioned responding during the extinction procedure, the infants actually increased it, even 24 hr later. This result cannot be due to behavioral arousal from training.

Insert Figure 31 here

Discussion

This series of experiments suggests that an extinction manipulation can eliminate a conditioned response at 3 months of age. Yet, this conclusion is drawn with caution. In spite of the failure of all groups of 3-month-olds to inhibit their ongoing behavior *during* the extinction manipulation, the extinction effect was apparent later. Testing independent groups at multiple time points across the normal forgetting function for the mobile conjugate reinforcement task demonstrated that once the extinction effect was observed, the effect persisted throughout the normal retention interval. The 3-min forgetting

control groups, which exhibited significant retention, confirms this conclusion. Although these data alone do not indicate whether or not the original response was *eliminated*, Cuevas et al. (2008) were unable to reactivate an extinguished response at 3 months, despite several attempts to do so.

When extinction was presented immediately after acquisition, 6-min was a sufficient duration of training to produce a robust extinction effect. In previous research using the same task (Gekoski, 1977; Hayne, 1990), 3 min of nonreinforcement at the end of acquisition was not a sufficient duration of extinction to produce a subsequent extinction effect. In the present study, significant retention was observed 1, 3, 5, and possibly 6 days after the 3-min procedure.

Four minutes was also an appropriate duration of extinction for 3-month-olds to learn the new contingency (i.e., responding produces no reinforcement). Each test group that received a 4-min extinction manipulation also failed to show spontaneous recovery after any test delay. The groups that received a 2-min extinction treatment and a truncated acquisition phase demonstrated partial retention on Day 1 following Session 2, but infants failed to exhibit significant retention when they were tested on Day 3 or 5. The failure of the any group to show significant retention for longer than 1 day, combined with the significant response decrement identified by RR analysis, suggests that the truncated reinforcement training regimen may have contributed to the failure of groups to exhibit spontaneous recovery. Infants significantly increased responding during the IRT, relative to baseline, so infants did learn the response. Ohr, Fagen, Rovee-Collier, Hayne, & Vander Linde (1989) found that longer acquisition produces longer retention of the task, but not better within-session learning. Further investigation is necessary to

determine if the relation between the duration of extinction and the duration of acquisition controls behavior following extinction.

Infants in Experiment 1a and 1b did not reduce responding during the extinction manipulation, but the extinction effect was expressed during the subsequent LRT. The failure of infants to appropriately adjust responding during the manipulation is characteristic of the behavioral persistence commonly observed with infants in a variety of tasks (Diamond, Cruttenden, & Neiderman, 1994; Diamond, 1995; Fagen et al., 1984; Riviére et al., 2000; Rovee-Collier, et al., 2001; Thelen et al., 2001). Fagen, Yengo, Rovee-Collier, and Enright (1981) trained 3-month-olds to discriminate between a mobile that predicted response-contingent reinforcement and another that predicted nonreinforcement. Training consisted of alternating 2-min blocks with each mobile. Infants discriminated between the two stimuli during a cued-recall test 21 days after training, but the authors pointed out that most did not reduce the previously reinforced motor response during the prior training session. Thus, infants' failure to reduce responding during a nonreinfocement period cannot be taken as evidence of a failure to learn.

Rescorla (2004a) advocated assessing extinction both during the opportunity to learn (t1) and in a subsequent test following some delay (t2). The common assumption is that responding during t1 reflects what is learned under current (extinction) conditions. He argued that responding at t1 is necessarily confounded by the learning that has occurred during the prior (reinforcement) treatment. This caution applies to immediate extinction procedures, when the subject is likely to be experiencing a variety of emotional consequences resulting from the altered stimulus properties.

Data with infants using the mobile conjugate reinforcement task have indicated that a brief nonreinforcement period can actually facilitate long-term retention, depending on when they occur relative to acquisition (reinforcement) training (Enright, Rovee-Collier, Fagen, & Caniglia, 1983). An interpolated 3-min nonreinforcement procedure was presented either before or after each of three 6-min acquisition sessions. Presenting the 3-min nonreinforcement phase prior to the acquisition phase both prolonged retention of the response and eliminated the characteristic response decrement at the outset of the second and third training session that is typically observed in infant operant learning studies. The authors concluded that this so-called "warm-up" effect might be produced by young infants' long latency to notice appropriate retrieval cues in the mobile. The "warm-up" effect is not species-specific and may actually reflect ontogenetic differences in sensory and motor integration (Spear, 1979, as cited in Enright, Rovee-Collier, Fagen & Caniglia, 1983). Clearly, the task demands of even brief periods of nonreinforcement change with the context in which they are presented.

Devenport's (1998) temporal weighting rule (TWR) predicts that spontaneous recovery should be a positive function of the extinction-test interval and a negative function of the acquisition-extinction interval. When long intervals of time separate acquisition and extinction, the extinction experience benefits from the advantage of recency, and the contribution of the original training is diminished. The present data do not support the predictions of Devenport's TWR, and are contrary to findings from some studies using adult animals as subjects (Bouton et al., 2006; Rescorla, 2004b). The results are more consistent with extinction models that assume that some aspect of the original association or response is weakened or lost.

Rovee-Collier and Cuevas (2008) have argued from an ecological standpoint the importance of culling or eliminating irrelevant memories that are formed early in life. It has repeatedly been demonstrated that nonhuman and human infants readily form numerous associations between stimuli and events, but many of these associations are not useful; they are formed nonselectively. Spear (1984) speculated that infants more readily form and "unitize" separate sensory events than adults, potentially creating numerous useless associations. Which of these many memories will be maintained and which will be culled is particularly important to the developing organism. Rapid forgetting may be highly adaptive for young human infants, whose behavioral repertoire changes rapidly over the first year of life. The present investigation represents an initial attempt to characterize the extinction process and the elimination of conditioned responses as a means of sellective associative pruning in early infancy. The finding that extinction occurs within a relatively short training period and is complete thereafter is consistent with an ecological account of its adaptive function in infancy.

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

Table 1. Group mean response rate during the Baseline, Immediate Retention Test (IRT), and Long-term Retention Test (LRT) for immediate extinction groups (Experiment 1). Parentheses contain ±1 *SD*.

	Baseline	IRT	LRT
	M (*SD*)	*M* (*SD*)	*M* (*SD*)
Experiment 1: Immediate Extinction			
1a. 18 min Acquisition			
6 min Extinction			
Day 1	7.93 (3.74)	12.55 (5.50)	6.27 (5.12)
Day 3	7.22 (2.81)	12.67 (9.36)	6.17 (1.70)
Day 5	7.54 (5.90)	11.33 (3.80)	6.72 (2.85)
Day 6	6.83 (5.04)	12.11 (2.42)	6.50 (4.85)
3 min Extinction			
Day 1	9.50 (5.19)	17.19 (7.28)	21.28 (8.22)
Day 3	9.22 (5.01)	23.67 (4.73)	19.11 (3.72)
Day 5	5.72 (2.06)	20.17 (10.85)	11.89 (5.97)
Day 6	5.52 (0.74)	11.67 (7.18)	8.29 (4.50)
1b. 15 min Acquisition			
4 min Extinction			
Day 1	5.78 (2.25)	10.83 (2.25)	5.22 (1.50)
Day 3	7.83 (3.72)	13.33 (8.88)	8.29 (4.82)
Day 5	4.17 (1.55)	7.88 (2.27)	5.50 (3.45)
2 min Extinction			
Day 1	10.50 (8.50)	21.47 (13.95)	14.94 (12.55)
Day 3	9.89 (7.23)	19.64 (13.62)	12.71 (7.00)
Day 5	11.06 (7.72)	21.25 (14.38)	11.11 (7.18)

Table 2. Group mean Baseline Ratios (BR), mean Retention Ratios (RR) and *t* (*df*) and *p* values for Experiments 1a and 1b. Parentheses contain ±1 *SD*.

	Baseline Ratio			Retention Ratio		
	M (*SD*)	*t*(*df*)	*p*	*M* (*SD*)	*t*(*df*)	*p*
Experiment 1: Immediate Extinction						
1a. 18 min Acquisition						
6 min Extinction						
Day 1	0.84 (0.50)	0.81 (5)	0.77	0.47 (0.26)	5.12 (5)	0.002*
Day 3	0.95 (0.38)	0.33 (5)	0.62	0.64 (0.30)	3.00 (5)	0.02*
Day 5	1.22 (0.75)	0.71 (5)	0.26	0.59 (0.13)	8.27 (5)	0.0005*
Day 6	0.82 (0.31)	1.46 (4)	0.90†	0.56 (0.44)	2.42 (5)	0.03*
3 min Extinction						
Day 1	2.44 (0.85)	4.13 (5)	0.005*	1.20 (0.35)	1.39 (4)	0.11†
Day 3	2.49 (1.07)	3.42 (5)	0.01*	0.83 (0.20)	2.10 (5)	0.05*
Day 5	2.05 (0.70)	3.65 (5)	0.007*	0.68 (0.39)	2.04 (5)	0.05*
Day 6	1.32 (0.46)	1.85 (5)	0.06†	0.81 (0.44)	1.16 (5)	0.15†
1b. 15 min Acquisition						
4 min Extinction						
Day 1	0.82 (0.22)	2.02 (4)	0.95†	0.52 (0.25)	4.80 (5)	0.002*
Day 3	1.45 (1.22)	0.91 (5)	0.20	0.81 (0.53)	0.88 (5)	0.21
Day 5	1.07 (0.35)	0.52 (4)	0.32†	0.59 (0.21)	4.75 (4)	0.003*†
2 min Extinction						
Day 1	1.58 (0.22)	6.33 (4)	0.0007*†	0.70 (0.09)	8.42 (5)	0.0002*
Day 3	1.72 (1.11)	1.72 (6)	0.07	0.62 (0.33)	3.09 (6)	0.01*
Day 5	1.21 (0.92)	0.55 (5)	0.30	0.65 (0.44)	1.94 (5)	0.06

† Outlier replaced
* $p < 0.05$

Note. One-sample, directional *t* tests compared mean BRs and RRs with a theoretical population ratio of 1.00.

Table 3. Group mean responses during the Baseline, Immediate Retention Test (IRT), and Long-term Retention Test (LRT) for delayed extinction groups (Experiments 2a, 2b, and 2c). Parentheses contain ±1 *SD*.

	Baseline	IRT	LRT
	M (*SD*)	*M* (*SD*)	*M* (*SD*)
Experiment 2: Delayed Extinction			
2a. 18 min Acquisition - Extinction 24 hr after S2			
6 min Extinction			
Day 2	6.78 (1.53)	11.89 (10.29)	21.45 (12.64)
Day 3	8.89 (3.38)	24.06 (8.52)	14.67 (8.23)
Day 5	11.78 (7.42)	22.72 (12.76)	13.17 (6.63)
Day 6	9.38 (6.57)	22.50 (9.80)	11.00 (7.84)
3 min Extinction			
Day 2	9.62 (4.39)	22.28 (4.39)	11.39 (3.93)
Day 6	10.23 (7.08)	21.22 (10.12)	16.00 (11.23)
2b. 15 min Acquisition - 4-6 min Extinction 24 hr after S2			
Day 2	4.83 (2.70)	12.78 (6.83)	8.06 (4.83)
Day 3	7.89 (5.84)	18.11 (8.62)	7.00 (1.67)
Day 6	4.67 (1.66)	14.89 (10.53)	5.44 (2.05)
2c. 18 min Acquisition - Extinction 24 hr prior to LRT			
6 min Extinction			
Day 3	10.78 (8.24)	21.39 (11.79)	16.61 (10.45)
Day 5	12.83 (6.06)	24.06 (9.19)	18.28 (6.71)
Day 6	7.72 (5.48)	22.94 (10.52)	9.39 (4.77)
3 min Extinction			
Day 3	8.11 (2.96)	18.67 (6.10)	10.83 (6.40)
Day 6	10.72 (4.05)	18.28 (8.60)	11.17 (4.02)

Table 4. Group mean Baseline Ratios (BR), mean Retention Ratios (RR) and *t(df)* and *p* values for delayed extinction groups (Experiment 2a, 2b, and 2c).

	Baseline Ratio			Retention Ratio		
	M (*SD*)	*t*(*df*)	*p*	*M* (*SD*)	*t*(*df*)	*p*
Experiment 2: Delayed Extinction						
2a. 18 min Acquisition – Extinction 24 hr after S2						
6 min Extinction						
Day 2	3.34 (2.20)	2.60 (5)	0.02*	2.20 (0.92)	3.19 (5)	0.99
Day 3	1.71 (0.68)	2.54 (5)	0.03*	0.53 (0.17)	6.82 (4)	0.0005*†
Day 5	1.27 (0.56)	1.18 (5)	0.15	0.63 (0.33)	2.72 (5)	0.02*
Day 6	1.11 (0.34)	0.80 (4)	0.23†	0.48 (0.22)	5.89 (5)	0.001*
3 min Extinction						
Day 2	1.34 (0.46)	2.00 (5)	0.05*	0.55 (0.16)	7.12 (5)	0.0004*
Day 6	1.77(0.88)	2.15 (5)	0.04*	0.76 (0.28)	2.20 (5)	0.04*
2b. 15 min Acquisition – 4-6 min Extinction 24 hr after S2						
Day 2	1.53 (0.36)	3.58 (4)	0.008*†	0.58 (0.20)	5.05 (4)	0.002*†
Day 3	1.14 (0.66)	0.51 (5)	0.32	0.43 (0.22)	6.26 (5)	0.0008*
Day 6	1.36 (0.85)	1.03 (5)	0.18	0.62 (0.58)	1.60 (5)	0.08
2c. 18 min Acquisition						
6 min Extinction						
Day 3	1.74 (1.03)	1.91 (5)	0.05*	0.91 (0.15)	1.43 (5)	0.11
Day 5	1.67 (0.80)	2.04 (5)	0.05*	0.83 (0.35)	1.20 (5)	0.14
Day 6	1.71 (1.47)	1.18 (5)	0.15	0.43 (0.25)	5.50 (4)	0.001*†
3 min Extinction						
Day 3	1.52 (1.06)	1.19 (5)	0.14	0.64 (0.38)	2.29 (5)	0.04*
Day 6	0.99 (0.11)	0.31 (4)	0.62†	0.54 (0.09)	12.08 (4)	0.0001*†

† Outlier replaced
* $p < 0.05$

Figure 1. A 3-month-old during a reinforcement phase (acquisition).

Figure 2. A 3-month-old during a nonreinforcement phase (Baseline, Extinction, Long-term Retention Test).

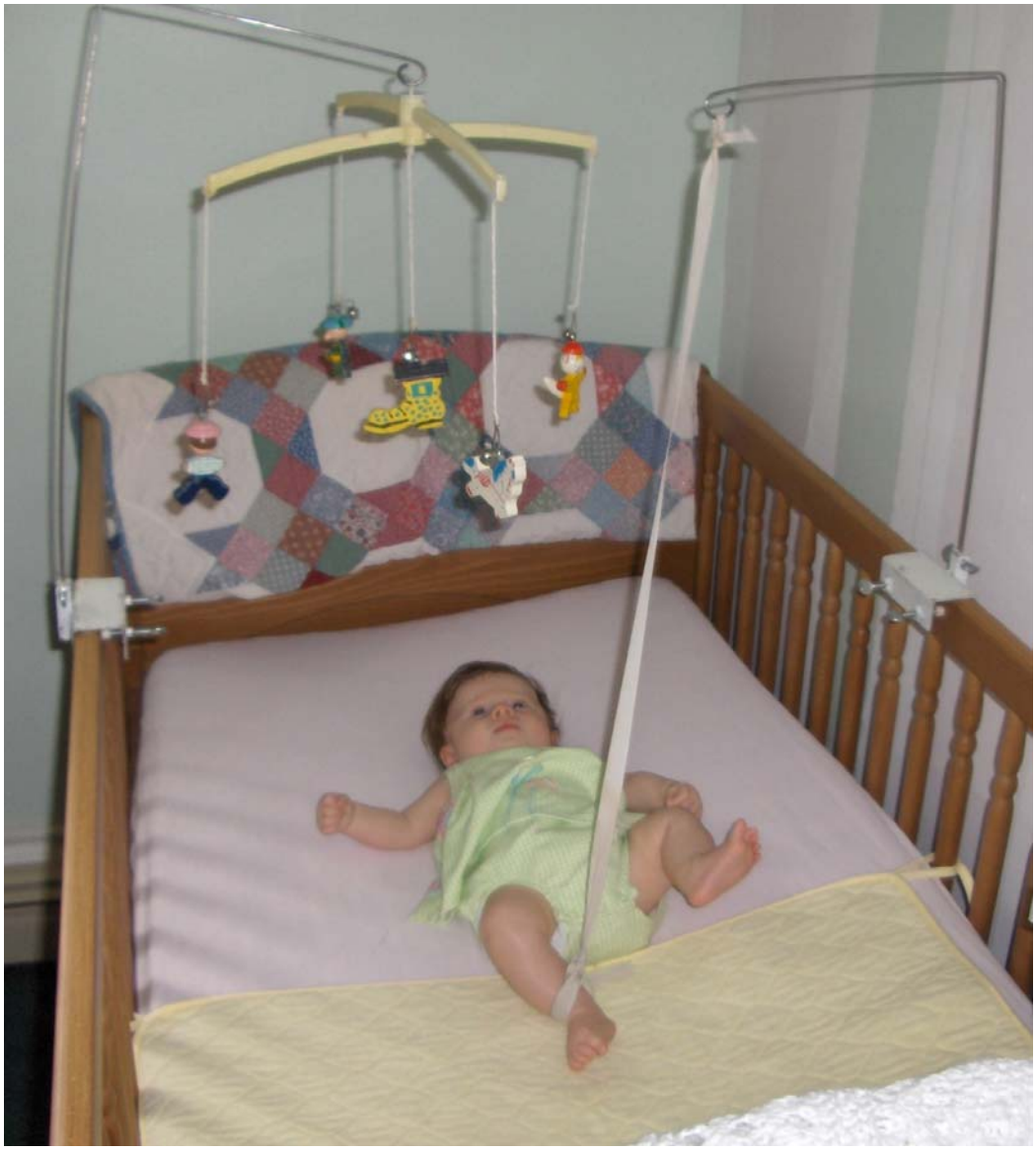
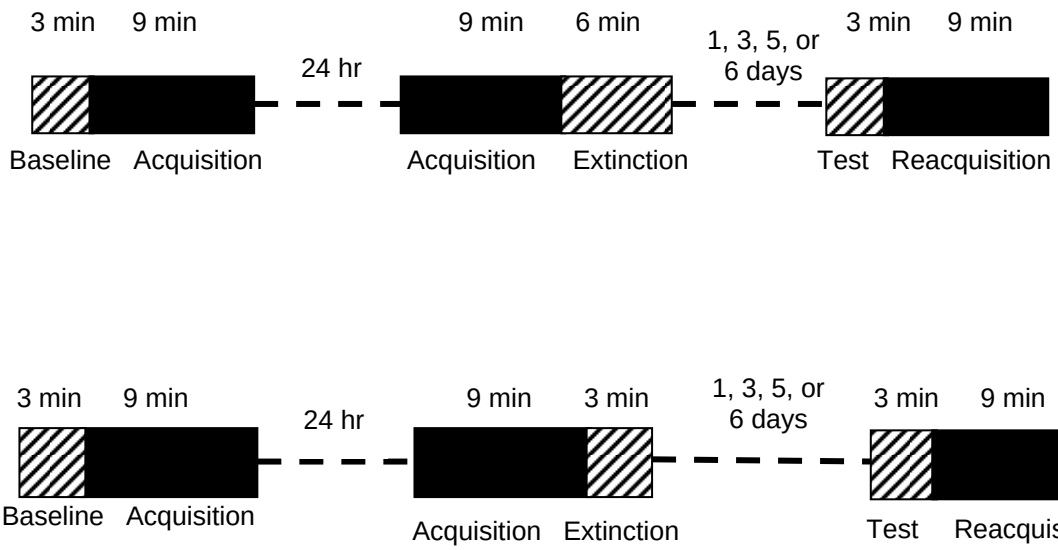


Figure 3. The experimental design for Experiment 1a. Independent groups received two training sessions over two consecutive days, concluded with either 6 or 3 min of extinction at the end of the second session. Long-term retention was assessed 1, 3, 5, or 6 days later. (Experiment 1a: Immediate extinction, 18-min acquisition)


3 min
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Acquisition
Acquisition
Extinction
Test
Reacquisition
3 min
9 min
24 hr
9 min
3 min
1, 3, 5, or
6 days
3 min
9 min
Baseline
Acquisition
Acquisition
Extinction
Test
Reacquisition
Reinforcement
Nonreinforcement

Figure 4. Mean baseline ratios of independent groups of infants receiving either 6 (dark green bars) or 3 minutes (light green bars) of extinction immediately following acquisition at the end of Session 2. Asterisks indicate that a group exhibited significant retention ($M > 1.00$). Vertical bars indicate ± 1 SE. (Experiment 1a: Immediate extinction, 18-min acquisition)

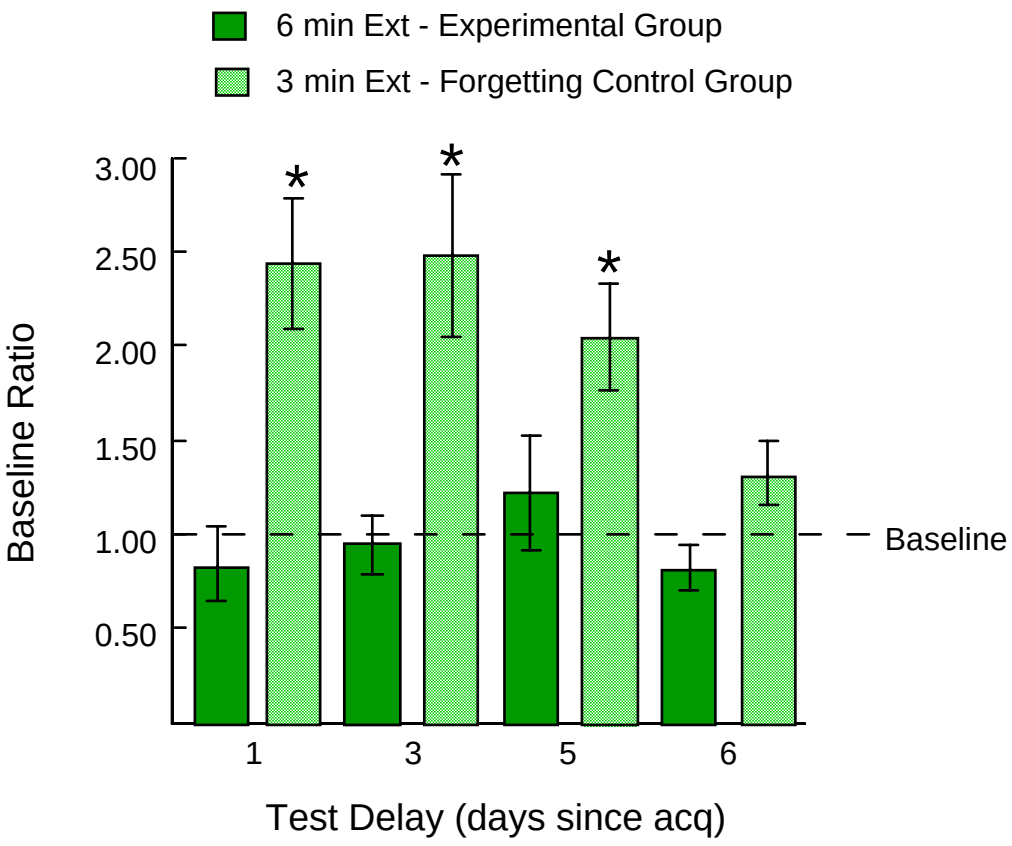

6 min Ext - Experimental Group
3 min Ext - Forgetting Control Group
Baseline Ratio
3.00
2.50
2.00
1.50
1.00
0.50
*
*
*
Baseline
1
3
5
6
Test Delay (days since acq)

Figure 5. Mean retention ratios of independent groups of infants who received either 6 (yellow bars) or 3 (green bars) minutes of extinction immediately following acquisition. Asterisks indicate that a group exhibited a significant response decrement at the long-term retention test, relative to responding during the immediate retention test. Vertical bars indicate ± 1 SE. (Experiment 1a: Immediate extinction, 18-min acquisition)

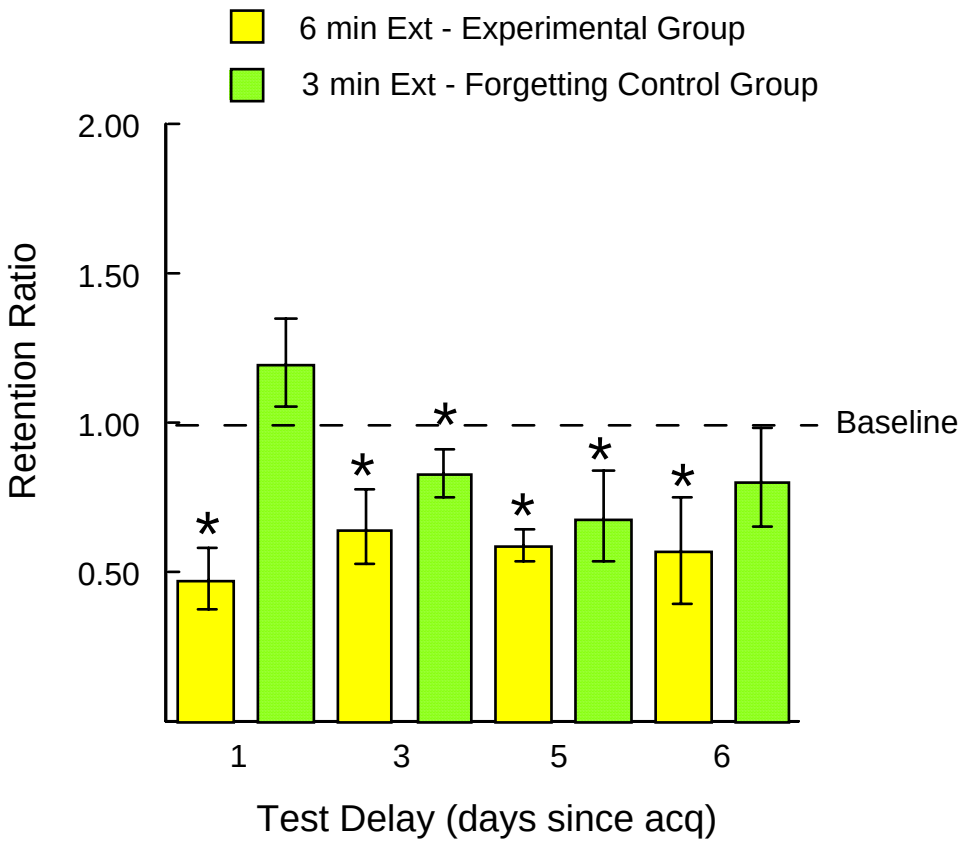

6 min Ext - Experimental Group
3 min Ext - Forgetting Control Group
2.00
1.50
1.00
0.50
Retention Ratio
Baseline
1
3
5
6
Test Delay (days since acq)

Figure 6. Mean responses of four experimental groups, collapsed across 3-min blocks over two consecutive training sessions and subsequent test. Session 1 (S1) began with a 3-min nonreinforcement period (baseline, or BL) and was followed by a 9-min acquisition (Acq) period. Session 2 (S2), 24 hr later, began with a 9-min Acq period and was immediately followed by a 6-min extinction (Ext) period. The long-term retention test (LRT), a 3-min nonreinforcement period, occurred 1, 3, 5, or 6 days after S2. (Experiment 1a: Immediate 6-min extinction, 18-min acquisition)

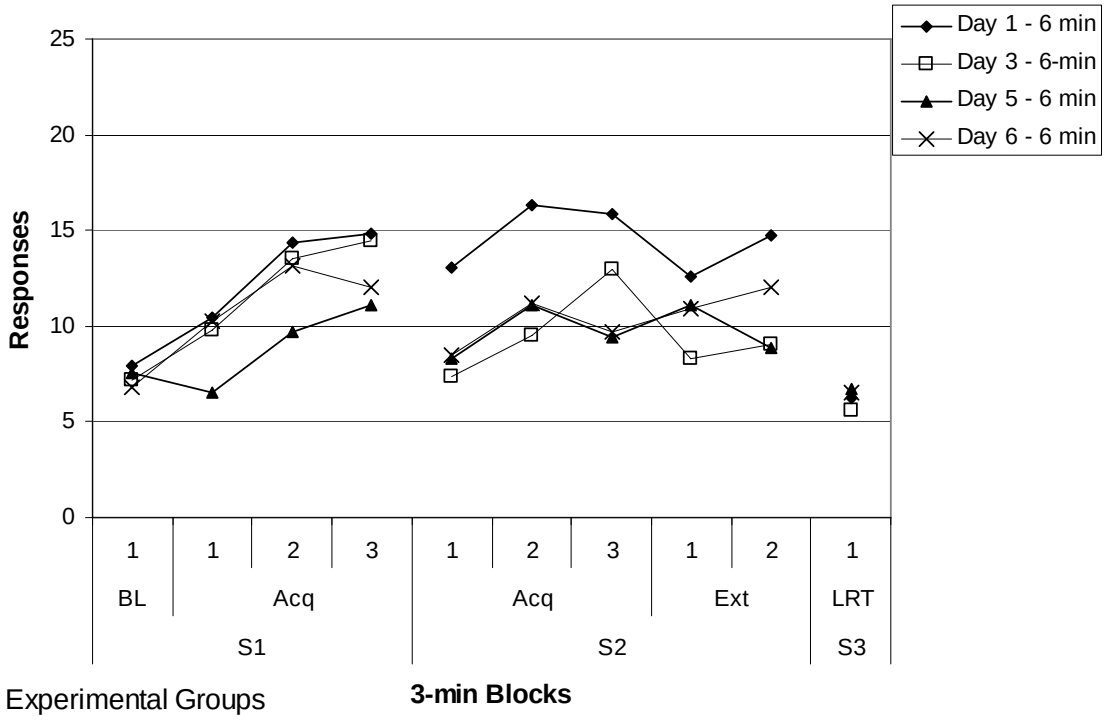
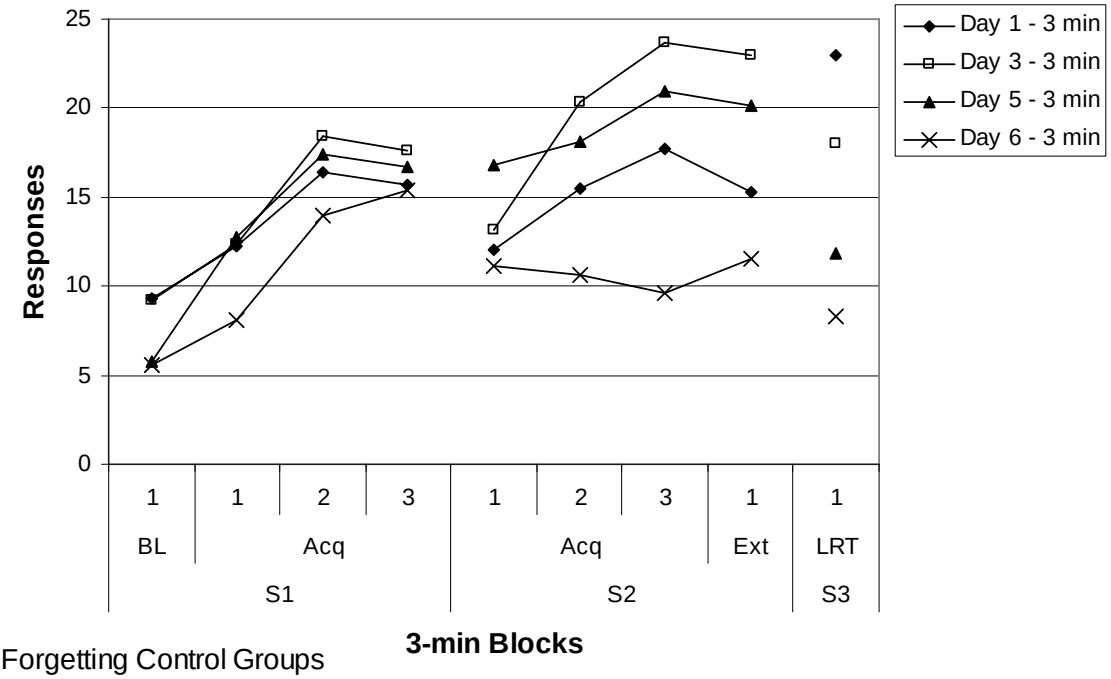

Day 1 - 6 min
Day 3 - 6-min
Day 5 - 6 min
Day 6 - 6 min
Responses
25
20
15
10
5
0
1 1 2 3 1 2 3 1 2 1
BL
Acq
Acq
Ext
LRT
S1
S2
S3
Experimental Groups
3-min Blocks

Figure 7. Mean responses of four forgetting control groups, collapsed across 3-min blocks of two consecutive training sessions and subsequent test. Session 1 (S1) began with a 3-min nonreinforcement period (baseline, or BL) and was followed by a 9-min acquisition (Acq) period. Session 2 (S2), 24 hr later, began with a 9-min Acq period and was immediately followed by a 3-min extinction (Ext) period. The long-term retention test (LRT), another 3-min nonreinforcement period, occurred 1, 3, 5, or 6 days after S2. (Experiment 1a: Immediate 3-min extinction, 18-min acquisition)



Forgetting Control Groups

Figure 8. Mean responses during the extinction manipulation for experimental and forgetting control groups. Each groups baseline (BL) and immediate retention test (IRT) are plotted for comparison. (Experiment 1a: Immediate extinction, 18-min acquisition)

Experiment 1a

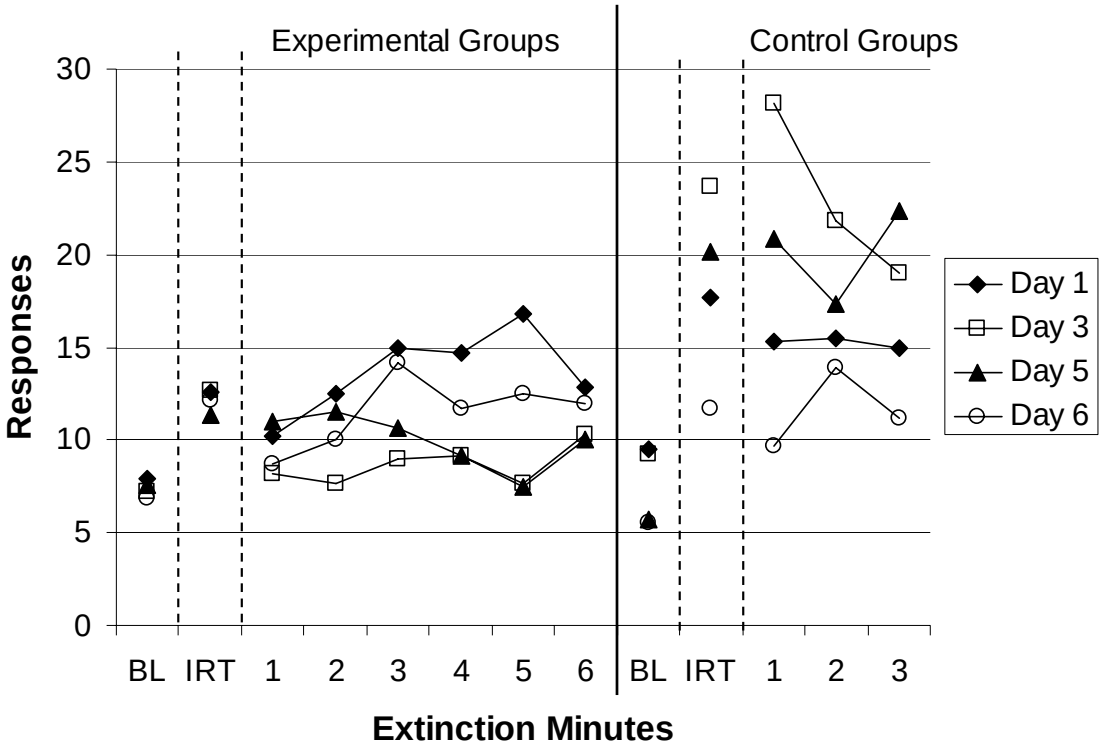
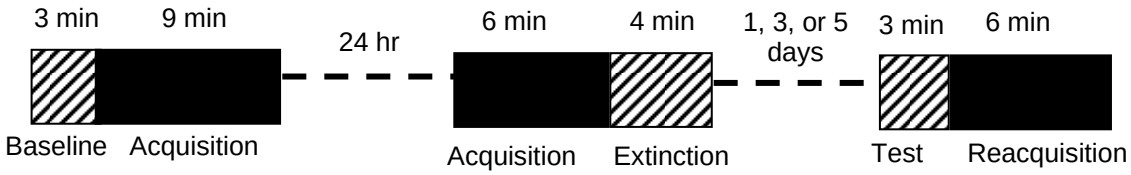
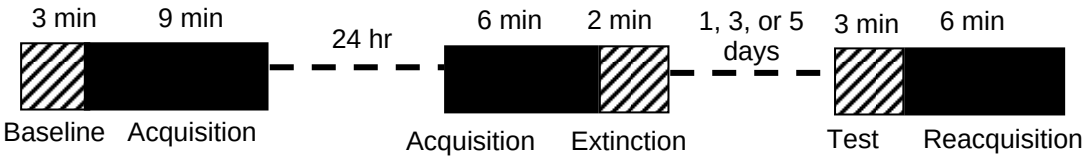


Figure 9. The experimental design for Experiment 1b. Independent groups received two training sessions over two consecutive days, concluded with either 4 or 2 min of extinction at the end of the second session. Long-term retention was assessed 1, 3, or 5 days later. (Experiment 1b: Immediate extinction, 15-min acquisition)


3 min
9 min
24 hr
6 min
4 min
1, 3, or 5 days
3 min
6 min
Baseline
Acquisition
Acquisition
Extinction
Test
Reacquisition


3 min
9 min
24 hr
6 min
2 min
1, 3, or 5 days
3 min
6 min
Baseline
Acquisition
Acquisition
Extinction
Test
Reacquisition

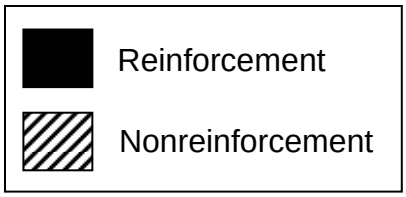

Reinforcement
Nonreinforcement

Figure 10. Mean baseline ratios of independent groups of infants receiving either 4 (dark blue bars) or 2 minutes (light blue) of extinction immediately following acquisition at the end of Session 2. Asterisks indicate that a group exhibited significant retention ($M >$ 1.00). Vertical bars indicate ± 1 SE. (Experiment 1b. Immediate extinction, 15-min acquisition)

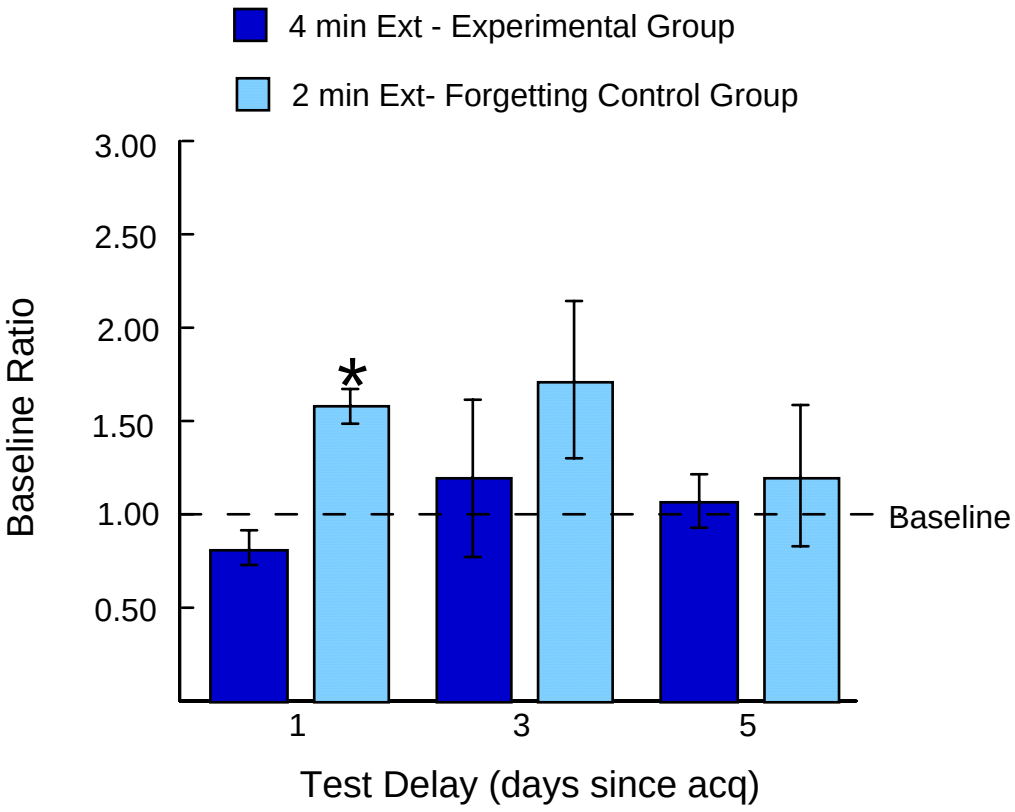

4 min Ext - Experimental Group
2 min Ext- Forgetting Control Group
3.00
2.50
2.00
1.50
1.00
0.50
Baseline Ratio
*
Baseline
1
3
5
Test Delay (days since acq)

Figure 11. Mean retention ratios of independent groups of infants who received either 4 (solid orange bars) or 2 (striped orange bars) minutes of extinction immediately following acquisition. Asterisks indicate that a group exhibited a significant response decrement at the long-term retention test, relative to responding during the immediate retention test. Vertical bars indicate ± 1 SE. (Experiment 1b: Immediate extinction, 15-min acquisition)

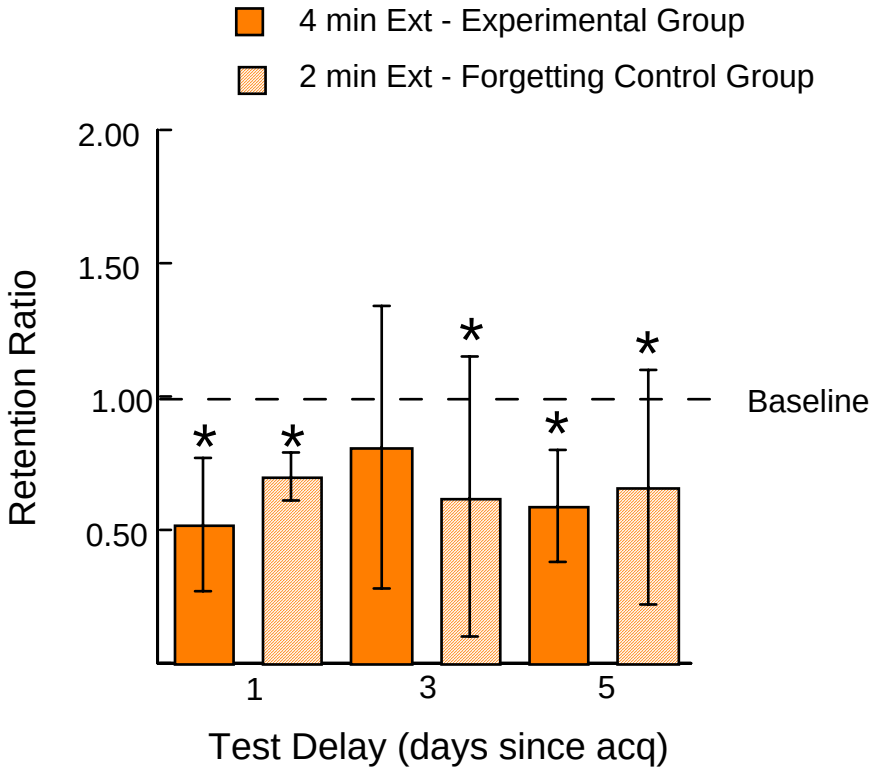

4 min Ext - Experimental Group
2 min Ext - Forgetting Control Group
2.00
1.50
1.00
0.50
Retention Ratio
Baseline
*
*
*
*
1
3
5
Test Delay (days since acq)

Figure 12. Mean responses of the three experimental groups, collapsed across 3-min blocks of acquisition in two consecutive training sessions. Session 1 (S1) began with a 3-min nonreinforcement period (baseline, or BL) and was followed by a 9-min acquisition (Acq) period. Session 2 (S2), 24 hr later, began with a 6-min Acq period and was immediately followed by a 4-min extinction (Ext) period. During Ext, data were collapsed across 2-min blocks. The long-term retention test (LRT), a 3-min nonreinforcement period, occurred 1, 3, or 5 days after S2. (Experiment 1b: Immediate 4-min extinction, 15-min acquisition)

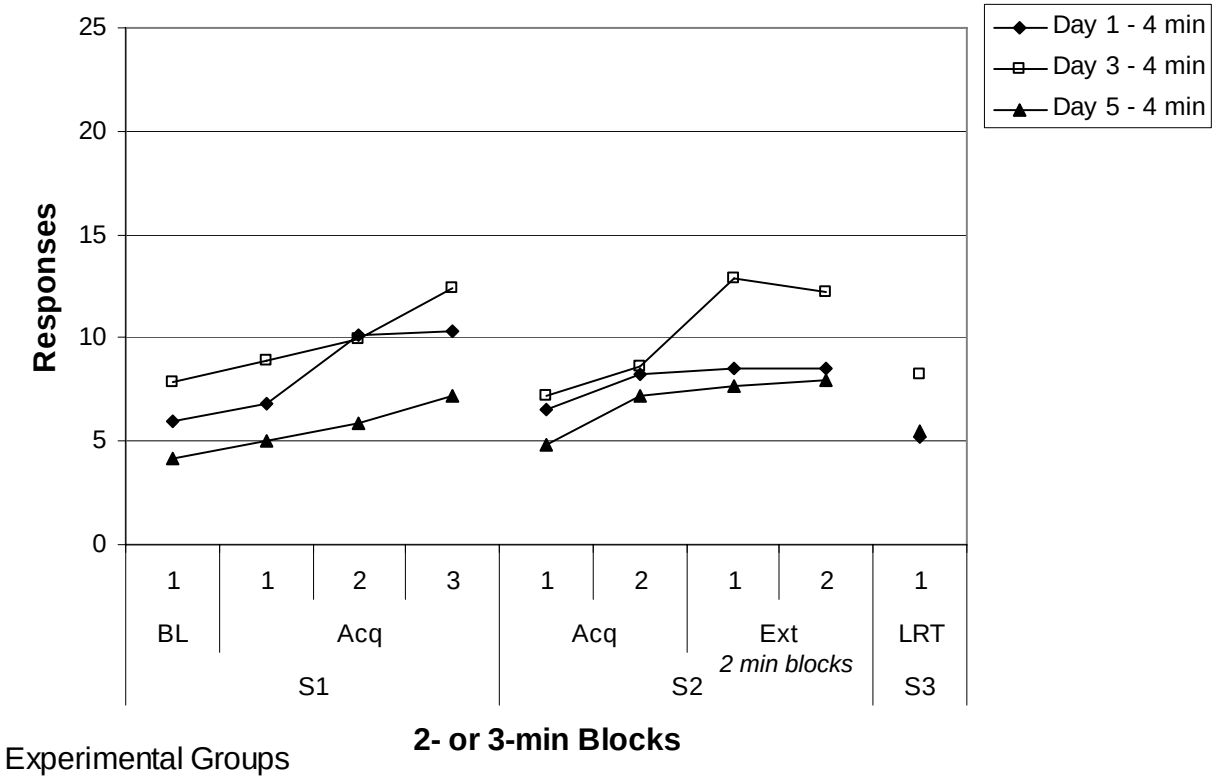

Day 1 - 4 min
Day 3 - 4 min
Day 5 - 4 min
Responses
25
20
15
10
5
0
1
1
2
3
1
2
1
2
1
BL
Acq
Acq
Ext
LRT
2 min blocks
S1
S2
S3
2- or 3-min Blocks
Experimental Groups

Figure 13. Mean responses of the three forgetting control groups, collapsed across 2- or 3-min blocks of acquisition in two consecutive training sessions. Session 1 (S1) began with a 3-min nonreinforcement (baseline, or BL) period and was followed by a 9-min acquisition (Acq) period. Session 2 (S2), 24 hr later, began with a 6-min Acq period and was immediately followed by a 2-min extinction (Ext) period. During Ext, data were collapsed across 2-min blocks. The long-term retention test (LRT), a 3-min nonreinforcement period, occurred 1, 3, or 5 days after S2. (Experiment 1b: Immediate 2-min extinction, 15-min acquisition)

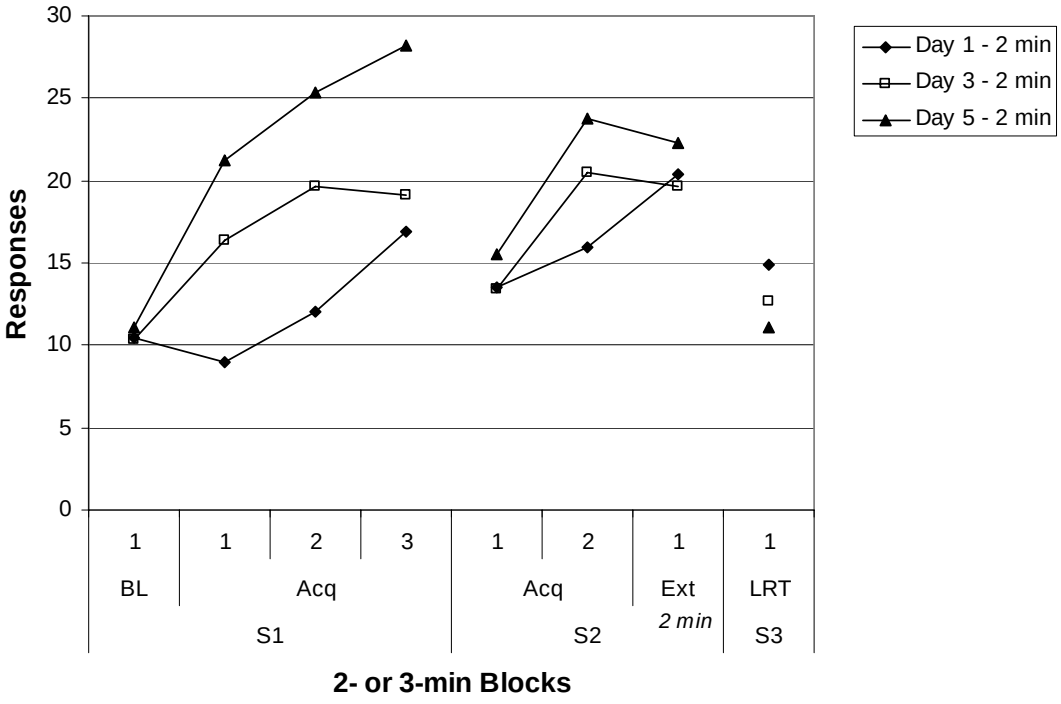

30
25
20
15
10
5
0
Responses
Day 1 - 2 min
Day 3 - 2 min
Day 5 - 2 min
1
1
2
3
1
2
1
1
BL
Acq
Acq
Ext
LRT
2 min
S1
S2
S3
2- or 3-min Blocks

Figure 14. Mean responses during the extinction phase for experimental and forgetting control groups. Each groups baseline (BL) and immediate retention test (IRT) are plotted for comparison. (Experiment 1b: Immediate extinction, 15-min acquisition)

Experiment 1b

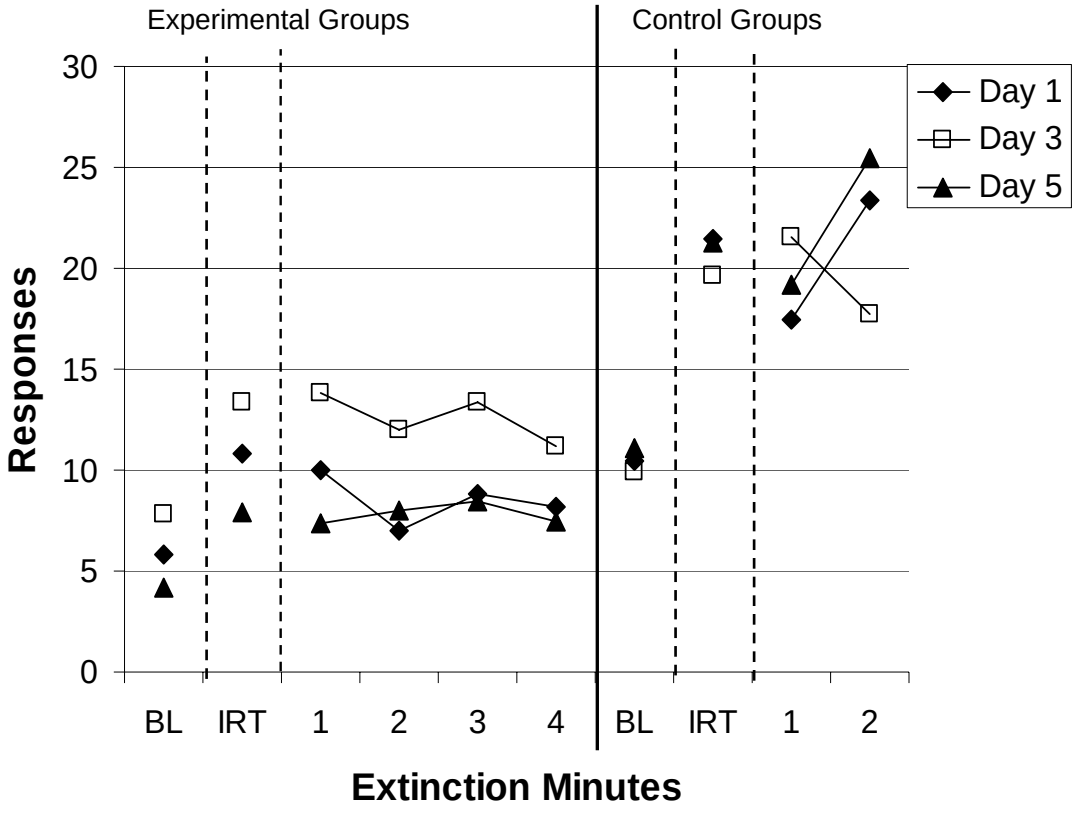


Figure 15. The experimental design for Experiment 2a. Independent groups received two training sessions over two consecutive days and extinction in a separate session 24 hr later on Day 1. Extinction lasted either 6 or 3 min. Long-term retention was assessed 2, 3, 5, or 6 days after the end of acquisition for experimental (6 min) groups and after 2 or 6 days for the forgetting control (3 min) groups. (Experiment 2a: Delayed extinction, 18-min acquisition)

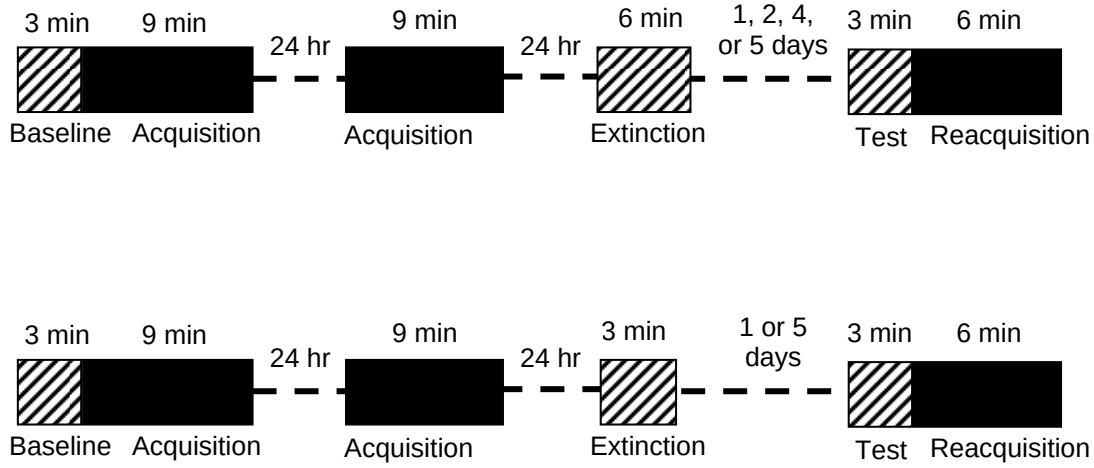

3 min
9 min
24 hr
9 min
24 hr
6 min
1, 2, 4, or 5 days
3 min
6 min
Baseline
Acquisition
Acquisition
Extinction
Test
Reacquisition
3 min
9 min
24 hr
9 min
24 hr
3 min
1 or 5 days
3 min
6 min
Baseline
Acquisition
Acquisition
Extinction
Test
Reacquisition
Reinforcement
Nonreinforcement

Figure 16. Mean baseline ratios of independent groups of infants receiving either 6 (dark red bars) or 3 minutes (red striped bars) of extinction 24 hr following acquisition in Session 3. Asterisks indicate that a group exhibited significant retention ($M > 1.00$). Vertical bars indicate ± 1 SE. (Experiment 2a: Delayed extinction, 18-min acquisition)

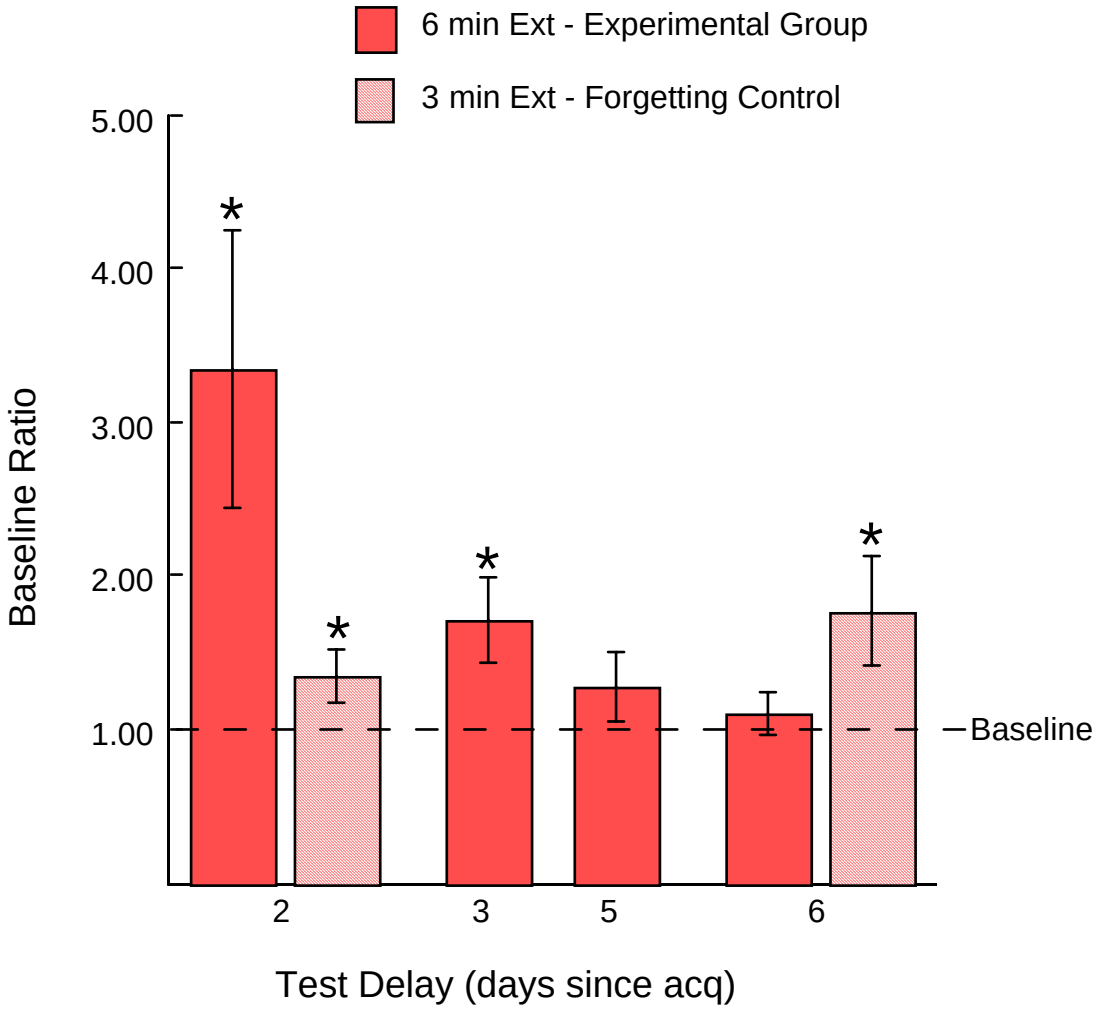

6 min Ext - Experimental Group
3 min Ext - Forgetting Control
5.00
4.00
3.00
2.00
1.00
Baseline Ratio
Baseline
2
3
5
6
Test Delay (days since acq)

Figure 17. Mean retention ratios of independent groups of infants who received either 6 (solid red bars) or 3 (red striped bars) minutes of extinction in Session 3, 24 hr following acquisition. Asterisks indicate that a group exhibited a significant response decrement at the long-term retention test, relative to responding during the immediate retention test. Vertical bars indicate ± 1 SE. (Experiment 2a: Delayed extinction, 18-min acquisition)

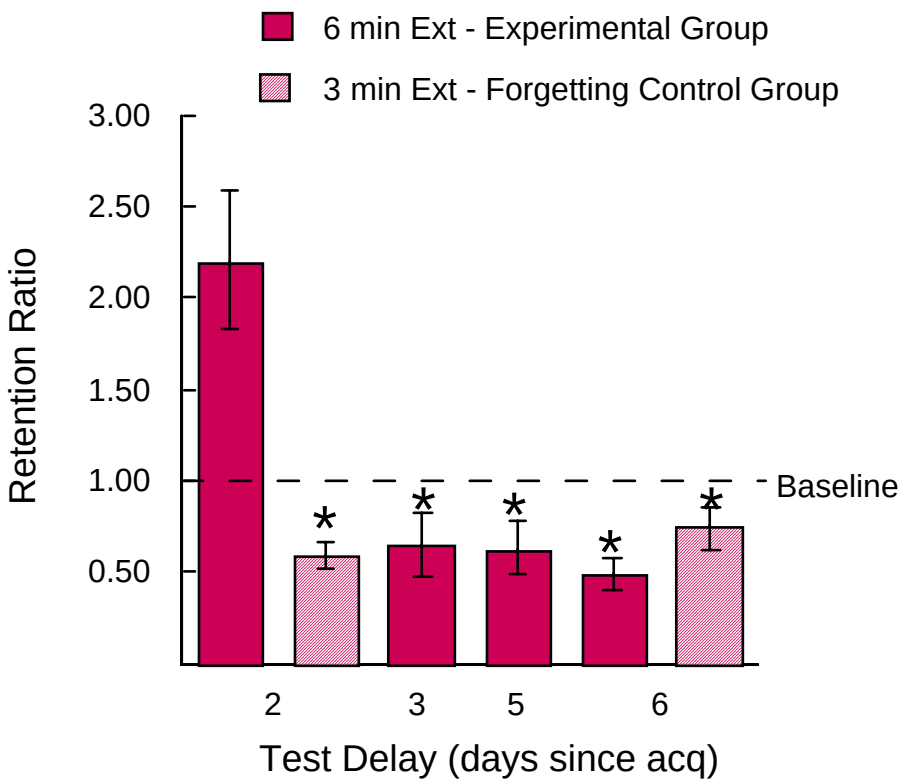
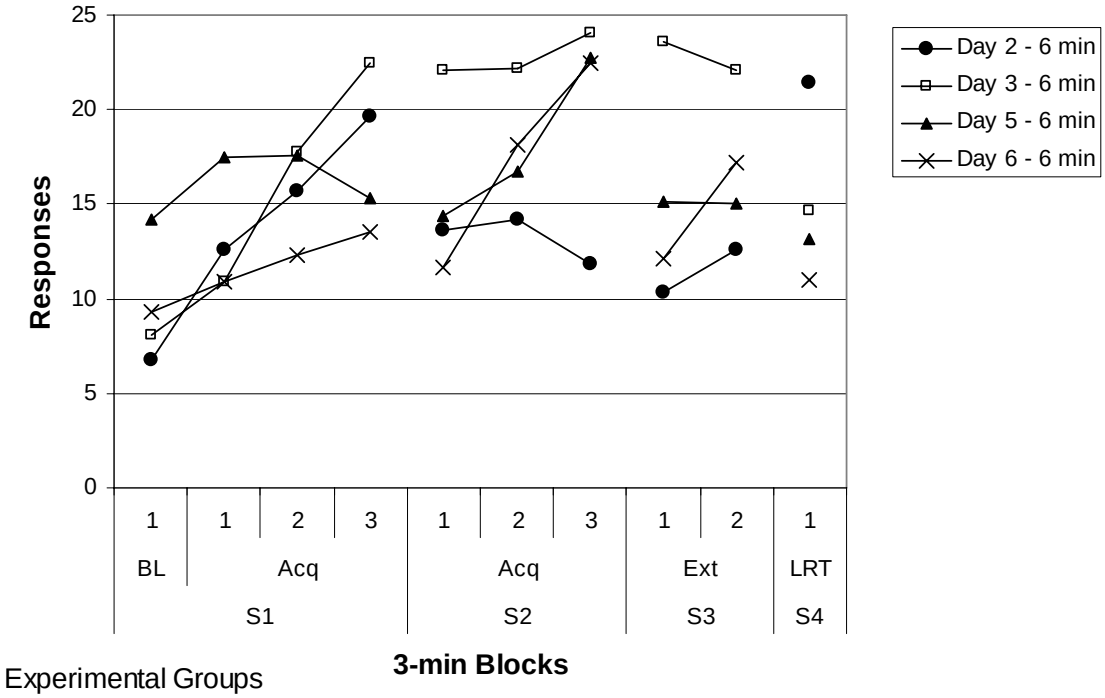
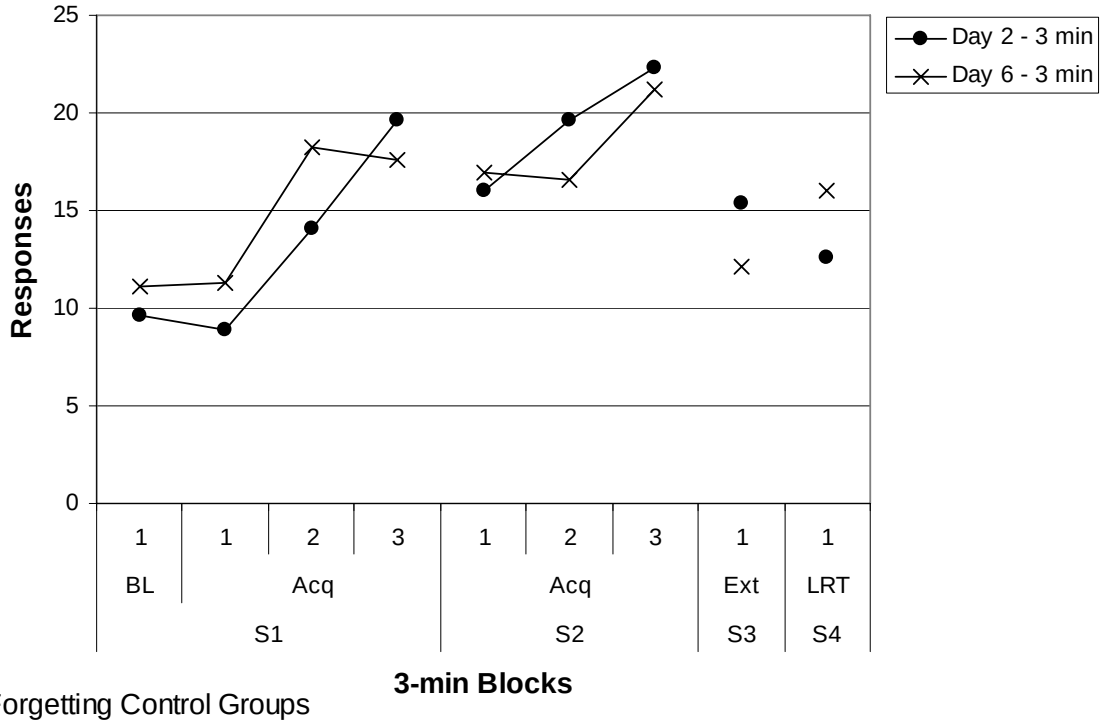

6 min Ext - Experimental Group
3 min Ext - Forgetting Control Group
3.00
2.50
2.00
1.50
1.00
0.50
Retention Ratio
Baseline
*
*
*
*
*
2
3
5
6
Test Delay (days since acq)

Figure 18. Mean responses of four experimental groups, collapsed across 3-min blocks of acquisition in two consecutive training sessions. Session 1 (S1) began with a 3-min nonreinforcement baseline (BL) period and was followed by a 9-min reinforcement period (acquisition, or Acq). An additional 9-min Acq period took place 24 hr later, during the second session (S2). Session 3 (S3) was 6 min of nonreinforcement training (extinction, or Ext). The long-term retention test (LRT), a 3-min nonreinforcement period, occurred 2, 3, 5, or 6 days after S2. (Experiment 2a: Delayed 6-min extinction, 18-min acquisition)



Experimental Groups

Figure 19. Mean responses of two forgetting control groups, collapsed across 3-min blocks of acquisition in two consecutive training sessions. Session 1 (S1) began with a 3-min nonreinforcement baseline (BL) period and was followed by a 9-min reinforcement (acquisition, or Acq) period. An additional 9-min Acq period took place 24 hr later, during the second session (S2). Session 3 (S3) was 3 min of nonreinforcement training (extinction, or Ext). The long-term retention test (LRT), a 3-min nonreinforcement period, occurred 2 or 6 days after S2. (Experiment 2a: Delayed 3-min extinction, 18-min acquisition)



Forgetting Control Groups

Figure 20. Mean responses during the extinction manipulation for experimental and forgetting control groups. Each groups baseline (BL) and immediate retention test (IRT) are plotted for comparison. (Experiment 2a: Delayed extinction, 18-min acquisition)

Experiment 2a

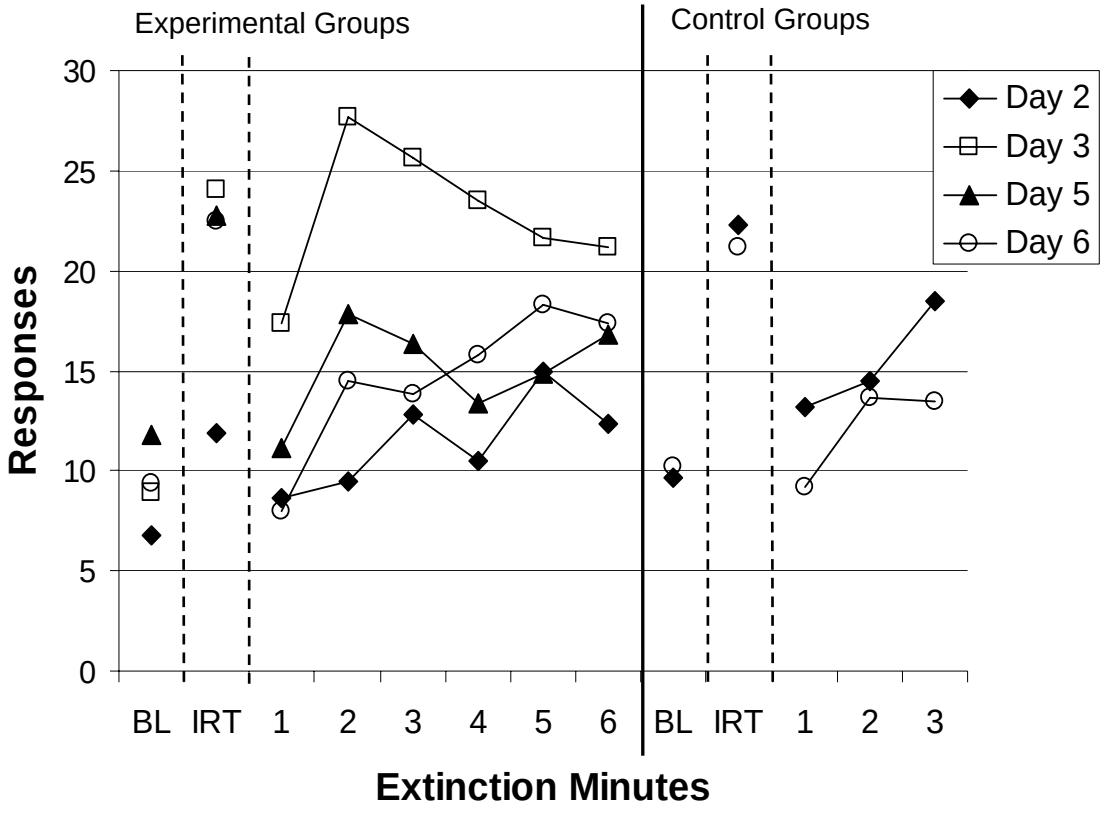
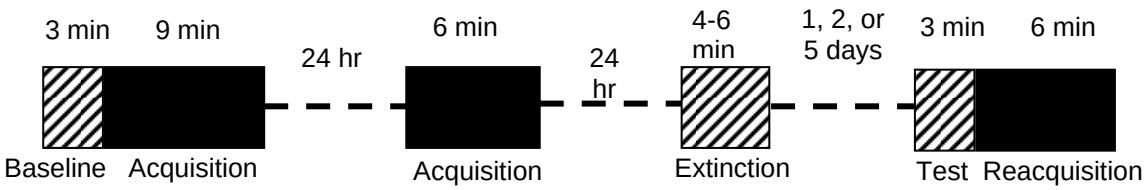


Figure 21. The experimental design for Experiment 2b. Independent groups received two training sessions over two consecutive days and extinction in a separate session 24 hr later on Day 1. Extinction lasted 4-6 min. Long-term retention was assessed 2, 3, or 6 days after the end of acquisition. (Experiment 2b: Delayed extinction, 15-min acquisition)


3 min
9 min
24 hr
6 min
24 hr
4-6 min
1, 2, or 5 days
3 min
6 min
Baseline
Acquisition
Acquisition
Extinction
Test
Reacquisition

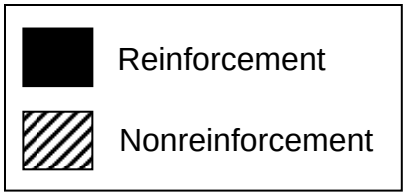

Reinforcement
Nonreinforcement

Figure 22. Mean baseline ratios of independent groups of infants receiving 4-6 min extinction in Session 3, 24 hr following acquisition. Asterisks indicate that a group exhibited significant retention ($M > 1.00$). Vertical bars indicate ± 1 SE. (Experiment 2b: Delayed 4-6 min extinction, 15-min acquisition)

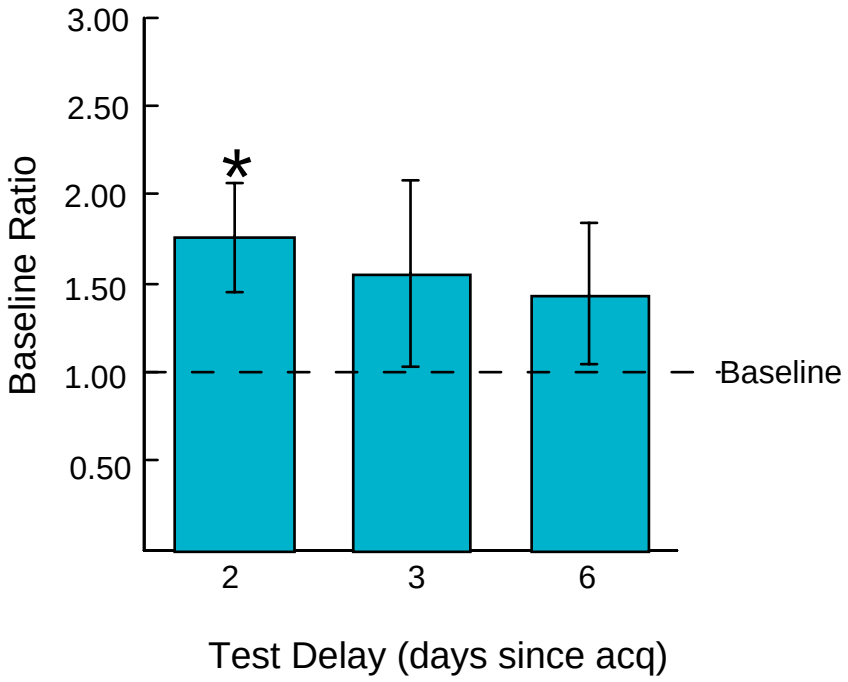

3.00
2.50
2.00
1.50
1.00
0.50
Baseline Ratio
*
Baseline
2
3
6
Test Delay (days since acq)

Figure 23. Mean retention ratios of independent groups of infants who received 4-6 minutes of extinction in Session 3, 24 hr following acquisition. Asterisks indicate that a group exhibited a significant response decrement at the long-term retention test, relative to responding during the immediate retention test. Vertical bars indicate ± 1 SE. (Experiment 2b: Delayed 4-6 min extinction, 15-min acquisition)

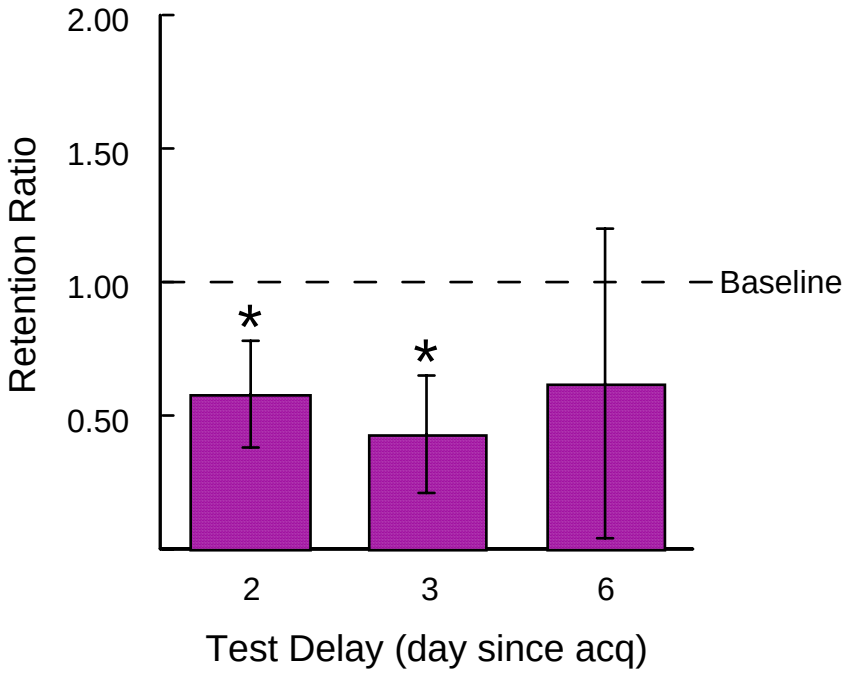
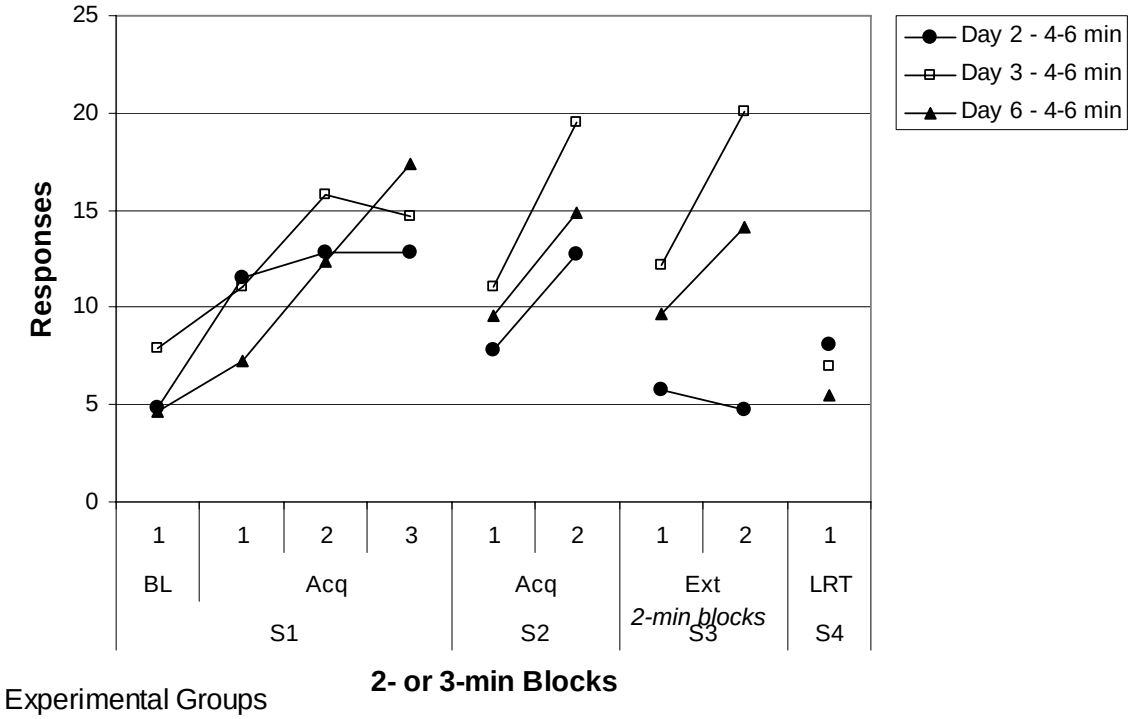

2.00
1.50
1.00
0.50
Retention Ratio
Baseline
*
*
2
3
6
Test Delay (day since acq)

Figure 24. Mean responses of three experimental groups, collapsed across 2- or 3-min blocks of acquisition over two consecutive days. Session 1 (S1) began with a 3-min nonreinforcement baseline (BL) period and was followed by a 9-min reinforcement (acquisition, or Acq) period. An additional 6-min Acq period took place 24 hr later, during the second session (S2). Session 3 (S3) was 4-6 min of nonreinforcement training (extinction, or Ext). The long-term retention test (LRT), a 3-min nonreinforcement period, occurred 2, 3 or 6 days after S2. (Experiment 2b: Delayed 4-6 min extinction, 15-min acquisition)



Experimental Groups

Figure 25. Mean responses during the extinction manipulation for experimental and forgetting control groups. Each groups baseline (BL) and immediate retention test (IRT) are plotted for comparison. (Experiment 2b: Delayed 4-6 min extinction, 15-min acquisition)

Experiment 2b

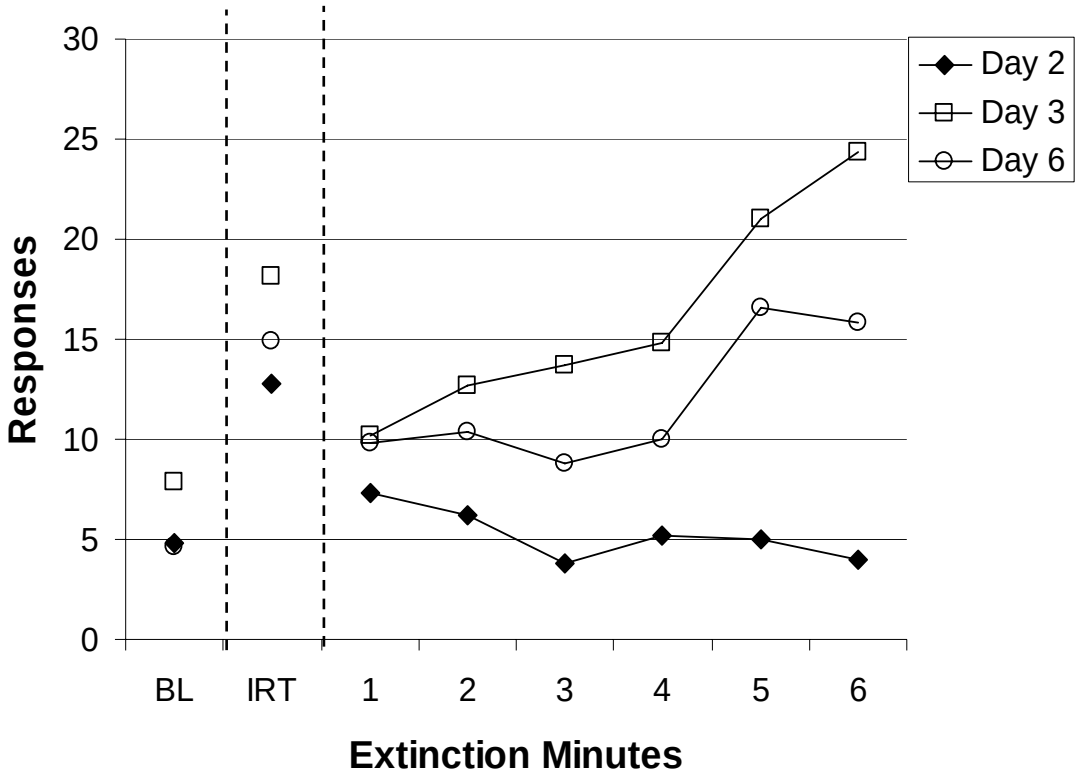


Figure 26. The experimental design for Experiment 2c. Independent groups received two training sessions over two consecutive days and extinction was presented in a separate session on Day 2, 4, or 5. Extinction lasted 6 or 3 min. Long-term retention was assessed 24 hr after extinction on Day 3, 5, or 6. (Experiment 2c: Delayed extinction 24 hr prior to LRT, 18-min acquisition)

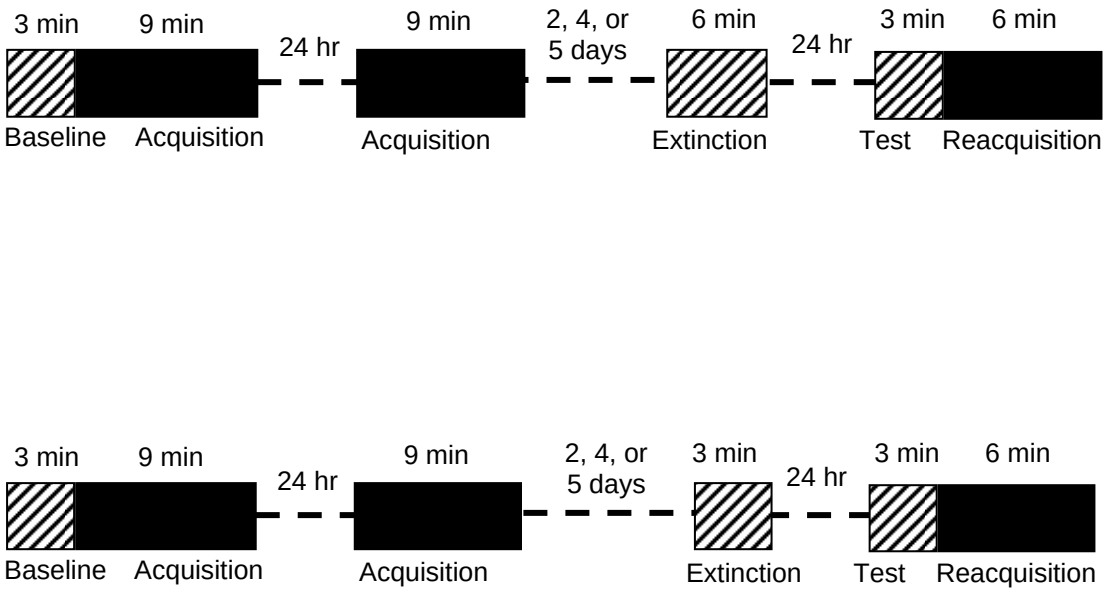

3 min
9 min
24 hr
9 min
2, 4, or
5 days
6 min
24 hr
3 min
6 min
Baseline
Acquisition
Acquisition
Extinction
Test
Reacquisition
3 min
9 min
24 hr
9 min
2, 4, or
5 days
3 min
24 hr
3 min
6 min
Baseline
Acquisition
Acquisition
Extinction
Test
Reacquisition
Reinforcement
Nonreinforcement

Figure 27. Mean baseline ratios of independent groups of infants receiving either 6 (purple bars) or 3 (light purple bars) minutes of extinction in Session 3, 24 hr prior to long-term retention testing. Asterisks indicate that a group exhibited significant retention ($M > 1.00$). Vertical bars indicate ± 1 SE. (Experiment 2c: Delayed extinction 24 hr prior to LRT, 18-min acquisition)

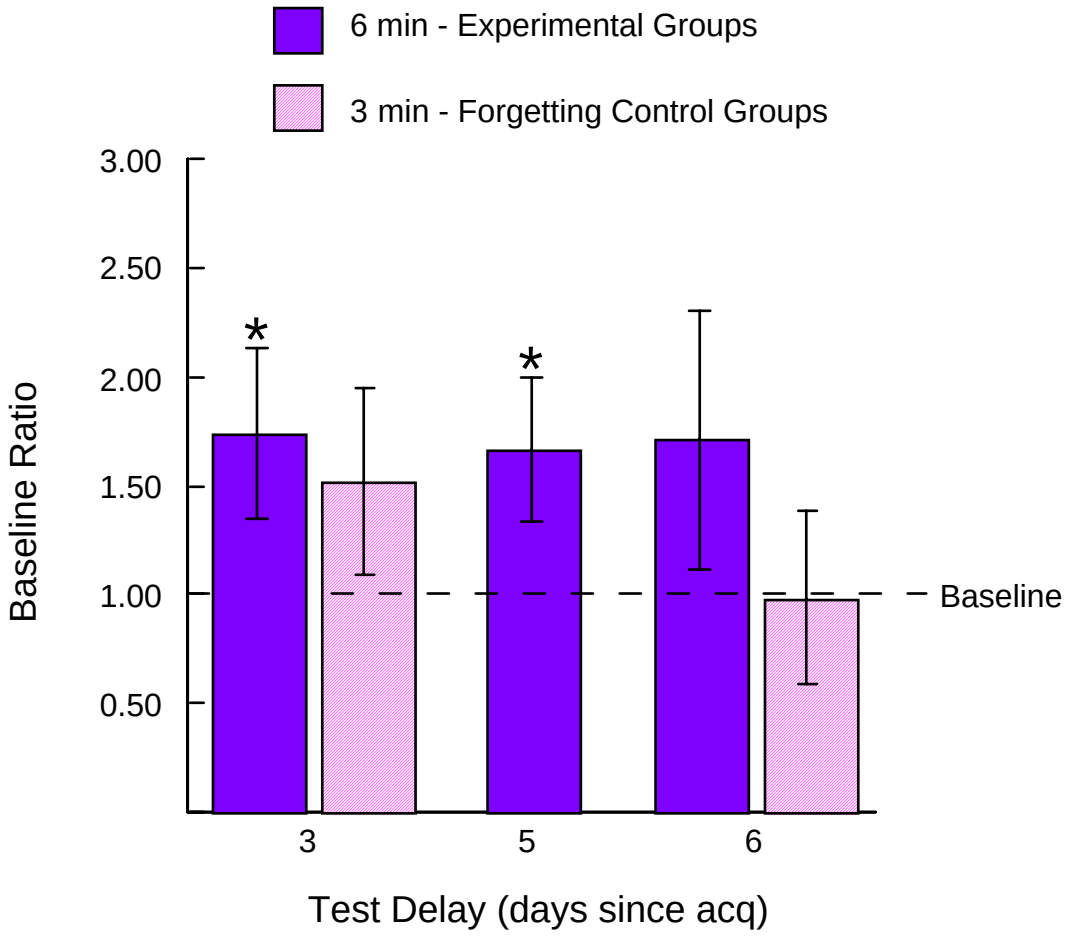

6 min - Experimental Groups
3 min - Forgetting Control Groups
3.00
2.50
2.00
1.50
1.00
0.50
Baseline Ratio
*
*
Baseline
3
5
6
Test Delay (days since acq)

Figure 28. Mean retention ratios of independent groups of infants who received 6 (solid purple bars) or 3 (light purple bars) minutes of extinction in Session 3, 24 hr prior to LRT. Asterisks indicate that a group exhibited a significant response decrement at the long-term retention test, relative to responding during the immediate retention test. Vertical bars indicate ± 1 SE. (Experiment 2c: Delayed extinction 24 hr prior to LRT, 18-min acquisition)

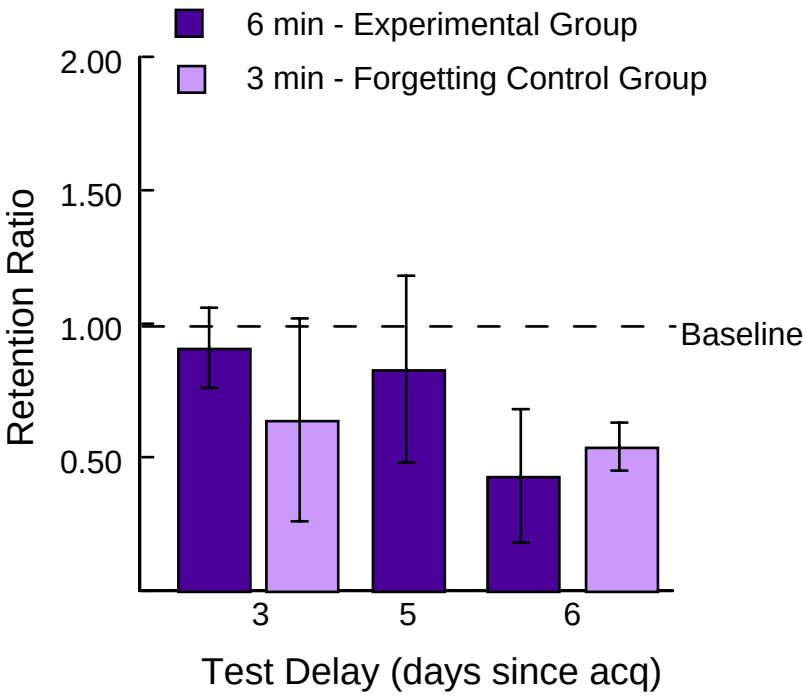
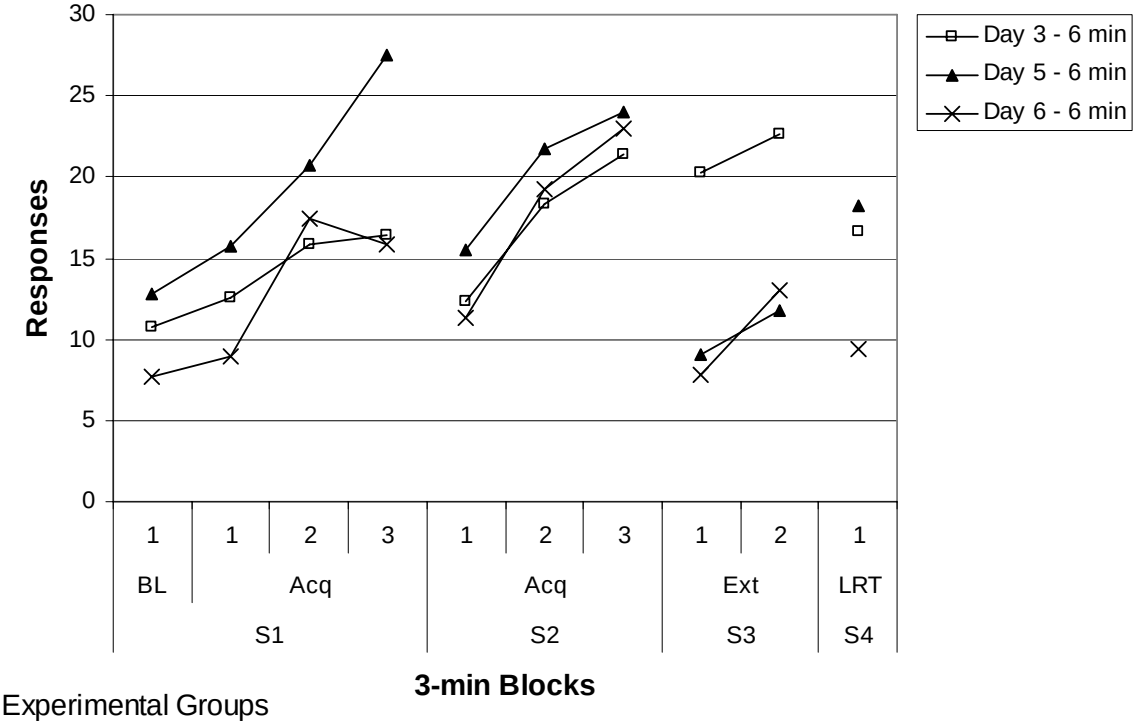
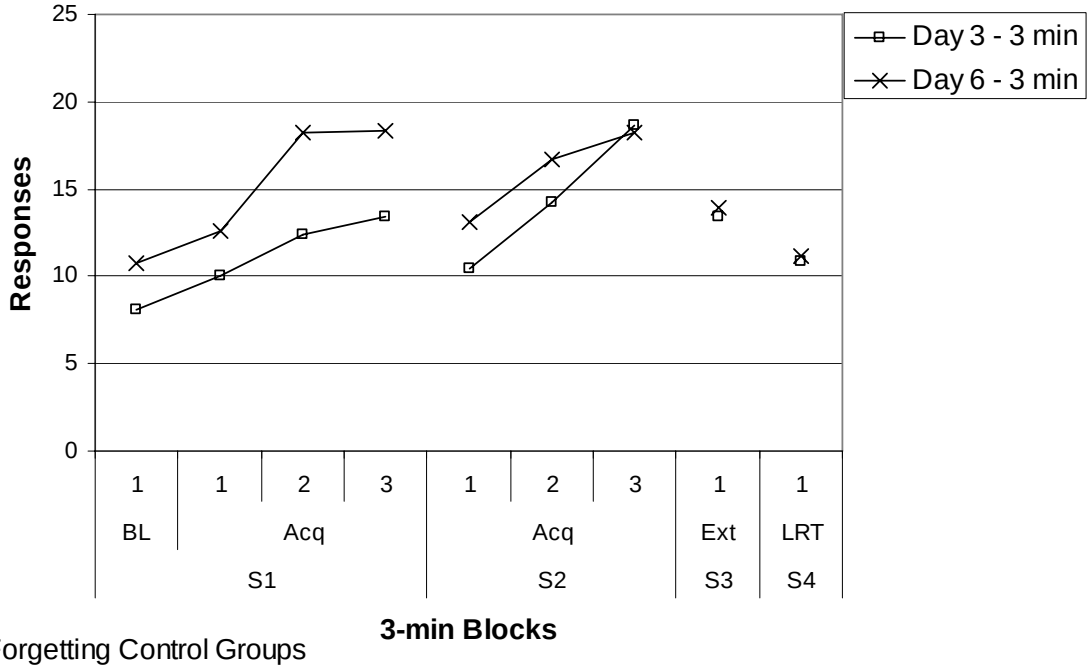

6 min - Experimental Group
3 min - Forgetting Control Group
2.00
1.50
1.00
0.50
Retention Ratio
Baseline
3
5
6
Test Delay (days since acq)

Figure 29. Mean responses of three experimental groups, collapsed across 3-min blocks of acquisition over two consecutive days. Session 1 (S1) began with a 3-min nonreinforcement baseline (BL) period and was followed by a 9-min reinforcement (acquisition, or Acq) period. An additional 9-min Acq period took place 24 hr later, during the second session (S2). Session 3 (S3) was 6 min of nonreinforcement training (extinction, or Ext) 24 hr before LRT. The long-term retention test (LRT), a 3-min nonreinforcement period, occurred 3, 5, or 6 days after S2. (Experiment 2c: Delayed 6-min extinction 24 hr prior to LRT)



Experimental Groups

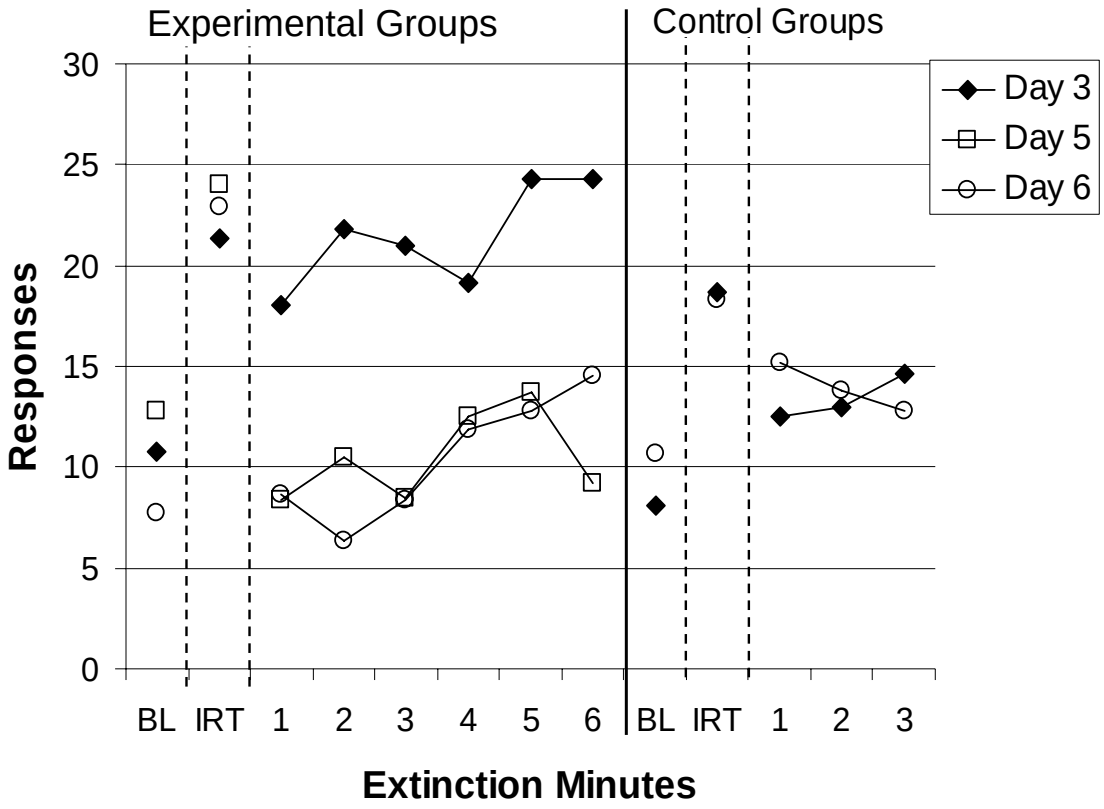
Figure 30. Mean responses of two forgetting control groups, collapsed across 3-min blocks of acquisition over two consecutive days. Session 1 (S1) began with a 3-min nonreinforcement baseline (BL) period and was followed by a 9-min reinforcement (acquisition, or Acq) period. An additional 9-min Acq period took place 24 hr later, during the second session (S2). Session 3 (S3) was 3 min of nonreinforcement training (extinction, or Ext) 24 hr before LRT. The long-term retention test (LRT), a 3-min nonreinforcement period, occurred 3 or 6 days after S2. (Experiment 2c: Delayed 6-min extinction 24 hr prior to LRT)



Forgetting Control Groups

Figure 31. Mean responses during the extinction manipulation for experimental and forgetting control groups. Each groups baseline (BL) and immediate retention test (IRT) are plotted for comparison. (Experiment 2c: Delayed 6-min extinction 24 hr prior to LRT)

Experiment 2c



Appendix A

Experiment 1a: Immediate extinction: 18-min acquisition

One-Way ANOVA Table for BR & RR

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
BR					
Group	7	19.10	2.73	6.79	0.000
Residual	38*	16.07	0.40		
RR					
Group	7	2.82	0.33	3.00	0.01
Residual	38*	4.34	0.11		

Test of Homogeneity of Variances

	Levene	df1	df2	Sig.
BR	2.09	7	38*	0.07
RR	2.73	7	38*	0.02

Tukey HSD

BR	BR	Mean Difference	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Day 1 - 6 min	Day 1 - 3 min	-1.44	0.37	0.01	-2.61	-0.27
Day 3 - 6 min	Day 3 - 3 min	-1.54	0.37	0.00	-2.71	-0.37

Games-Howell

RR	RR	Mean Difference	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Day 1 - 6 min	Day 1 - 3 min	-0.73	0.18	0.03	-1.41	-0.05

Note. * Denotes adjusted df due to replaced outlier values.

Appendix B

Experiment 1a: Immediate extinction: 18-min acquisition

Two-Way ANOVA Table for BR & RR

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
BR					
Group	7	19.26	2.75	6.92	0.000
Residual	39*	16.31	0.31		
RR					
Group	7	2.19	0.31	2.82	0.02
Residual	39*	4.56	0.11		

Pairwise Comparisons Based on Estimated Marginal Means

Adjustment for multiple comparisons: Sidak.

						95% Confidence Interval	
	Duration	Duration	Mean Difference	Std. Error	Sig.	Lower Bound	Upper Bound
BR	3	6	1.08	0.18	0.00	0.71	1.44
RR	3	6	0.32	0.10	0.00	0.12	0.51

Note. * Denotes adjusted df due to replaced outlier values.

Appendix C

Age (in days), Sex, Parental Socioeconomic Index, Ethnicity, Baseline, Immediate Retention Test (IRT), and Long-term Retention Test (LRT) Response Rates, Individual Baseline Ratios (BR) and Retention Ratios (RR) for Participants in Experimental Groups (6-min Extinction) for Experiment 1a.

Group	Subject	Age	Sex	SEI	Eth.	Baseline	IRT	LRT	BR	RR
Day 1	HG	105	M	27.53	C	3.33	9.33	3.67	1.10	0.39
	AV	93	F	83.65	A	13.30	13.30	2.00	0.15	0.15
	YL	93	M	86.98	C	6.67	19.00	7.30	1.09	0.38
	NR	93	F	NR	C	11.30	17.00	15.00	1.33	0.88
	EW	92	F	75.17	C	7.67	13.00	8.33	1.09	0.64
	KW	96	F	50.51	C	5.33	3.67	1.33	0.25	0.36
Day 3	MF	97	F	78.50	C	5.33	9.33	7.67	1.44	0.82
	ES	91	F	84.24	C	7.67	9.00	8.67	1.13	0.96
	JP	88	M	NR	C	7.00	10.33	5.00	0.71	0.48
	AD	98	M	92.30	C	12.00	7.67	6.33	0.53	0.83
	ML	111	F	74.09	C	7.67	8.00	4.67	0.61	0.58
	AH	98	F	68.80	C	3.67	31.67	4.67	1.27	0.15
Day 5	RS	109	F	76.45	C	6.60	6.00	3.30	0.50	0.55
	RM	108	F	NR	C	4.00	10.00	7.33	1.83	0.73
	SC	100	M	73.23	C	2.67	12.00	6.33	2.38	0.53
	TG	104	M	87.90	C	3.33	10.33	4.00	1.20	0.39
	JD	106	M	76.31	C	18.00	17.67	11.00	0.61	0.62
	JL	104	M	83.65	C	10.67	12.00	8.33	0.78	0.69
Day 6	JM	99	M	73.61	C	11.67	9.67	12.00	1.03	1.24
	CP	107	M	36.51	H	14.67	14.00	6.00	0.41	0.43
	MS	99	F	61.91	H	4.00	13.33	13.00	3.25*	0.98
	DR	103	M	62.49	C	3.00	9.00	3.00	1.00	0.33
	SW	104	F	61.91	C	4.67	15.00	2.00	0.43	0.13
	AR	112	F	73.23	M	3.00	11.67	3.00	1.00	0.26

Note. SEI = Parental Socioeconomic Index. IRT = Immediate Retention Test. LRT = Long-term Retention Test. BR = Baseline Ratio. RR = Retention Ratio. M = Male. F = Female. NR = Not Reported. A = Asian. C = Caucasian. H = Hispanic. M = Mixed. * denotes an outlying value prior to adjustment.

Appendix D

Age (in days), Sex, Parental Socioeconomic Index, Ethnicity, Baseline, Immediate Retention Test (IRT), and Long-term Retention Test (LRT) Response Rates, Individual Baseline Ratios (BR) and Retention Ratios (RR) for Participants in Forgetting Control Groups (3-min Extinction) for Experiment 1a.

Group	Subject	Age	Sex	SEI	Eth.	Baseline	IRT	LRT	BR	RR
Day 1	1005-002	99	F	76.43	C	6.67	20.00	19.33	2.90	0.97
	1005-003	101	M	29.29	M	8.33	20.50	20.33	2.44	0.99
	1005-204	88	M	76.43	C	5.00	7.00	19.33	3.87	2.76*
	1005-203	88	M	76.43	C	18.33	20.00	33.00	1.80	1.65
	1005-004	103	M	NR	A	5.67	9.67	8.67	1.53	0.90
	1105-001	97	F	61.91	C	13.00	26.00	27.00	2.08	1.04
Day 3	1105-005	90	M	76.43	C	9.00	25.33	24.00	2.67	0.95
	0805-209	106	M	78.50	C	6.33	26.00	13.00	2.05	0.50
	0606-005	93	M	75.17	M	4.67	22.00	18.33	3.93	0.83
	1206-008	97	F	NR	A	5.33	18.33	18.33	3.44	1.00
	0506-207	101	F	83.65	A	17.67	19.33	19.33	1.09	1.00
	0506-003	93	M	NR	H	12.33	31.00	21.67	1.76	0.70
Day 5	0706-209	98	M	49.50	C	8.00	14.67	17.67	2.21	1.20
	0706-009	97	M	54.67	AA	2.33	20.00	3.67	1.57	0.18
	0706-210	102	M	83.22	C	5.00	8.67	9.33	1.87	1.08
	0806-004	93	F	NR	C	7.67	18.00	10.00	1.30	0.56
	1006-210	98	M	73.61	C	6.00	40.67	20.00	3.33	0.49
	1006-211	98	M	73.61	C	5.33	19.00	10.67	2.00	0.56
Day 6	0706-213	100	F	83.65	M	5.67	18.67	4.00	0.71	0.21
	0806-213	105	F	NR	M	5.67	8.33	10.33	1.82	1.24
	0806-211	99	F	NR	M	6.67	5.33	6.67	1.00	1.25
	0806-005	94	M	44.23	C	5.33	23.67	17.00	3.19*	0.72
	0806-003	95	M	NR	A	4.33	10.67	6.33	1.46	0.59
	AC	100	F	81.91	H	6.00	3.67	9.33	1.56	2.55*
	0807-207	95	F	62.49	C	5.00	11.33	4.33	0.87	0.38

Note. SEI = Parental Socioeconomic Index. Eth = Ethnicity. IRT = Immediate Retention Test. LRT = Long-term Retention Test. BR = Baseline Ratio. RR = Retention Ratio. M = Male. F = Female. NR = Not Reported. A = Asian. C = Caucasian. H = Hispanic. M = Mixed. * denotes an outlying value prior to adjustment.

Appendix E

Experiment 1a: Immediate extinction: 18-min acquisition

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon Greenhouse-Geisser
Phase	0.75	11.56	2	0.003	0.80

Repeated Measures ANOVA for Phase (BL, IRT, LRT)
Between-Subject Factors: Extinction Duration & Test Delay

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
Phase					
Group	1.60	1448.10	905.81	34.08	0.000
Residual	65.55	1742.04	26.58		
Duration					
Group	1	874.49	874.49	17.77	0.000
Residual	41	2017.70	49.21		
Delay					
Group	3	464.87	154.96	3.15	0.04
Residual	41	2017.70	49.21		
Phase x Duration					
Group	1.60	475.58	297.49	11.19	0.000
Residual	65.55	1742.04	26.58		

Pairwise Comparisons Based on Estimated Marginal Means
Adjustment for multiple comparisons: Sidak.

Phase	Phase	Mean Difference	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
BL	IRT	-7.68	1.09	0.000	-10.39	-4.97
	LRT	-3.36	0.67	0.000	-5.04	-1.69
IRT	BL	7.68	1.09	0.000	4.97	10.39
	LRT	4.32	0.98	0.000	1.87	6.77
LRT	BL	3.36	0.67	0.000	1.69	5.04
	IRT	-4.32	0.98	0.000	-6.77	-1.87

Appendix F

Experiment 1a: Immediate extinction: 18-min acquisition

Repeated Measures ANOVA on Extinction Minutes
Between-Subject Factors: Extinction Duration & Test Delay

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
6 min Ext					
Group	1	99.95	19.99	0.98	0.44
Residual	100	2046.03	20.46		
3 min Ext					
Group	2	16.25	8.12	0.19	0.83
Residual	40	1691.69	42.29		

Appendix G

Experiment 1b: Immediate extinction, 15-min acquisition

One-Way ANOVA Table for BR & RR

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
BR					
Group	5	3.58	0.72	1.10	0.38
Residual	28*	20.20	0.66		
RR					
Group	5	1.18	0.24	0.45	0.81
Residual	29*	16.12	0.52		

Note. * Denotes adjusted df due to replaced outlier values.

Appendix H

Age (in days), Sex, Socioeconomic Index (SEI), Ethnicity (Eth), Baselines (BL; kicks/min), Immediate Retention Test Scores (IRT; kicks/min), Long-Term Retention Test Scores (LRT; kicks/min), Baseline Ratios (BR) and Retention Ratios (RR) of Participants in Experimental Groups (4 min of Extinction) in Experiment 1b.

Group	Subject	Age	Sex	SEI	Eth	BL	IRT	LRT	BR	RR
Day 1	RB	98	M	38.77	C	2.67	8.33	7.67	2.88*	0.92
	KK	102	F	61.91	C	5.67	8.67	3.33	0.59	0.38
	PJ	101	M	61.91	A	4.33	11.33	4.67	1.08	0.41
	LB	102	M	32.73	C	8.00	16.00	6.00	0.75	0.38
	AR	94	M	61.95	C	5.33	6.00	4.33	0.81	0.72
	GB	96	F	46.80	C	8.67	18.33	5.33	0.62	0.29
Day 3	RT	107	M	86.67	C	4.00	7.00	11.00	2.75	1.57
	AT	89	M	73.26	C	9.00	12.33	11.33	1.26	0.92
	MS	95	F	49.31	C	7.00	4.33	4.33	0.62	1.00
	BL	94	M	63.53	M	4.67	15.00	14.67	3.14	0.98
	AS	101	M	92.30	C	14.33	11.67	2.00	0.14	0.17
	CS	88	F	44.66	C	8.00	29.67	6.33	0.79	0.21
Day 5	KI	96	F	76.43	C	3.00	5.00	3.67	1.22	0.73
	TK	104	F	83.65	A	6.33	9.67	7.33	1.16	0.76
	JK	102	M	81.74	C	4.33	11.00	2.33	0.54	0.21
	GL	100	M	73.61	C	5.67	8.67	4.33	0.76	0.50
	NT	103	M	76.31	A	3.00	6.30	11.67	3.89*	1.85*
	JY	102	M	87.90	A	2.67	6.67	3.67	1.38	0.55

Note. M = Male; F = Female; NR = Not Reported; A = Asian; C = Caucasian; H = Hispanic; M = Mixed Race.
* value of an outlier prior to correction.

Appendix I

Age (in days), Sex, Parental Socioeconomic Index (SEI), Ethnicity (Eth), Baseline (BL), Immediate Retention Test Scores (IRT), and Long-term Retention Test Scores (LRT), Individual Baseline Ratios (BR) and Retention Ratios (RR) of Participants in Forgetting Control Groups (2 min of Extinction) in Experiment 1b.

Group	Subject	Age	Sex	SEI	Eth	Baseline	IRT	LRT	BR	RR
Day 1	JS	96	M	76.45	C	7.00	11.33	3.00	0.43*	0.27*
	SM	89	M	88.27	C	10.00	24.50	16.00	1.60	0.65
	MS	101	F	83.65	C	27.00	45.00	37.33	1.38	0.83
	MD	104	F	64.36	C	4.67	11.00	8.67	1.86	0.79
	CP	94	M	NR	C	10.33	28.00	19.00	1.84	0.68
	CB	90	M	73.61	C	4.00	9.00	5.67	1.42	0.63
Day 3	AP	105	F	86.82	C	13.33	28.00	21.00	1.58	0.75
	JR	98	M	87.90	C	6.67	8.00	3.00	0.45	0.38
	AP	103	M	57.12	C	19.25	15.50	16.67	0.87	1.08
	AA	98	M	75.17	C	2.00	36.50	5.67	2.83	0.16
	TM	104	F	80.86	C	19.00	40.50	19.00	1.00	0.47
	AW	91	F	69.19	C	4.67	16.00	8.33	1.79	0.52
	MK	101	F	97.16	C	4.33	16.00	15.33	3.54	0.96
Day 5	CC	100	F	28.58	M	6.33	17.50	13.00	2.05	0.74
	LA	93	F	68.06	C	8.33	15.50	22.33	2.68	1.44
	JS	98	M	73.61	C	6.00	10.50	4.67	0.78	0.44
	AS	96	M	38.07	C	8.00	6.00	4.33	0.54	0.72
	JA	87	M	68.80	C	11.33	37.00	6.67	0.59	0.18
	CS	100	M	63.53	C	26.33	41.00	15.67	0.59	0.38

Note. M = Male; F = Female; NR = Not Reported; A = Asian; C = Caucasian; H = Hispanic; M = Mixed Race.
* denotes an outlying value prior to adjustment.

Appendix J

Experiment 1b: Immediate extinction, 15-min acquisition

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon Greenhouse-Geisser
Phase	0.71	10.33	2	0.01	0.77

Repeated Measures ANOVA for Phase (BL, IRT, LRT)
Between-Subject Factors: Extinction Duration & Test Delay

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
Phase					
Group	1.55	1122.53	724.70	14.86	0.000
Residual	48.01	2342.36	48.79		
Duration					
Group	1	13.42.41	13707.07	103.38	0.000
Residual	31	4110.20	132.59		
Delay					
Group	2	30.29	30.29	0.23	0.80
Residual	31	4110.20	132.59		
Phase x Duration					
Group	2	104.88	52.44	0.40	0.68
Residual	31	4110.20	132.59		

Pairwise Comparisons Based on Estimated Marginal Means
Adjustment for multiple comparisons: Sidak.

Phase	Phase	Mean Difference	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
BL	IRT	-7.36	1.52	0.000	-11.19	-3.52
	LRT	-1.42	0.99	0.41	-3.93	1.08
IRT	BL	7.36	1.52	0.000	3.52	11.19
	LRT	5.93	1.69	0.004	1.67	10.19
LRT	BL	1.42	0.99	0.41	-1.08	3.93
	IRT	-5.93	1.69	0.004	-10.19	-1.67
Duration	Duration					
2 min	4 min	6.97	2.19	0.003	2.50	11.43

Appendix K

Experiment 1b: Immediate extinction, 15-min acquisition

Repeated Measures ANOVA on Extinction Minutes
Between-Subject Factors: Extinction Duration & Test Delay

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
4 min Ext					
Group	3	32.28	10.76	0.90	0.45
Residual	45	540.83	12.02		
2 min Ext					
Group	1	72.50	72.50	3.49	0.80
Residual	16	332.51	20.78		

Appendix L

Experiment 2a: Delayed extinction, 18-min acquisition

One-Way ANOVA Table for BR & RR

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
BR					
Group	5	22.13	4.43	4.52	0.003
Residual	30*	30.37	0.98		
RR					
Group	5	13.01	2.60	11.67	0.000
Residual	30*	6.91	0.22		

Test of Homogeneity of Variances

	Levene	df1	df2	Sig.
BR	7.87	5	30*	0.000
RR	4.71	5	30*	0.003

Games-Howell

					95% Confidence Interval	
RR	RR	Mean Difference	Std. Error	Sig.	Lower Bound	Upper Bound
Day 2 - 6 min	Day 2 - 3 min	1.61	0.38	0.05	0.02	3.20

Note. * Denotes adjusted df due to replaced outlier values.

Appendix M

Experiment 2a: Delayed extinction, 18-min acquisition

Two-Way ANOVA Table for BR & RR

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
BR					
Group	5	22.13	4.43	4.52	0.003
Residual	30*	30.37	0.98		
Duration					
Group	1	6.33	6.33	6.46	0.02
Residual	30*	30.37	0.98		
Delay					
Group	3	11.70	3.90	3.98	0.02
Residual	30*	30.37	0.98		
Duration x Delay					
Group	1	7.53	7.53	7.68	0.009
Residual	30*	30.37	0.98		
RR					
Group	5	13.01	2.60	11.67	0.000
Residual	30*	6.91	0.22		
Duration					
Group	1	3.19	3.19	14.29	0.001
Residual	30*	6.91	0.22		
Delay					
Group	3	7.25	2.42	10.85	0.000
Residual	30*	6.91	0.22		
Duration x Delay					
Group	1	4.96	4.96	22.26	0.000
Residual	30*	6.91	0.22		

Note. * Denotes adjusted df due to replaced outlier values.

Appendix N

Experiment 2a: Delayed extinction, 18-min acquisition

Pairwise Comparisons Based on Estimated Marginal Means

Adjustment for multiple comparisons: Sidak

						95% Confidence Interval	
	Duration	Duration	Mean Difference	Std. Error	Sig.	Lower Bound	Upper Bound
BR	6	3	0.64	0.34	0.07	-0.06	1.34
RR	6	3	0.36	0.16	0.03	0.03	0.69

Tukey HSD

					95% Confidence Interval	
Group RR	Group RR	Mean Difference	Std. Error	Sig.	Lower Bound	Upper Bound
Day 2	Day 3	0.69	0.23	0.03	0.03	0.06
	Day 5	0.71	0.23	0.02	0.02	0.07
	Day 6	0.77	0.19	0.002	0.002	0.25

Appendix O

Age (in days), Sex, Parental Socioeconomic Index, Ethnicity, Baseline, Immediate Retention Test (IRT), and Long-term Retention Test (LRT) Response Rates, Individual Baseline Ratios (BR) and Retention Ratios (RR) for Participants in Experimental Groups (6 min extinction) for Experiment 2a.

Group	Subject	Age	Sex	SEI	Eth.	Baseline	IRT	LRT	BR	RR
Day 2	0806-204	103	F	NR	A	5.67	4.00	7.00	1.24	1.75
	1106-002	91	M	61.91	O	8.33	28.00	29.33	3.52	1.05
	1206-004	98	F	NR	C	6.00	21.67	40.67	6.78	1.88
	0107-002	104	F	32.28	M	8.00	5.67	20.00	2.50	3.53
	1206-207	99	F	83.22	C	8.00	4.67	9.00	1.13	1.93
	0207-002	105	F	73.67	C	4.67	7.33	22.67	4.86	3.09
Day 3	0107-212	108	F	57.12	C	9.00	26.33	10.67	1.19	0.41
	0107-203	92	F	78.50	C	12.33	34.33	12.33	1.00	0.36
	0107-204	88	M	64.08	C	10.33	17.33	25.33	2.45	1.46*
	0207-004	91	M	NR	C	3.00	14.67	7.00	2.33	0.48
	0207-202	89	M	77.77	C	11.33	33.33	24.67	2.18	0.74
	0607-007	99	M	66.08	C	7.33	18.33	8.00	1.09	0.44
Day 5	0806-214	105	F	NR	M	19.67	38.00	13.67	0.69	0.36
	0906-003	103	M	97.16	C	11.67	22.00	20.67	1.77	0.94
	1006-203	98	F	35.07	C	8.67	15.67	18.00	2.08	1.15
	1206-006	102	M	83.65	C	2.33	7.00	2.67	1.14	0.38
	0107-012	103	M	73.61	C	7.00	15.67	8.33	1.19	0.53
	0307-015	88	F	22.62	H	21.33	38.00	15.67	0.73	0.41
Day 6	0806-212	105	F	76.31	C	3.33	12.33	4.33	1.30	0.35
	0107-210	94	F	63.2	H	19.67	31.33	26.33	1.34	0.84
	0207-205	95	M	63.2	C	13.67	15.67	6.33	0.46	0.40
	0207-001	96	M	NR	NR	7.33	37.00	9.00	1.23	0.24
	0407-015	95	F	87.9	H	10.00	22.67	10.00	1.00	0.44
	0507-221	96	M	73.61	M	2.25	16.00	10.00	4.44*	0.63

Note. SEI = Parental Socioeconomic Index. Eth = Ethnicity. IRT = Immediate Retention Test. LRT = Long-term Retention Test. BR = Baseline Ratio. RR = Retention Ratio. M = Male. F = Female. NR = Not Reported. A = Asian. C = Caucasian. H = Hispanic. M = Mixed. * denotes an outlying value prior to adjustment.

Appendix P

Age (in days), Sex, Parental Socioeconomic Index, Ethnicity, Baseline, Immediate Retention Test (IRT), and Long-term Retention Test (LRT) Response Rates, Individual Baseline Ratios (BR) and Retention Ratios (RR) for Participants in Forgetting Control Groups (3 min extinction) for Experiment 2a.

Group	Subject	Age	Sex	SEI	Eth.	Baseline	IRT	LRT	BR	RR
Day 2	0507-006	105	M	NR	C	11.67	20.67	12.00	1.03	0.58
	0507-017	101	F	NR	C	14.67	34.00	17.00	1.16	0.50
	0506-207	101	F	83.65	A	3.40	16.67	7.67	2.25	0.46
	0607-010	98	F	45.79	AA	5.33	9.67	6.67	1.25	0.69
	0607-207	96	M	66.11	C	12.67	33.33	10.67	0.84	0.32
	0707-006	106	M	76.31	C	10.00	19.33	14.33	1.43	0.74
Day 6	0607-205	106	M	50.51	AA	23.00	28.67	36.00	1.57	1.26
	0707-010	106	M	NR	O	14.00	37.00	27.33	1.95	0.74
	0707-209	107	F	76.43	C	9.20	16.00	9.33	1.01	0.58
	0807-019	93	F	64.23	C	7.33	15.67	8.33	1.14	0.53
	0807-018	93	M	64.23	C	7.67	21.00	11.67	1.52	0.56
	0807-202	105	F	28.40	A	2.33	9.00	8.00	3.43	0.89

Note. SEI = Parental Socioeconomic Index. Eth = Ethnicity. IRT = Immediate Retention Test. LRT = Long-term Retention Test. BR = Baseline Ratio. RR = Retention Ratio. M = Male. F = Female. NR = Not Reported. A = Asian. C = Caucasian. H = Hispanic. M = Mixed. * denotes an outlying value prior to adjustment.

Appendix Q

Experiment 2a: Delayed extinction, 18-min acquisition

Repeated Measures ANOVA for Phase (BL, IRT, LRT)
Between-Subject Factors: Extinction Duration & Test Delay

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
Phase					
Group	2	2258.71	1129.35	34.96	0.000
Residual	62	2002.93	32.31		
Phase x Delay					
Group	6	521.81	86.97	2.69	0.02
Residual	62	2002.93	32.31		

Pairwise Comparisons Based on Estimated Marginal Means
Adjustment for multiple comparisons: Sidak

					95% Confidence Interval	
Phase	Phase	Mean Difference	Std. Error	Sig.	Lower Bound	Upper Bound
BL	IRT	-11.04	1.24	0.000	-14.18	-7.91
	LRT	-4.84	1.21	0.001	-7.89	-1.79
IRT	BL	11.04	1.24	0.000	7.91	14.18
	LRT	6.20	1.50	0.001	2.41	9.99
LRT	BL	4.84	1.21	0.001	1.79	7.89
	IRT	-6.20	1.50	0.001	-9.99	-2.41

Appendix R

Experiment 2a: Delayed extinction, 18-min acquisition

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon Greenhouse-Geisser
Minute	0.19	30.44	14	0.007	0.56

Repeated Measures ANOVA on Extinction Minutes Between-Subject Factors: Extinction Duration & Test Delay

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
6 min Ext					
Group	5	682.33	243.3	2.72	0.06
Residual	56.09	5016.5	89.44		
2 min Ext					
Group	2	142.17	71.08	1.79	0.19
Residual	20	794.11	39.71		

Pairwise Comparisons Based on Estimated Marginal Means

Adustment for Multiple Comparisons: Sidak

Minute	Minute	Mean Difference	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
2	1	6.08	1.69	0.03	0.46	11.71
3	1	5.87	1.59	0.02	0.59	11.16

Appendix S

Experiment 2b: Delayed extinction, 15-min acquisition

One-Way ANOVA Table for BR & RR

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
BR					
Between	2	0.32	0.16	0.15	0.86
Within	14	15.99	1.07		
RR					
Between	2	0.23	0.12	0.36	0.70
Within	14	4.76	0.32		

Appendix T

Age (in days), Sex, Parental Socioeconomic Index, Ethnicity, Baseline, Immediate Retention Test (IRT), and Long-term Retention Test (LRT) Response Rates, Individual Baseline Ratios (BR) and Retention Ratios (RR) for Participants in Experiment 2b.

Group	Subject	Age	Sex	SEI	Eth.	Baseline	IRT	LRT	BR	RR
Day 2	RB	94	M	86.67	C	2.33	8.67	3.67	1.58	0.42
	SR	103	F	76.31	A	3.67	10.67	6.00	1.64	0.56
	KR	101	F	73.86	C	5.00	10.00	4.00	0.80	0.40
	TN	99	M	63.53	H	9.67	20.00	16.67	1.72	0.83
	LB	102	M	89.95	A	5.67	22.33	9.67	1.71	0.43
	CM	106	M	54.67	C	2.67	5.00	8.33	3.13*	1.67*
Day 3	OP	96	F	NR	C	5.00	12.00	9.33	1.87	0.78
	SH	102	F	78.50	C	11.67	15.67	8.00	0.69	0.51
	GH	107	M	73.61	C	17.67	28.33	4.33	0.25	0.15
	SA	102	M	78.50	M	3.67	13.33	7.00	1.91	0.53
	AA	102	M	NR	A	6.67	26.67	7.00	1.05	0.26
	TC	103	M	78.50	C	6.00	19.33	6.33	1.06	0.33
Day 6	MH	103	M	84.24	M	6.33	18.00	5.67	0.89	0.31
	TP	107	M	76.31	A	4.33	21.33	6.33	1.46	0.30
	TR	95	M	50.51	C	3.25	5.00	7.67	2.36	1.53
	AL	101	F	52.44	H	5.00	10.33	3.67	0.73	0.35
	TL	101	M	53.44	H	6.67	31.00	2.33	0.35	0.08
	LK	94	F	NR	C	3.00	4.33	7.00	2.33	1.62

Note. SEI = Parental Socioeconomic Index. Eth = Ethnicity. IRT = Immediate Retention Test. LRT = Long-term Retention Test. BR = Baseline Ratio. RR = Retention Ratio. M = Male. F = Female. NR = Not Reported. A = Asian. C = Caucasian. H = Hispanic. M = Mixed. * denotes an outlying value prior to adjustment.

Appendix U

Experiment 2b: Delayed extinction, 15-min acquisition

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon Greenhouse-Geisser
Phase	0.46	8.61	2	0.01	0.65

Repeated Measures ANOVA for Phase (BL, IRT, LRT) Between-Subject Factors: Extinction Duration & Test Delay

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
Phase					
Group	1.30	448.28	345.86	7.66	0.01
Residual	15.55	702.12	45.14		

Pairwise Comparisons Based on Estimated Marginal Means

Adjustment for multiple comparisons: Sidak

Phase	Phase	Mean Difference	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
BL	IRT	-8.15	2.15	0.01	-14.11	-2.20
	LRT	-1.35	1.41	0.74	-5.27	2.57
IRT	BL	8.15	2.15	0.01	2.20	14.11
	LRT	6.80	2.89	0.10	-1.19	14.80
LRT	BL	1.35	1.41	0.74	-2.57	5.27
	IRT	-6.80	2.89	0.10	-14.80	1.19

Repeated Measures ANOVA on Extinction Minutes
Between-Subject Factors: Extinction Duration & Test Delay

	df	Sum of Squares	Mean Square	*F* Value	*P* Value
4-6 min Ext					
Group	5	127.22	25.44	0.81	0.55
Residual	30	941.56	31.39		
4 min Ext					
Group	3	18.06	6.02	0.42	0.74
Residual	18	255.73	14.21		

Appendix V

Age (in days), Sex, Parental Socioeconomic Index, Ethnicity, Baseline, Immediate Retention Test (IRT), and Long-term Retention Test (LRT) Response Rates, Individual Baseline Ratios (BR) and Retention Ratios (RR) for Participants in Experimental Groups (6 min extinction) for Experiment 2c.

Group	Subject	Age	Sex	SEI	Eth.	Baseline	IRT	LRT	BR	RR
Day 3	0307-002	100	F	73.61	C	6.00	24.67	20.33	3.39	0.82
	0307-010	97	F	NR	C	6.00	15.67	15.67	2.61	1.00
	0307-209	97	M	86.82	C	10.67	14.00	16.33	1.53	1.17
	0307-206	110	F	66.11	M	4.33	10.00	9.00	2.08	0.90
	0407-005	90	F	82.67	C	26.67	43.00	34.33	1.29	0.80
	0707-002	92	F	69.19	C	11.00	21.00	4.00	0.36	0.80
Day 5	0407-010	92	M	78.5	C	13.00	29.67	30.33	2.33	1.02
	0407-004	92	M	48.59	O	23.33	13.67	19.00	0.81	1.39
	0407-014	100	M	78.78	C	12.00	35.67	17.67	1.47	0.50
	0407-202	95	F	92.3	C	5.00	14.67	13.67	2.73	0.93
	0507-223	99	M	29.38	H	9.67	30.67	18.33	1.90	0.60
	0607-002	103	M	NR	A	14.00	20.00	10.67	0.76	0.53
Day 6	0307-008	99	F	76.43	C	4.00	7.00	11.00	2.75	1.57*
	0207-204	104	M	NR	NR	2.67	33.33	11.33	4.25	0.34
	0307-012	95	F	64.36	C	10.33	14.67	9.67	0.94	0.66
	0307-004	102	F	88.82	C	7.67	33.67	4.67	0.61	0.14
	0307-005	96	F	63.53	C	17.33	25.67	16.33	0.94	0.64
	0807-015	97	M	32.28	H	4.33	23.33	3.33	0.77	0.14

Note. SEI = Parental Socioeconomic Index. Eth = Ethnicity. IRT = Immediate Retention Test. LRT = Long-term Retention Test. BR = Baseline Ratio. RR = Retention Ratio. M = Male. F = Female. NR = Not Reported. A = Asian. C = Caucasian. H = Hispanic. M = Mixed. * denotes an outlying value prior to adjustment.

Appendix W

Age (in days), Sex, Parental Socioeconomic Index, Ethnicity, Baseline, Immediate Retention Test (IRT), and Long-term Retention Test (LRT) Response Rates, Individual Baseline Ratios (BR) and Retention Ratios (RR) for Participants in Forgetting Control Groups (3 min extinction) for Experiment 2c.

Group	Subject	Age	Sex	SEI	Eth.	Baseline	IRT	LRT	BR	RR
Day 3	0807-208	102	M	NR	M	5.33	14.00	5.00	0.94	0.36
	0907-010	91	M	74.42	H	11.67	20.33	17.67	1.51	0.87
	1007-017	98	M	73.61	H	6.33	9.67	11.33	1.79	1.17
	1007-004	97	M	33.06	M	5.33	23.33	18.00	3.38	0.77
	1007-008	95	F	65.06	A	11.67	26.33	2.33	0.20	0.09
	1007-202	94	F	NR	C	8.33	18.33	10.67	1.28	0.58
Day 6	0407-208	102	M	80.33	O	8.33	15.33	9.33	1.12	0.61
	0407-218	97	F	54.67	H	8.33	14.33	7.33	0.88	0.51
	0407-219	96	M	66.11	C	7.00	16.33	6.33	0.91	0.39
	0507-018	104	F	76.43	C	9.00	8.00	14.00	1.56*	1.75*
	0507-203	104	M	86.67	C	16.67	33.00	16.00	0.96	0.48
	0507-214	99	F	97.16	C	15.00	22.67	14.00	0.93	0.62

Note. SEI = Parental Socioeconomic Index. Eth = Ethnicity. IRT = Immediate Retention Test. LRT = Long-term Retention Test. BR = Baseline Ratio. RR = Retention Ratio. M = Male. F = Female. NR = Not Reported. A = Asian. C = Caucasian. H = Hispanic. M = Mixed. * denotes an outlying value prior to adjustment.