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Contrasting AAC and ABC renewal: the role of context associations

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Abstract Rats were used in a lick suppression preparation to assess the contribution of conditioned-stimulus (CS)–context and context–unconditioned-stimulus (US) associations to experimental extinction. Experiment 1 investigated whether strengthening the CS–acquisition context association enhances extinction by determining whether stronger extinction is observed when CS-alone trials (i.e., extinction treatment) are administered in the acquisition context (AAC renewal), relative to a context that is neutral with respect to the US (ABC renewal). Less recovery of responding to the CS was observed in the former than in the latter case, extending the finding that AAC renewal is weaker than ABC renewal to our lick suppression preparation. Experiment 2 assessed the contribution of the acquisition context–US association to extinction of a CS by examining the effect of postextinction exposure to the acquisition context on responding to the extinguished CS. This manipulation enhanced responding to the extinguished CS in AAC, but not ABC, renewal. Experiment 3 addressed the contribution of the CS–acquisition context association by examining the potential of a neutral stimulus, presented in compound with the target CS during extinction treatment, to overshadow the CS–acquisition context association. This manipulation enhanced responding to the extinguished CS in AAC, but not ABC, renewal. The results stress the important role of contextual association in extinction and renewal.

Keywords Pavlovian conditioning · Extinction · Renewal · Context · Relapse

One of the most widely studied phenomena of associative learning is experimental extinction (Pavlov, 1927; for reviews, see Delamater, 2004; Rescorla, 2001). After an association between a conditioned stimulus (CS) and an unconditioned stimulus (US) has been formed through contiguous pairings (CS–US), the repeated presentation of the CS by itself decreases its behavioral control. The empirical study of extinction has been important for theories of associative learning (e.g., Miller & Matzel, 1988; Rescorla & Wagner, 1972; Wagner, 1981) and for animal models of exposure therapies (e.g., Bouton, 2000; Bouton & Nelson, 1998), as well as for the development of associative accounts of the etiology of anxiety disorders (e.g., Bouton, Mineka, & Barlow, 2001; Laborda & Miller, in press; Mineka & Oehlberg, 2008; Mineka & Zinbarg, 2006). In the last 3 decades, evidence has been reported indicating that extinction does not erase the original association between a CS and a US, as some contemporary associative models have proposed (e.g., Rescorla & Wagner, 1972), but creates a new inhibitory-like association, the expression of which can be modulated by the context (for reviews, see Bouton, 1993, 2000, 2004). More recently, researchers have returned to Pavlov's (1927) view of extinction as a new learning experience (e.g., Bouton, 1993).

At least four associative phenomena have been cited to support the new learning account of extinction. First, a long delay between extinction treatment and testing has been found to provoke a *spontaneous recovery* of the extinguished conditioned response (CR) (e.g., Brooks & Bouton,

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1993; Pavlov, 1927; Robbins, 1990). Second, postextinction presentations of the US often induce a recovery of the extinguished CR, a phenomenon referred to as *reinstatement* (e.g., Bouton, 1984; Bouton & Bolles, 1979b; Rescorla & Heth, 1975). Third, an extinguished cue can be retrained more quickly than a novel cue–that is, *rapid reacquisition* (e.g., Napier, Macrae, & Kehoe, 1992; Pavlov, 1927; Ricker & Bouton, 1996; but see Denniston & Miller, 2003). Fourth, a recovery of the extinguished CR occurs when testing take place outside the extinction context, a phenomenon referred to as *renewal* (e.g., Bouton & Bolles, 1979a; Bouton & King, 1983; Bouton & Ricker, 1994). Taken together, these empirical results strongly suggest that little or no erasure occurs during extinction; rather, new learning about a second relationship between the CS and the US is established, as Pavlov (1927) initially proposed.

The present series of experiments examines the renewal effect. Renewal is commonly characterized as the recovery from extinction of a CR when testing occurs in a context different from that in which extinction took place. There are three types of renewal, which differ on the basis of the context in which acquisition, extinction, and testing take place. ABA renewal is the recovery of an extinguished CR when subjects are tested in the acquisition context after extinction treatment in a different context (e.g.. Bouton & King, 1983). ABC renewal is the recovery of an extinguished CR when acquisition, extinction, and testing all take place in different contexts (e.g., Bouton & Bolles, 1979a). AAC renewal is the recovery of an extinguished CR when acquisition and extinction occur in the same context but testing occurs in a different, neutral one (e.g., Bouton & Ricker, 1994). Most evidence suggests that ABA and ABC renewal are stronger than AAC renewal, which sometimes is not even observed (Crombag & Shaham, 2002; Cuevas, Rovee-Collier, & Learmonth, 2008; Nakajima, Tanaka, Urushihara, & Imada, 2000; Rescorla, 2008; Tamai & Nakajima, 2000; Tamai, Nakajima, Kitaguchi, & Imada, 2001; Thomas, Larsen, & Ayres, 2003; Üngör & Lachnit, 2008; Yap & Richardson, 2007). But in our opinion, why AAC renewal is weaker than ABA and ABC renewal has not yet been adequately explained.

The specific intent of the present experiments was to evaluate the role of context associations in the different strengths of ABC and AAC renewal. Our hypotheses were driven by predictions of the extended comparator hypothesis (Denniston, Savastano, & Miller, 2001) and its mathematical implementation (SOCR; Stout & Miller, 2007). Although the comparator theory does not provide a full account of renewal effects, it should be noted that it does provides a post hoc account of why AAC renewal results in less recovery of the extinguished CR than does ABC renewal. In this framework, AAC renewal is weaker than ABC renewal because of the association between the target CS and the acquisition context (Context A), which is stronger in the AAC condition as a result of the CS extinction trials in Context A (this assumes that the Context A–US associations are held equal in the two conditions by equating exposure to Context A during the extinction phase). The CS–Context A association (together with the Context A–US association) indirectly activates a representation of the US that is compared with the directly activated US representation, thereby producing a greater decrease in behavioral control by the CS at test, which is manifest as deeper extinction. In ABC renewal, the CS–Context A association is weaker because the extinction phase takes place in a context (B) that is different from the one in which the US occurred during acquisition (i.e., extinguishing the CS in Context B decreases not only the CS–US association, but also, potentially, the CS–Context A association). This weaker CS–Context A association is less effective in downmodulating the direct representation of the US, which, in turn, produces a less pronounced decrease in behavioral control. Consequently, this model predicts that treatments that undermine the Context A–US (e.g., posttraining context exposure) or the CS–Context A (e.g., overshadowing by a nontarget stimulus) associations should reduce the difference between AAC and ABC renewal, and they should do so by making the AAC renewal stronger.

To test these predictions, we assessed the role of the CS–Context A and Context A–US associations in extinction in three lick suppression experiments with rats. In Experiment 1, we sought to replicate prior results suggesting that extinction in the acquisition context produces a deeper extinction effect than when extinction takes place in a neutral context (i.e., AAC vs. ABC renewal, respectively). This difference has been previously reported, but not within the present task. In Experiment 2, we assessed the role of the Context A–US association through postextinction exposure to the acquisition context (A). Although extinction of the acquisition context following CS extinction has been reported to enhance AAC renewal (Witnauer & Miller, 2009), no one has previously contrasted the effects of this manipulation on AAC renewal, relative to ABC renewal. Finally, in Experiment 3, we evaluated the role of the CS–Context A association in AAC and ABC renewal by presenting a neutral cue during extinction treatment to overshadow this association.

Experiment 1

To determine the contribution of the target CS–Context A association to extinction, Experiment 1 examined whether stronger extinction is observed when the CS-alone trials are conducted in the acquisition context (AAC) or in a context that is neutral with respect to the US (ABC). If the association between the target CS and the acquisition context contributes to extinction, less responding should be observed in the AAC condition than in the ABC condition. In addition, there was an A–C group to assess acquisition without extinction. See Table 1 for the design of Experiment 1.

Method

Subjects

The subjects were 18 male and 18 female, experimentally naive, Sprague-Dawley-descended rats obtained from our own breeding colony. Body weight ranges were 263–354 g for males and 195–250 g for females. The subjects were randomly assigned to one of three groups (*n*s = 12), counterbalanced within groups for sex. The animals were individually housed in standard hanging stainless steel wire-mesh cages in a vivarium maintained on a 16:8-hr light:dark cycle. Experimental manipulations occurred near the middle portion of the light phase. The animals received free access to Purina Lab Chow, whereas water availability was limited to 20 min per day, following a progressive deprivation schedule initiated 1 week prior to the start of the experiment. From the time of weaning until the start of the experiment, all the animals were handled for 30 s, three times per week.

Apparatus

Six identical copies of each of three different types of experimental chambers were used. Chamber V was a 27-cm-long box in a truncated-V shape (29.5-cm height, 21.5 cm wide at top, and 5.5 cm wide at bottom). The floor was comprised of two 27-cm-long, 2-cm-wide stainless steel plates, with a 1.5-cm gap between the two plates. A 0.9-mA, 0.5-s constant-current footshock, produced by a high voltage AC circuit in series with a 1.0-MΩ resistor, could be delivered through the metal walls and floor of the chamber. The ceiling was clear Plexiglas, the front and back walls were black Plexiglas, and the sidewalls were stainless steel. Each of six copies of Chamber V was housed in a separate sound- and light-attenuating environmental isolation chest. The chamber was illuminated by a 7-W (nominal at 120 VAC, but driven at 50 VAC) light bulb, which was mounted on the inside wall of the environmental enclosure, approximately 30 cm from the center of the experimental chamber. The light entered the chamber primarily by reflection from the ceiling of the environmental chest.

Table 1 Design summary of Experiment 1

Groups	Phase 1 Acquisition	Phase 2 Extinction	Test
AAC	$(6\ X+)_A\ /\ (-)_B$	$(16\ X-)_A\ /\ (-)_B$	$(X)_C$
ABC	$(6\ X+)_A\ /\ (-)_B$	$(16\ X-)_B\ /\ (-)_A$	$(X)_C$
A–C	$(6\ X+)_A\ /\ (-)_B$	$(-)_A\ /\ (-)_B$	$(X)_C$

CS X was a 15-s click train. “+” denotes reinforcement with a brief footshock. “−” denotes no reinforcement. A, B, and C are different contexts. Numbers preceding the letter X indicate total number of trials in that phase

Chamber R was rectangular, measuring 24.0 × 9.0 × 12.5 cm (l × w × h). The walls and ceiling of Chamber R were clear Plexiglas, and the floor was made up of stainless steel rods measuring 0.5 cm in diameter, spaced 1.3 cm apart (center to center). The rods were connected by NE-2 bulbs, which allowed for the delivery of a 0.9-mA, 0.5-s constant-current footshock. Each of six copies of Chamber R was housed in separate light- and sound-attenuating environmental isolation chambers. Each chamber was dimly illuminated by a 2-W (nominal at 120 VAC, but driven at 50 VAC) incandescent houselight mounted on an inside wall of the environmental chest located approximately 30 cm from the animal enclosure.

Chamber Modified-R was Chamber R again, but with four modifications: (1) There was a different instance of Chamber R; (2) there was a clear Plexiglas floor; (3) the house light was off; and (4) a daily drop of 98% methyl salicylate was placed onto a small block of wood located inside the isolation chest.

All the chambers (V, R, and Modified-R) could be equipped with a water-filled lick tube that extended 1 cm into a cylindrical niche, which was 4.5 cm in diameter, left–right centered, with its bottom 1.75 cm above the floor of the apparatus and 5.0 cm deep. There was a photobeam detector 1 cm in front of the lick tube that was broken whenever the subject licked the tube. Two 45-Ω speakers on the inside walls of each isolation chest could deliver a click train (6 Hz) and a complex tone (500 and 520 Hz) 6 dB above background. Ventilation fans in each enclosure provided a constant 76-dB background noise. All auditory cues were measured on the C-scale. The light intensities inside the two illuminated chambers were approximately equal, due to the difference in opaqueness of the walls of Chambers V and R.

The click train served as CS X and was 15 s in duration. The footshock served as the US. The physical identity of Contexts A and B was counterbalanced between Chambers R and V within groups. Context C was the Modified-R chamber for all the subjects.

Procedure

Acclimation On days 1 and 2, all the subjects were acclimated to drinking in their test context during a daily

60-min session. During the acclimation phase, subjects had free access to water-filled lick tubes. There were no presentations of the CS or US during this phase. At the end of acclimation, the water tubes were removed until reacclimation.

Phase 1 (acquisition) On day 3, all the subjects received 60-min conditioning training sessions in Context A and an equal amount of exposure to Context B without any presentation of nominal stimuli. Subjects received six presentations of CS X, with X coterminating with the 0.5-s US. The mean intertrial interval was 10 min. The reinforced trials were initiated 5, 21, 25, 35, 42, and 55 min into the session. The order of the sessions in Context A and exposure to Context B was counterbalanced within groups, and the time between sessions within a day was approximately 210 min.

Phase 2 (extinction) On days 4 and 5, subjects in the AAC group received one 30-min extinction session in Context A where they received eight daily presentations of CS X alone initiated 2, 6, 13, 14, 19, 21, 24, and 28 min into the 30-min session. Subjects in this group also received 30 min of exposure to Context B. This was done to equate Phase 2 exposure to Context B. Subjects in the ABC group received the same amount of extinction trials as the AAC group, but in Context B, and an equal amount of exposure to Context A. The A–C group received 30 min of exposure to Contexts A and B but no presentations of CS X. The order of the treatment trials and of the exposure to the other context was counterbalanced within groups, and the time between sessions within a day was approximately 120 min.

Reacclimation On days 6 and 7, all the subjects were reacclimated to their test contexts in daily 60-min sessions. Subjects had free access to the water-filled lick tubes, and no nominal stimuli were programmed to occur. The purpose of these sessions was to reestablish stable drinking behavior (which might have been differentially disrupted by the footshock US), thereby providing similar baseline behavior across the four groups upon which conditioned lick suppression could be assessed.

Testing On day 8, all the subjects were tested for conditioned lick suppression to CS X in Context C. Upon placement in the test chamber, time spent drinking by each subject was recorded. Immediately after completion of an initial five cumulative seconds of licking in the absence of any nominal stimulus, subjects were presented with CS X. Thus, all the subjects were drinking at the time of CS onset. Time to complete an additional five cumulative seconds of licking in the presence of CS X was recorded. The times recorded during the presentation of CS X were interpreted as reflecting subjects' expectancy of the US following onset of the CS. The test session was 16 min in duration, and a ceiling score of 15 min was imposed on the time to complete five cumulative seconds of drinking in the presence of CS X.

Data analysis

Following the convention of our laboratory, all the animals that took more than 60 s to complete their first five cumulative seconds of licking (i.e., prior to CS onset) during the test session were scheduled to be eliminated from the study, because such long latencies may be considered indicative of unusually great fear of the test context. In practice, no subjects met this elimination criterion in any of the experiments in this series.

For this and the following experiments, latencies to drink for five cumulative seconds before the onset of the CS (pre-CS) and after the onset of the CS were transformed to $\log_{10}$ to better approximate the normal distributions assumed by parametric statistical analyses. To maintain consistency across experiments in this series and to control for potential baseline differences, we used an analysis of covariance (ANCOVA), with log pre-CS as the covariate, to determine whether our manipulations would affect subjects' log latencies to drink in the presence of the CS. It should be noted that none of the results of this series of experiments was appreciably affected because of the use of ANCOVAs instead of analyses of variance (ANOVAs). The error term from the ANCOVA served as an estimate of within-group variance in planned comparisons. Effect size was estimated using Cohen's *f* (Myers & Wells, 2003). Alpha was set at .05.

Results and discussion

The results of Experiment 1 are illustrated in Fig. 1. As can be observed, when CS X-alone trials (i.e., extinction trials) were conducted in a context that was neutral with respect to the US (ABC group), subjects suppressed more than when extinction took place in the same context as acquisition (AAC group). In other words, Experiment 1 showed that renewal of the extinguished CR in the ABC group was stronger than that in the AAC group. The following statistical analysis supported these conclusions.

Prior to testing, 1 subject in the ABC condition was found to be ill, so its data were excluded from all analyses. A one-way ANOVA on the log pre-CS scores from the test session was conducted to determine whether there were any between-group differences in fear to the test contexts prior to the onset of the test stimulus. This analysis showed no effect of group in baseline drinking, $p = .66$. The ANCOVA conducted on the log CS scores, with the log pre-CS scores as a covariate, showed an effect of group, $F(2, 31) = 16.16$,

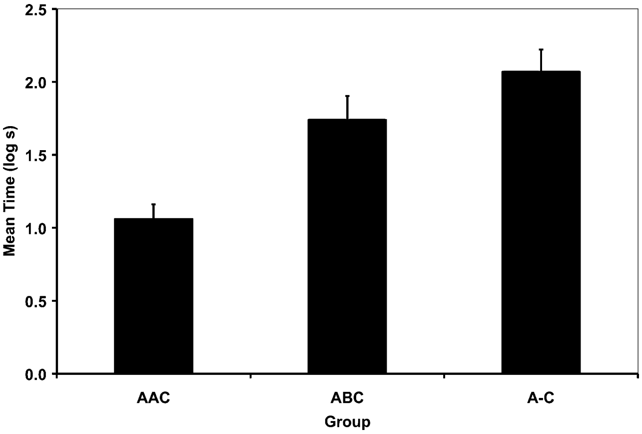

Fig. 1 Mean log time to complete five cumulative seconds of licking in the presence of target CS (X) in Context C. See Table 1 for treatments. Brackets represent standard errors of the means. Higher scores indicate more conditioned suppression

MSE = 0.21, Cohen's *f* = .93, indicating that there were differences in suppression between the different conditions. Planned comparisons were conducted to identify the sources of this effect. The difference between Groups AAC and A–C proved significant, *F*(1, 31) = 31.15, indicating that extinction in the acquisition context was effective in decreasing the CR despite any AAC renewal that might has occurred in Group AAC. We also examined the difference between Groups ABC and A–C and found a marginally significant difference, *F*(1, 31) = 3.18, *p* = .08, suggesting that any renewal was incomplete. More important, the difference between Groups AAC and ABC proved significant, *F*(1, 31) = 13.82, suggesting that renewal was stronger when extinction took place in a neutral context than when it took place in the context of acquisition. Clearly, less postextinction responding was observed when extinction took place in the training context (AAC) than when extinction took place in a neutral context (ABC). In other words, ABC renewal was found to be stronger than AAC renewal, as has been reported previously in other preparations (e.g., Nakajima et al., 2000).

Experiment 2

To further evaluate the role of context associations in AAC and ABC renewal effects, Experiment 2 assessed the role of the Context A–US association in extinction and renewal by examining the effects of postextinction exposure to Context A on reduced responding to an extinguished CS. When testing occurs outside of Context A, a strong CS–Context A association should be necessary to activate the representation of Context A and, consequently, the Context A–US association. If the Context A–US association is important to reduced responding to an extinguished CS, postextinction exposure to Context A should enhance responding to the extinguished CS in the AAC condition more than in the ABC condition. This follows because the CS–Context A association is stronger in the AAC condition than in the ABC condition, thereby making the AAC subjects more sensitive to changes in the Context A–US association. See Table 2 for the design of Experiment 2.

Method

Subjects and apparatus

Subjects were 24 male and 24 female, experimentally naive, Sprague-Dawley-descended rats obtained from our own breeding colony. Body weight ranges were 296–363 g for males and 201–256 g for females. Subjects were randomly assigned to one of four groups (*n*s = 12), counterbalanced within groups for sex. The maintenance and housing of subjects, as well as the apparatus and stimuli used, were the same as in Experiment 1.

Procedure

Acclimation and phase 1 (acquisition) On days 1 and 2, all the subjects received a daily 60-min acclimation session in the test context, as in Experiment 1. On day 3, all the subjects received 60-min conditioning training sessions in

Table 2 Design summary of Experiment 2

Groups	Phase 1 Acquisition	Phase 2 Extinction	Phase 3 Context Extinction	Test
AAC-8	$(6\ X+)_A$ / $(-)_B$	$(16\ X-)_A$ / $(-)_B$	$(8\ \text{min})_A$	$(X)_C$
AAC-480	$(6\ X+)_A$ / $(-)_B$	$(16\ X-)_A$ / $(-)_B$	$(480\ \text{min})_A$	$(X)_C$
ABC-8	$(6\ X+)_A$ / $(-)_B$	$(16\ X-)_B$ / $(-)_A$	$(8\ \text{min})_A$	$(X)_C$
ABC-480	$(6\ X+)_A$ / $(-)_B$	$(16\ X-)_B$ / $(-)_A$	$(480\ \text{min})_A$	$(X)_C$

CS X was a 15-s click train. "+" denotes reinforcement with a brief footshock. "−" denotes no reinforcement. A, B, and C are different contexts. Numbers preceding the letter X indicate total number of trials in that phase. Numbers in Phase 3 indicate total exposure time in Context A during this phase

Context A and an equal amount of exposure to Context B, as in Experiment 1.

Phase 2 (extinction) On days 4 and 5, subjects in Condition AAC received extinction training in Context A and exposure to Context B, exactly as Group AAC in Experiment 1 did. Subjects in Condition ABC received extinction training in Context B and exposure to Context A, exactly as Group ABC in Experiment 1 did.

Phase 3 (postextinction exposure of the acquisition context) On days 6–9, subjects in the 480 condition received one daily 120-min extinction session in Context A. Subjects in the 8 condition were placed in Context A for only 2 min daily.

Reacclimation and testing On days 10 and 11, all the subjects were reacclimated in Context C in daily 60-min sessions, as in Experiment 1. On day 12, all the subjects were tested for conditioned lick suppression to CS X in Context C, following the same procedure as that used in Experiment 1.

Results and discussion

The results of Experiment 2 are illustrated in Fig. 2. As can be seen, postextinction exposure to the acquisition context enhanced responding to the extinguished CS in Group AAC, but not in Group ABC, as would be expected if an acquisition context–US association contributes to the loss of behavioral control (i.e., extinction). These conclusions are supported by the following statistical analysis.

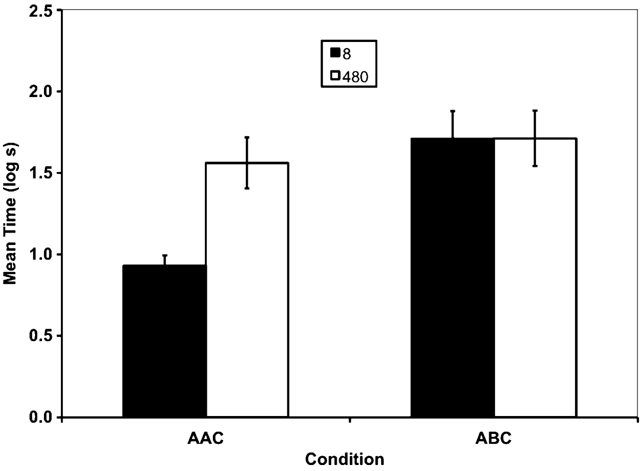

Fig. 2 Mean log time to complete five cumulative seconds of licking in the presence of target CS (X) in Context C for all groups. See Table 2 for treatments. Brackets represent standard errors of the means. Higher scores indicate more conditioned suppression

A two (context of extinction: A vs. B)×two (postextinction exposure of the acquisition context: 8 vs. 480) ANOVA conducted on log pre-CS scores of the test day showed differences between groups in fear of the context prior to the onset of the test stimulus. There was a main effect of context of extinction prior to test onset, *F*(1, 44) = 12.52, *MSE* = 0.03, mean latencies to complete five cumulative seconds of drinking were 0.86 log s for Group AAC-8, 0.89 log s for Group AAC-480, 1.03 log s for Group ABC-8, and 1.05 log s for Group ABC-480. To compensate for these baseline differences, the log CS scores were analyzed using an ANCOVA, with the log pre-CS measure as a covariate. There was a main effect of the amount of postextinction exposure to Context A, *F*(1, 43) = 4.46, *MSE* = 0.23, Cohen's *f* = .27, and an interaction between the context of extinction and the amount of postextinction exposure to Context A, *F*(1, 43) = 4.89, Cohen's *f* = .29. The main effect of context of extinction was only marginally significant, *F*(1, 43) = 3.12, *p* = .084. Planned comparisons were conducted to identify the sources of these differences. The difference between Groups AAC-8 and AAC-480 proved significant, *F*(1, 43) = 9.33, which indicates that AAC renewal increased when the acquisition context was extinguished. The comparison between Groups ABC-8 and ABC-480 showed no significant difference, *p* = .95, meaning that the renewed association in the ABC condition was not appreciably affected by postextinction exposure to the acquisition context. Finally, a difference was found between Groups AAC-8 and ABC-8, *F*(1, 43) = 7.66, replicating the results of Experiment 1, in which greater ABC renewal than AAC renewal was evidenced when no appreciable postextinction exposure to the acquisition context took place. In summary, postextinction exposure to the acquisition context enhanced responding to the extinguished CS in the AAC, but not the ABC, design.

Experiment 3

To further evaluate the role of contextual associations in the different magnitudes of AAC and ABC renewal, Experiment 3 examined the contribution of the CS–Context A association by using a neutral stimulus during extinction treatment to overshadow this association. If extinction is stronger when CS-alone trials are administered in the acquisition context (AAC) than in a neutral context (ABC), because CS-alone presentations strengthen the association between the target CS (X) and the acquisition context, overshadowing of this CS–Context A association by another stimulus (Y) should decrease the extinction effect more in the AAC condition than in the ABC condition. See Table 3 for the design of Experiment 3.

Table 3 Design summary of Experiment 3

Groups	Phase 1 Acquisition	Phase 2 Extinction	Test
AAC X-	$(6\ X+)_A$ / $(-)_B$	$(16\ X-)_A$ / $(-)_B$	$(X)_C$
AAC XY-	$(6\ X+)_A$ / $(-)_B$	$(16\ XY-)_A$ / $(-)_B$	$(X)_C$
ABC X-	$(6\ X+)_A$ / $(-)_B$	$(16\ X-)_B$ / $(-)_A$	$(X)_C$
ABC XY-	$(6\ X+)_A$ / $(-)_B$	$(16\ XY-)_B$ / $(-)_A$	$(X)_C$

CS X was a 15-s click train. CS Y was a 15-s tone. "+" denotes reinforcement with a brief footshock. "–" denotes no reinforcement. A, B, and C are different contexts. Numbers preceding the letter X indicate total number of trials in that phase.

Method

Subjects and apparatus

Subjects were 24 male and 24 female, experimentally naive, Sprague-Dawley-descended rats obtained from our own breeding colony. Body weight ranges were 225–285 g for males and 167–203 g for females. Subjects were randomly assigned to one of four groups (*n*s = 12), counter-balanced within groups for sex. Maintenance and housing of subjects, as well as the apparatus and stimuli used, were the same as in Experiment 1 and Experiment 2. The only exception was the use of a second CS (Y) that consisted of a complex, 15-s tone (500 and 520 Hz; 6 dB above background).

Procedure

Acclimation and phase 1 (acquisition) On days 1 and 2, all the subjects received a daily 60-min acclimation session in the test context, as in Experiment 1 and Experiment 2. On day 3, all the subjects received 60-min conditioning training sessions in Context A and an equal amount of exposure to Context B, as in Experiment 1 and Experiment 2.

Phase 2 (extinction) On days 4 and 5, subjects in Groups AAC X− and ABC X− received extinction training and context exposure, like Groups AAC and ABC in Experiment 1, respectively. Subjects in Group AAC XY− received the same treatment as those in Group AAC X−, but during the extinction sessions, they experienced presentations of X in compound with another stimulus, Y. Subjects in Group ABC XY− received the same treatment as those in Group ABC X−, but in the extinction sessions, they experienced presentations of X in compound with Stimulus Y. As in the previous experiments, the order of extinction sessions and exposure to the nonextinction context was counterbalanced within groups, and the time between sessions within a day was approximately 120 min.

Reacclimation and testing On days 6 and 7, all the subjects were reacclimated to Context C in daily 60-min sessions, as in the prior experiments. On day 8, all the subjects were tested for conditioned lick suppression to X in Context C, following the same procedure as that used in Experiment 1 and Experiment 2.

Results and discussion

The results of Experiment 3 are illustrated in Fig. 3. As can be seen, extinction trials in the presence of another stimulus enhanced responding to the extinguished CS in the AAC condition, but not in the ABC condition. This would be expected if the CS–acquisition context association were important for extinction and the inclusion of the novel stimulus overshadowed X's association with Context A during Phase 2. These results are supported by the following statistical analysis.

A two (context of extinction: A vs. B)×two (extinction cues: X vs. XY) ANOVA conducted on the log pre-CS scores of the testing day showed no main effect or interaction in this baseline measure, all *p*s > .73. An ANCOVA conducted on the log CS data, with log pre-CS as covariate, detected a main effect of extinction cues (X vs. XY), $F(1, 43) = 29.51$, $MSE = 0.10$, Cohen's $f = .77$, a main effect of extinction contexts, $F(1, 43) = 7.68$, Cohen's $f = .37$, and an interaction between the context of extinction and the cues used in extinction, $F(1, 43) = 10.43$, Cohen's $f = .44$. Planned comparisons were conducted to identify the sources of these differences. Groups AAC X− and AAC XY− were found to differ in suppression, $F(1, 43) = 37.45$, indicating that the extinguished fear response was more thoroughly

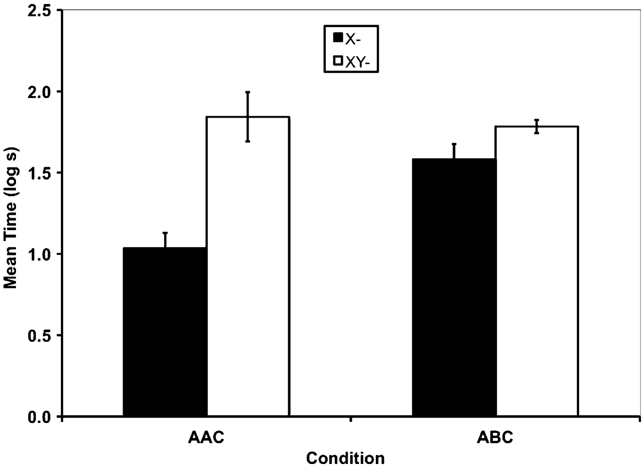

Fig. 3 Mean log time to complete five cumulative seconds of licking in the presence of target CS (X) in Context C for all groups. See Table 3 for treatments. Brackets represent standard errors of the means. Higher scores indicate more conditioned suppression

renewed in the AAC condition when extinction occurred in the presence of a neutral cue, as opposed to when extinction occurred elementally. A comparison of the groups in the ABC condition failed to detect a significant difference, $p = .13$. This suggests that the renewed response in the ABC groups was not appreciably affected by the presence of a neutral stimulus during extinction. Finally, a difference was found between Groups AAC X− and ABC X−, $F(1, 43) = 18.01$, thereby replicating the results of Experiment 1 and Experiment 2. In summary, extinction of the target CS in the presence of a neutral cue reduced the difference between AAC and ABC renewal by making extinction in Context A less effective in the AAC condition (see Experiment 1), thereby resulting in an extinction effect more susceptible to renewal.

It should be noted that the effect of Y's reducing extinction effectiveness could have alternative explanations to the proposed overshadowing of the CS–Context A association. However, such interpretations (e.g., generalization decrement, protection from extinction, cue competition) could not explain why the inclusion of Y affected extinction in the acquisition context (i.e., the AAC condition), but not in a neutral but familiar context (i.e., the ABC condition).

General discussion

In three lick suppression experiments, we evaluated the role of context associations in renewal following extinction. In Experiment 1 and in control groups in Experiment 2 and Experiment 3, deeper extinction was evidenced when extinction took place in the acquisition context (the AAC condition) than when extinction took place in a novel context (the ABC condition). This deeper extinction was attenuated by postextinction exposure to the acquisition context (i.e., context extinction, Experiment 2) and by extinction of the target cue in the presence of a neutral stimulus (Experiment 3). Both of these manipulations decreased the effectiveness of the extinction treatment (i.e., increased conditioned suppression to the target CS at test) when extinction took place in the acquisition context (the AAC condition), but they had little effect when extinction occurred in a neutral context with respect to the US (the ABC condition).

These results are in general concordance with previous research on extinction. First, the difference found between AAC and ABC renewal in the present series of experiments is in agreement with previous evidence showing ABC renewal to be stronger than AAC renewal in other preparations (e.g., Rescorla, 2008; Thomas et al., 2003). Second, postextinction exposure to Context A (i.e., context extinction) was effective in decreasing extinction in Experiment 2, as was recently reported by Witnauer and Miller (2009; Experiment 2), but here we demonstrate this effect to be much larger for AAC renewal than for ABC renewal. And third, as was suggested by Rescorla (2003), extinction in the presence of a neutral cue provided protection from extinction of the target cue in Experiment 3. Importantly, this effect was more pronounced with an AAC procedure than with an ABC procedure.

At the theoretical level, Bouton's (1993) retrieval theory anticipates the basic renewal effect and also leads to the expectation that AAC renewal will be weaker than ABC renewal. The model predicts less recovery from extinction in the AAC renewal situation than in the ABC renewal situation because, in the AAC condition, the extinction context is delayed in becoming a negative occasion setter during extinction treatment. This occurs because the X–US training during acquisition in Context A is effectively a latent inhibition treatment for negative occasion setting (e.g., Oberling, Gunther, & Miller, 1999). Despite its success in anticipating some of the present data, Bouton's model erroneously predicts (1) no effect of postextinction exposure to the acquisition context (an effect demonstrated in Experiment 2) and (2) an equal increase in ABC and AAC renewal when extinction occurs in the presence of a neutral stimulus (seen to be unequal in Experiment 3). No effect of postextinction exposure to the acquisition context is predicted, because the model attributes no role to Context A in the renewal of extinguished CRs (i.e., Context A in the AAC condition can acquire only negative occasion-setting properties, which presumably are immune to extinction when the occasion setter is presented by itself). Finally, an increase in both types of renewal is predicted after extinction in the presence of a novel cue. For this model, compounding X with Y during extinction treatment should have enhanced the difference between the context of extinction and the context of testing because Y presumably would have become part of the context of extinction, but not that of testing. In other words, the effect of a change in context between extinction and testing should summate with the effect of removing the signal for extinction (the novel cue used during extinction trials) before test, thereby causing equal enhancements in renewal in the ABC and AAC conditions.

Another model that anticipates basic renewal is the replaced elements model of Wagner and colleagues (Brandon, Vogel, & Wagner, 2000; Vogel et al., 2007; Wagner, 2003). This is a hybrid model that can behave like an elemental (e.g., Rescorla & Wagner, 1972) or a configurational model (e.g., Pearce, 1994), depending on the value assigned to one parameter, r, which specifies the proportion of elements that are activated only during elemental presentation of a given stimulus (i.e., the proportion of elements from each stimulus that are replaced when the stimulus is compounded with another stimulus). This model readily predicts ABA renewal, using parameters that make the model work like the Rescorla–Wagner (1972) model (r = 0), Pearce's (1994) model (r = .5), and even an extreme configurational model (r = 1). The model is also able to predict the results of Experiment 1 (weak or nonexistent AAC renewal and strong ABC renewal), but only using parameters that make the model work like the Rescorla–Wagner model. However, the model fails to predict the differential effects of postextinction exposure to the acquisition context (Experiment 2).

SOCR (Stout & Miller, 2007) provides an account of the present experiments that is based on CS–Context A and Context A–US associations. First, SOCR anticipates deeper extinction in the AAC than in the ABC condition (Experiment 1, Experiment 2, and Experiment 3) because, during extinction in the training context (AAC condition), the excitatory association between the CS and Context A becomes stronger and, hence, better down-modulates the directly activated representation of the US evoked by the CS during testing. It should be noted that a weakened Context A–US association, due to exposure to this context during Phase 2, partially counters the effect of the strengthened CS–Context A association in the AAC condition. But this weakening of the Context A–US association occurs in the ABC condition as well, because these subjects were also exposed to Context A during Phase 2. In the ABC condition, strengthening of the CS–Context B association is irrelevant, because the US has never been presented in Context B. Alternatively stated, in the SOCR framework, AAC renewal is weaker than ABC renewal because, during the extinction trials in Context A, the CS becomes strongly associated with the acquisition context, producing an increase in the indirectly activated representation of the US. This inflated, indirectly activated representation of the US then down-modulates the directly activated representation of the US evoked by the CS at the time of testing. Finally, this greater extinction in the AAC condition presumably results in greater resistance to recovery of the extinguished CR in the AAC condition. Second, postextinction exposure to the acquisition context in the AAC group presumably attenuates the Context A–US association. This results in a decrease in the indirectly activated representation of the US, which, in turn, allows the behavioral expression of the directly activated representation of the US evoked by the CS during test. This account predicts less of an effect of postextinction exposure to the acquisition context in the ABC condition, because of the relatively weak association between the target CS and the acquisition context in this condition. (Note that there is a second interpretation of this result. It is possible that extinguishing the acquisition context debilitates also the CS–Context A association, rather than only the Context A–US association as SOCR suggests. However, such interpretation cannot explain why extinction of Context A affected only subjects in the AAC condition, and not those in the ABC condition.) Third, SOCR predicts that, during extinction in the presence of a neutral cue (Y) in Context A, the CS X–Context A association is partially overshadowed by the CS Y–Context A association. This is due to the CS X–Context A association being down-modulated by the product of the CS X–CS Y association and the CS Y–Context A association. Consequently, the product of the CS X–Context A and the Context A–US association is reduced, thereby resulting in a decrease in the indirectly activated US representation, which facilitates an increase in stimulus control by the target CS. This is not expected in the ABC condition because, although CS Y competes with CS X in forming a strong association to Context B, Context B was never paired with the US.

Consistent with our central notion that the associative status of the extinction context determines the strength of extinction, Van Hamme and Wasserman's (1994) modification of the Rescorla–Wagner (1972) model predicts the present results, because the context also plays an important role in extinction according to this approach. This modified version of the Rescorla–Wagner model accurately predicts (1) deeper extinction in the AAC than in the ABC condition (Experiment 1, Experiment 2, and Experiment 3); (2) a greater recovery of the extinguished CR as a result of postextinction exposure to the acquisition context in the AAC condition (Experiment 2), relative to the ABC condition, at least under certain conditions; and (3) a greater decrease in extinction when extinction treatment occurs in the presence of a neutral cue in the AAC condition, relative to extinction treatment in the presence of a neutral cue in the ABC condition (Experiment 3). Deeper extinction in the AAC than in the ABC condition is predicted because the training context, as well as the target CS, acquires an excitatory association with the US during acquisition. During the extinction trials, subjects in Group AAC have a greater expectation of the US than do the subjects in Group ABC. This greater expectancy should have supported deeper extinction when the US was not presented during the extinction trials. A greater increase in the renewal of the CR after postextinction exposure to the acquisition context is predicted in the AAC than in the ABC condition because this treatment causes subjects to retrospectively revalue the target stimulus, due to the conjoint absence of the expected CS and expected US, which strengthens the CS–US association. In Group ABC, postextinction exposure to the acquisition context should not have had a strong effect, because of the relatively weak association between the target CS and the acquisition context. Thus, the target CS should not have been strongly activated during exposure to Context A. Extinction in the presence of a neutral cue is predicted to decrease extinction in the AAC more than in the ABC condition because the neutral stimulus (Y) should become more inhibitory in the former than in the latter case, thereby providing more protection from extinction. This is to be expected, because the extinction trials took place in a more excitatory circumstance in the AAC groups (in which the context, and not only the target CS, predicts the US). The Rescorla–Wagner model shares with its modified version (Van Hamme & Wasserman, 1994) success in anticipating the results of Experiment 1, and Experiment 3. However, the original Rescorla–Wagner model does not predict the results of Experiment 2, because of its inability to explain retrospective reevaluation phenomena.

As was stated previously, Stout and Miller's (2007) SOCR model does not account for basic ABC renewal (i.e., ABC vs. ABB), because SOCR does not provide a rule for associative summation of the target cue with the test context. However there is no principled reason why such a summation should not occur, thereby providing a SOCR-based account of renewal similar to that of Rescorla and Wagner (1972). But our goal in this article was to explain why AAC renewal is ordinarily weaker than ABC renewal, using the precise model of Stout and Miller without any modification. SOCR, as stated in 2007, does achieve this despite its not accounting for the difference between ABC renewal and an ABB control group.

In summary, Bouton's (1993) retrieval theory and Wagner and colleagues' (e.g., Brandon et al., 2000) replaced elements model predict the basic renewal effect and some additional parts of the data presented here, but they do poorly anticipating the results of Experiment 2. The Rescorla and Wagner (1972) model predicts the basic renewal effect (but only by invoking an inhibitory process inconsistent with some existing data [e.g., Bouton & King, 1983]) and is able to account for the results of Experiment 1, and Experiment 3. Van Hamme and Wasserman's (1994) modified Rescorla–Wagner model emphasizes an inhibitory interaction between the extinction context and the target cue, which allows it to account for all of the present data and also to account for the failure of the extinction context to transfer inhibition to an independently trained CS (Bouton & King, 1983). Finally, SOCR (Stout & Miller, 2007) can account for all the data reported here and can also account for the failure of the extinction context to transfer inhibition to an independently trained CS, as Van Hamme and Wasserman do. Critically, SOCR also emphasizes an inhibitory interaction between the extinction context and the target cue (albeit through a mechanism different from that used by Van Hamme and Wasserman, 1994). Considering that both models that predict the present set of results (i.e., SOCR and the modified Rescorla–Wagner model) emphasize the role of context associations, it is likely that the associative status of the extinction context is an important determinant of extinction's effectiveness.

Because experimental extinction has been used as a model of exposure therapy (e.g., Bouton & Nelson, 1998), our findings can inform clinical practice. The present results suggest that exposure-based treatments should take place in a context as similar as possible to the acquisition context. If that is accomplished, the exposures will be more effective in decreasing the CRs, and the possibility of relapse (after the treatment context changes) will be diminished (for a discussion of this and other behavioral techniques to prevent recovery from extinction, see Laborda, McConnell, & Miller, in press). This conclusion is congruent with the view that exposure therapy is more effective when the treatment sessions are held in a location that closely approximates the one in which the original trauma took place (Massad & Hulsey, 2006).

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