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Occasional reinforced trials during extinction can slow the rate of rapid reacquisition[☆]

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Abstract

Two appetitive conditioning experiments with rats examined reacquisition after conditioned responding was eliminated by either extinction or by a partial reinforcement procedure in which reinforced trials were occasionally presented among many nonreinforced trials. In Experiment 1, reacquisition to a conditional stimulus (CS) that had been conditioned and extinguished was more rapid than acquisition in a group that had received no prior conditioning. However, the addition of occasional reinforced trials to extinction slowed this rapid reacquisition effect. Experiment 2 replicated the result and showed that a procedure in which the CS and the unconditional stimulus (US) were unpaired in extinction interfered even further with reacquisition. The results suggest that rapid reacquisition is ordinarily produced when reinforced trials provide a contextual cue that can renew responding by signaling other acquisition trials (Ricker & Bouton, 1996). The effects of partial reinforcement in extinction are surprising from several theoretical perspectives and have useful clinical implications.
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The present article is concerned with "reacquisition," the phenomenon in which conditioned responding returns following extinction when the conditional stimulus (CS) is paired with the unconditional stimulus (US) again. It is widely believed that reacquisition is more rapid than original conditioning, a possibility that is consistent with the idea that at least some of the original learning is "saved" following extinction (e.g., Bouton, 1993; Kehoe & Macrae, 1997; Pavlov, 1927; Rescorla, 2001). Bouton (1986) noted that rapid reacquisition in studies prior to 1986 could have been examples of spontaneous recovery (e.g., Pavlov, 1927) or reinstatement, in which presentation of the US on its own prior to testing can restore extinguished conditioned responding (e.g., Bouton, 1984; Bouton & King, 1983; Rescorla & Heth, 1975). More recent studies have provided good evidence that reacquisition can be truly rapid following extinction. Using appropriate controls, Napier, Macrae, and Kehoe (1992) separated rapid reacquisition in the rabbit nictitating membrane response (NMR) paradigm from simple spontaneous recovery or reinstatement effects.

What causes reacquisition to be rapid? One idea is that the savings of some part of the original (hypothetical) association between the CS and US simply gives the extinguished CS a head start when it is paired with the US again (e.g., Kehoe, 1988). One problem for this sort of view is that it does not explain why reacquisition can be slow, rather than fast, in conditioned suppression (e.g., Bouton, 1986; Bouton & Swartzentruber, 1989) and in taste aversion learning (Calton, Mitchell, & Schachtman, 1996; Hart, Bourne, & Schachtman, 1995), even in the presence of evidence that the original learning has been saved (e.g., Bouton & Swartzentruber, 1989). The slow reacquisition phenomenon is known to depend on extensive extinction training (Bouton, 1986) and on the subject being in the context of extinction (Bouton & Swartzentruber, 1989). The extinction context might allow continued retrieval of extinction (e.g., a CS–no US association) during the reacquisition phase (Bouton, 1993). By implication, one potential cause of rapid reacquisition may be the retrieval of conditioning rather than extinction.

Ricker and Bouton (1996) demonstrated that reacquisition can be either rapid or slow in an appetitive conditioning preparation. Their results suggested a mechanism that Ricker and Bouton (1996) called "trial signaling." During conditioning, animals might learn not only that the CS predicts the US, but that reinforced trials follow other reinforced trials. In contrast, during extinction, animals might analogously learn not only that the CS no longer predicts the US, but that nonreinforced trials follow other nonreinforced trials. In effect, reinforced trials are part of the context of conditioning, and their reintroduction after extinction may cause a "renewal" (e.g., Bouton & King, 1983) of conditioned responding. The possibility that previous reinforced (R) and nonreinforced (N) trials can control responding on subsequent trials has been emphasized by E.J. Capaldi's sequential theory (e.g., Capaldi, 1967, 1994). Ricker and Bouton (1996) noted that one reason that reacquisition may be especially fast in the NMR preparation (Napier et al., 1992), as opposed to conditioned suppression or taste aversion, is that the method usually involves a much larger number of conditioning trials, and may therefore provide more opportunity to learn trial signaling. Consistent with this possibility, Ricker and Bouton (1996) found rapid

reacquisition in appetitive conditioning when it involved many conditioning trials, but slow reacquisition when it involved only a few.

One implication of this analysis is that, even after many acquisition trials, an extinction procedure that somehow weakens the link between reinforced trials and other reinforced trials should slow down rapid reacquisition. Bouton (2000) suggested that an extinction procedure that introduces occasional reinforced trials among many nonreinforced trials might effectively work this way. The idea is that introducing reinforced trials during extinction would allow them to be associated with extinction as well as conditioning, and thus render them less able to cause renewal when they are also present during reacquisition. Although a lean partial reinforcement (PRF) procedure might not eliminate conditioned responding as completely as extinction (e.g., Gibbs, Latham, & Gormezano, 1978), it would be expected, somewhat paradoxically, to yield slower reacquisition when CS–US pairings are fully restored in reacquisition.

An entirely different outcome is also possible. Robbins (1990) has emphasized the possibility that animals might pay less attention to the CS after extinction. Loss of attention in extinction is consistent with the attention rule of the Pearce–Hall model (Pearce & Hall, 1980), because once the CS is a reliable predictor of no US at the end of extinction, there is less of the surprise that is otherwise necessary to support attention to the CS. A partial reinforcement procedure that unpredictably intermixes reinforced and nonreinforced trials would be expected to maintain attention to the CS, because it maintains surprise (e.g., Kaye & Pearce, 1984). This perspective suggests that partial reinforcement might allow even faster reacquisition than extinction—a prediction opposite to that suggested by the trial-signaling view.

The present experiments were therefore designed to test the effects of introducing occasional reinforced trials during extinction on the rate of reacquisition. They used the conditioning method previously used by Ricker and Bouton (1996), in which the CS's association with a food pellet US was measured by the extent to which it elicited entries into the food cup where the US was delivered. Although food-cup entry is often characterized as a Pavlovian conditioned response, it is also partly operant; when it has been put on an omission schedule, both operant and Pavlovian components have been identified (Holland, 1979). Nonetheless, the results reported here were consistent with the trial-signaling view: Using a partial reinforcement procedure instead of extinction can indeed slow rapid reacquisition.

Experiment 1

Experiment 1 was designed to compare reacquisition following extinction with that following two schedules of partial reinforcement. After conditioning with a procedure in which every CS presentation was paired with the US, Group EXT received simple extinction, whereas two partial reinforcement groups (Groups PRF 1:8 and PRF 2:8) received the same number of CS exposures, but one or two out of every eight trials was reinforced. As explained above, the trial-signaling view predicts slower reacquisition in the PRF groups when the CS is ultimately reinforced again

during reacquisition. We explored two different PRF procedures because the 2:8 procedure could be seen as providing more R "extinction" trials, but on average the 1:8 procedure followed each R trial with more N trials.

A fourth group was a control group in which "reacquisition" constituted the first occasion on which the CS was paired with a US. Such a control was necessary to assess the rapidity of reacquisition in Group EXT, and more importantly, to know how effective or complete the partial reinforcement treatment was in slowing it down. The selection of a control treatment is not obvious, however. A "Rest" control in which the animal merely sits in the apparatus does not provide equivalent exposure to the US, which is desirable given the possibility that food pellets initially received by the experimental groups might either interfere with or facilitate conditioning of the goal-tracking response (e.g., see Timberlake, 1986). A treatment involving equivalent conditioning and extinction of a different CS has been used in conditioned suppression experiments (e.g., Bouton, 1986; Bouton & Swartzentruber, 1989), but is not neutral in the present preparation because conditioning with one CS transfers positively to conditioning with a second CS (i.e., creates a "learning to learn" effect, Ricker & Bouton, 1996). We therefore chose a control condition that received equal, but unsignaled, exposure to the US. Because unsignaled USs could cause more contextual conditioning than signaled USs and might therefore influence final conditioning more (e.g., Randich & Ross, 1985; see also Baker, Mercier, Gabel, & Baker, 1981), the control group in Experiment 1 received the USs in a different context (see also Ricker & Bouton, 1996). This might be considered unconventional; a similar control in Experiment 2 therefore received its unsignaled USs in the same context. The choice of context did not matter (see also Ricker & Bouton, 1996). Reacquisition was rapid after simple extinction, and the partial reinforcement treatment caused reacquisition that was slower than after extinction but not as slow as first conditioning.

Method

Subjects

The subjects were 32 female Wistar rats obtained from Charles River, in St. Constance, Quebec. They were approximately 100 days old at the start of the experiment and were individually housed in suspended stainless steel cages in a room maintained on a 12:12-h light:dark cycle. The experiment was conducted on consecutive days during the light portion of the cycle. The rats were food deprived to 80% of their free-feeding weights and maintained at that level throughout the experiment.

Apparatus

Two sets of four Skinner boxes, housed in sound attenuation chambers and located in two separate rooms, were used. These two sets of boxes have provided different contexts in other studies, but were not used for this purpose in the present experiment (with the only exception of Group Control). Each box in one set measured $26 \times 25 \times 19$ cm ($l \times w \times h$). The front, back, and one side wall were made of aluminum; the ceiling and other side wall were made of clear plastic. The floor consisted of tubular steel bars 16 mm in diameter, spaced 3.2 cm center to center, and

mounted perpendicular to the front wall. On the front wall of each box, 1 cm above the floor, was a recessed 4×4 cm food cup. A 2.5×2.5 cm lever protruded from the front wall, 5 cm above the floor and 1 cm to the right of the food cup. To provide a distinctive scent cue, a dish containing 10 ml of distilled white vinegar (H.J. Heinz, Pittsburgh, PA) was placed in the sound-attenuation chamber in which each box was housed. The subjects were placed in the boxes through a door in the right wall.

Each box in the second set measured $24 \times 22 \times 18$ cm ($l \times w \times h$). The front and black walls were aluminum, while the ceiling and side walls were clear plastic with vertical black stripes 2 cm wide and 2.5 cm apart. The floor consisted of stainless steel bars, 3 mm in diameter, spaced 1.5 cm from center to center and mounted parallel to the front wall. On the front wall of each box, 1 cm above the floor and centered 3.5 cm from the right wall, was a recessed 4×4 cm food cup. A 4×1 cm lever protruded from the front wall 5 cm above the floor and 6 cm to the left of the food cup. A dish containing approximately 1 g of Vicks Vaporub (Richardson-Vicks, Shelton, CT) was placed in each sound-attenuation chamber to provide a distinctive scent cue. The subjects were placed in the boxes through the ceiling.

In both sets of boxes, illumination was provided by two 7.5-W white incandescent bulbs mounted on the ceilings of the sound-attenuation chambers, 25 cm above the floor. The CS was a 30-s presentation of a 3000-Hz tone (80 dB re 20 μN/M^2 [A]) provided by a generator wired to identical speakers mounted in each chamber 25 cm above the floor. Background noise was 65 dB. The US consisted of two 45-mg food pellets (Traditional formula, P.J. Noyes, Lancaster, NH) delivered 0.2 s apart. Magazine entries were detected by photocells mounted within the magazines, just behind the plane of the wall of the Skinner boxes. The apparatus was controlled by computer equipment located in a nearby room.

Procedure

Magazine training. Half of the animals in each group were assigned to one set of boxes. On the day before the start of conditioning, each rat received one 30-min session of magazine training in which it was trained to approach and eat from the food cup upon activation of the feeder mechanism. Approximately 25 pellets were delivered during the session.

Conditioning. All subsequent sessions were 90 min in duration. After magazine training, the rats received eight daily sessions of conditioning. For 24 subjects, each session contained 24 pairings of the 30-s tone with the food US, with a mean ITI of 3.16 min (shortest ITI = 2 min). Throughout, the offset of the CS coincided with the onset of the US. These rats were eventually assigned to groups matched on their responding during the final block of 4 trials (Groups EXT, PRF 1:8, and PRF 2:8, ns = 8). Group Control ($n = 8$) received the same 24 US presentations during each session, but no CS. As explained above, this treatment was conducted in the context alternate to the one that would be used for reacquisition (Ricker & Bouton, 1996).

Extinction. Following conditioning, rats received 12 daily 90-min extinction sessions. For Groups EXT, PRF 1:8, and PRF 2:8, these sessions continued to contain 24 presentations of the tone, with a mean ITI of 3.16 min. For Group EXT, the tone

was always presented without the US. On the first eight sessions, Group PRF 1:8 received one out of every eight trials reinforced and Group PRF 2:8 received two out of every eight trials reinforced. To distribute the reinforced tones throughout the session, the session was divided into three blocks of 8 trials, each of which contained either one or two reinforced trials, respectively. To allow a hypothetical forward association between the R and N trials, for Group PRF 1:8 each R trial took place pseudorandomly in either the 2nd, 3rd, or 4th position of each 8-trial block (consistent in a given session). For Group PRF 2:8, the first R position within each block was the same as the R position in Group PRF 1:8, and the second R took place in the same relative position in the second half of each 8-trial block (i.e., Trials 2 and 6, 3 and 7, or 4 and 8). On Days 9–12, both PRF groups received only one R trial in the fourth position of each 8-trial block to further weaken responding. Throughout the extinction phase, Group Control was placed in the apparatus for each 90-min session, but no stimuli were presented. This group received two tone-alone presentations at the end of the final extinction session to reduce the influence of any unconditioned responding or orienting to the tone prior to the subsequent reacquisition session (a method used by Bouton, 1986; Bouton & Swartzentruber, 1989; and Ricker & Bouton, 1996).

Reacquisition. Following extinction, the rats received a single 90-min session of conditioning. All four groups received a treatment in which the 30-s tone was initially presented alone 4 times, and then paired with food 20 times, with a mean ITI of 3.16 min. The initial 4 tone-alone presentations were designed to eliminate any spontaneous recovery of responding that might be present at the beginning of reacquisition and could potentially influence responding during reacquisition.

Data analysis. Conditioned responding was measured by means of an elevation score of the form $e = c - p$, where c represents the number of magazine entries during the 30-sec CS and p represents the number of magazine entries made during the 30 sec immediately preceding the CS. These scores were then analyzed with a mixed design analysis of variance (ANOVA), with group as a between subjects factor and block as a repeated measure. An identical ANOVA was used to analyze responding during the pre-CS period (pre-CS scores). A rejection criterion of $p < .05$ was used throughout.

Results

Conditioning and extinction

Fig. 1 presents the data from conditioning and extinction. Conditioning proceeded uneventfully; the groups that received CS–US pairings acquired responding, whereas the control group did not (during dummy trials when the CS would otherwise have been presented). During the last session of conditioning, responding to the tone was roughly equivalent in Groups EXT, PRF 1:8, and PRF 2:8, which each differed from Group Control. A one-way ANOVA on these data confirmed an overall group effect, $F(3, 28) = 4.02$; pairwise comparisons indicated that Groups EXT, PRF 1:8 and PRF 2:8 did not differ from one another, $Fs(1, 28) \leqslant 1.57$, but all differed from Group Control, $Fs(1, 28) \geqslant 4.02$.
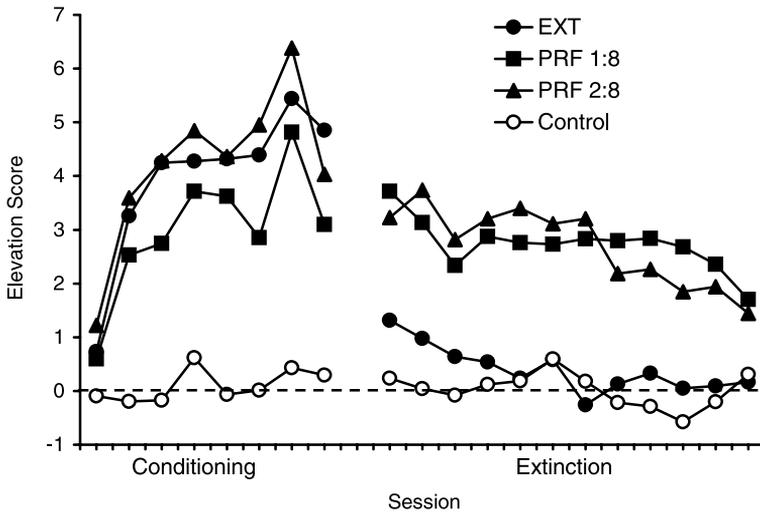
Fig. 1. Mean elevation scores during conditioning and extinction in Experiment 1.

Extinction then proceeded rapidly for Group EXT (the data during Session 2 were lost due to a computer failure and thus the mean of sessions 1 and 3 is shown). Response elimination in Groups PRF 1:8 and PRF 2:8 proceeded more slowly, and responding was not lost completely in either group at the end of the phase. These impressions were confirmed by a 4 (Group) × 11 (Session) ANOVA on the mean elevation scores from extinction (data from Session 2 of extinction were eliminated from the analysis due to the lack of data from group EXT). The ANOVA revealed main effects of Group, $F(3, 28) = 39.77$, and Session, $F(10, 280) = 3.89$. The Group × Session interaction was not significant, $F(30, 280) = 1.04$. Comparisons analyzing the Group effect revealed that the PRF groups both responded more than Groups EXT and Control, $Fs(1, 28) \geqslant 49.39$. Neither the PRF groups nor the EXT and Control groups differed, $Fs(1, 28) < 1.06$. The same pattern was evident when the last extinction session was isolated and analyzed: The overall difference among the groups was still reliable, $F(3, 28) = 4.23$, and the two PRF groups each still differed from Groups EXT and Control, $Fs(1, 28) \geqslant 4.47$ (all other $Fs < 1$). The results thus indicate that CS–US pairings during the extinction phase substantially slowed the loss of responding. However, an ANOVA comparing the PRF groups' performance on the last conditioning and the last extinction session revealed that responding had declined significantly by the end of the extinction phase, $F(1, 14) = 7.00$. (The Group and Group × Session effects had $Fs < 1$.)

An analogous ANOVA on the pre-CS scores during extinction revealed a main effect of Session, $F(10, 280) = 2.10$, with the pre-CS rates declining over sessions. There was no Group effect or Group × Session interaction, $Fs < 1$. The mean pre-CS scores during the last extinction session were 1.59, 1.11, 1.13, and 1.33, for Groups EXT, PRF 1:8, PRF 2:8, and Control, respectively.

Reacquisition

Responding during the last 8-trial block of extinction and during the three 8-trial blocks of the reacquisition session is shown in Fig. 2. The figure suggests that reacquisition occurred especially rapidly in the group that had received simple extinction (Group EXT) and in Group PRF 1:8, whereas Group PRF 2:8 reacquired responding more slowly. These impressions were confirmed by statistical analysis. We performed a 4 (Group) × 4 (Block) ANOVA on the elevation scores, which revealed significant effects of Group, $F(3, 28) = 9.84$, Block, $F(3, 84) = 18.09$, and a Group × Block interaction, $F(9, 84) = 3.15$. Planned comparisons on the data from the reacquisition session (using the error term from that session) confirmed that Group EXT showed higher responding than Group Control, $F(1, 28) = 26.75$, indicating that rapid reacquisition did occur. On the other hand, although Group PRF 2:8 also responded more than Group Control, $F(1, 28) = 9.17$, responding in this group was significantly lower than that in Group EXT, $F(1, 28) = 4.61$. Thus, a partial reinforcement schedule in which 2 of 8 trials were reinforced slowed the rapid reacquisition evident in Group EXT. Responding in Group PRF 1:8 was higher than Group Control, $F(1, 28) = 22.71$, but did not differ from Group EXT, $F < 1$. Thus, the slower reacquisition effect was specific to the 2:8 partial reinforcement procedure. It is worth noting that Group Control's performance during the reacquisition session was no different than the pooled performance of the conditioned groups on their analogous first conditioning trials, $F(1, 30) < 1$.
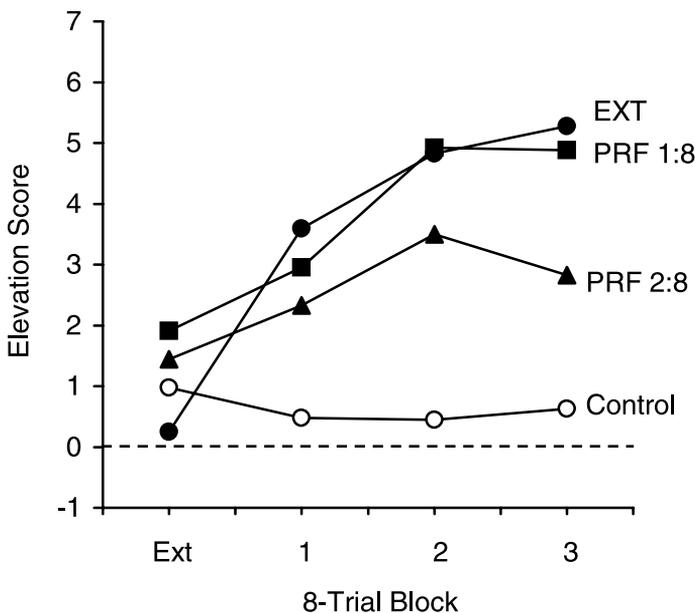

Fig. 2. Mean elevation scores during the last 8-trial block of the final extinction session and during 8-trial blocks of the reacquisition session in Experiment 1.

The mean pre-CS scores during the reacquisition session were 3.38, 2.36, 1.92, and 3.99, for Groups EXT, PRF 1:8, PRF 2:8, and Control, respectively. A parallel Group × Block ANOVA on the pre-CS scores revealed effects of Group, $F(3, 28) = 4.11$, Block, $F(3, 84) = 26.77$, and a Group × Block interaction, $F(9, 84) = 3.58$. During the reacquisition session, Group Control responded more than Groups PRF 1:8 and PRF 2:8, $Fs(1, 28) \geqslant 5.91$. In addition, Group EXT responded more during the pre-CS period than Group PRF 2:8, $F(1, 28) = 4.74$, which indicates that the significantly higher elevation score shown by Group EXT than Group PRF 2:8 reflected a much higher CS score in Group EXT. The remaining comparisons were not significant, $Fs \leqslant 2.31$.

Discussion

Reacquisition following extinction (Group EXT) was more rapid than acquisition in a group that had never received conditioning or extinction (Group Control). This finding replicates that of Ricker and Bouton (1996, Experiments 1a, 1b, & 2), who also observed rapid reacquisition with comparable procedures in this conditioning preparation, as well as research from other conditioning preparations (Napier et al., 1992). Not surprisingly, the results during the extinction phase also suggest that partial reinforcement slows the loss of responding that is ordinarily observed in extinction (Gibbs et al., 1978).

The crucial new finding, however, is partial reinforcement's effect on the rate of reacquisition. Both of the partial reinforcement groups showed higher responding than Group Control during reacquisition, which may reflect some carryover of the incomplete loss of responding that was evident in the extinction phase. However, Group PRF 2:8 showed significantly less responding than Group EXT at this time; this group's partial reinforcement treatment thus slowed down the rapid recovery of responding evident after extinction. The results therefore confirm that, consistent with a trial-signaling view, a partial reinforcement procedure can both slow the loss of responding in extinction and slow the rapid recovery of responding during reacquisition that occurs after a conventional extinction procedure. The fact that Group PRF 1:8 did not show the same effect suggests that the number of reinforced trials presented in extinction may be important in producing the effect: Group PRF 2:8 received twice the number of reinforced trials in extinction, each of which was a potential occasion on which the animal might associate a reinforced trial with further nonreinforced trials and thus reduce the basis of the trial-signaling effect.

Experiment 2

The second experiment was designed to replicate and extend the slowed reacquisition effect. Although the results of Experiment 1 were consistent with the trial-signaling view, they were ambiguous with respect to the actual rate of reacquisition after partial reinforcement. That is, the fact that Group PRF 2:8 responded more than Group Control during reacquisition might suggest that reacquisition after partial

reinforcement was still more rapid than with a neutral CS. Alternatively, the difference might merely be a result of the fact that partial reinforcement was only partially effective at reducing responding during extinction (see especially Fig. 1). To separate these possibilities, it was necessary to bring PRF responding closer to the level of the extinguished and control groups at the end of the extinction phase. Experiment 2 attempted to accomplish this by using a more extended fading procedure in which the number of reinforced trials in extinction was progressively decreased over multiple sessions. Extinction training was continued until the PRF group achieved a level of responding that was comparable to that observed in the EXT group. Other minor changes in the procedure also served to extend the generality of the previous findings.

Experiment 2 was also designed to determine the effect of CS–US *pairings* during extinction. One effect of a partial reinforcement procedure in extinction is simply to expose the animal to the US. The US itself is a salient part of the context of acquisition, and might therefore produce renewal when it is reintroduced during reacquisition in a group that receives ordinary CS-alone extinction. Thus, the slowed reacquisition in Group PRF 2:8 could have been due to the association of extinction trials with the US itself, rather than with reinforced trials per se. Consistent with this possibility, Frey and Butler (1977) and Rauhut, Thomas, and Ayres (2001) found that an extinction procedure that included unpaired USs in the intertrial interval slowed reacquisition in rabbit eyeblink conditioning and rat conditioned suppression preparations, respectively. Experiment 2 therefore added an unpaired group that received the same number of USs in extinction as a PRF group, but in the intertrial intervals instead of being paired with the CS. In addition to helping clarify the role of CS–US pairings in slowing reacquisition, the unpaired group also clarified the role of CS–US pairings in slowing down the loss of responding in extinction.

Method

Subjects

The subjects were 64 female Wistar rats of the same age and stock as Experiment 1. The rats were housed and maintained as in Experiment 1, except that the colony room was maintained on a 16:8-h light:dark cycle. The experiment was run in two replications of 32 animals each.

Apparatus

The experiment was run in two sets of four Skinner boxes housed in sound attenuation chambers (Med Associates, Georgia, VT) located in different rooms of the laboratory. Each box measured $30.5 \times 24.1 \times 21$ cm (l × w × h). The front and back walls were brushed aluminum; the side walls and ceiling were clear acrylic plastic. A 5.1×5.1 cm recessed food cup was centered in the front wall and positioned 2.5 cm above the floor. The food cups had infrared photobeams positioned approximately 1.2 cm behind the plane of the wall and 1.2 cm above the bottom of the cup. In one set of four boxes, the floor consisted of stainless steel bars, 0.48 cm in diameter, spaced 1.6 cm center to center and mounted parallel to the front wall. In the other set of four boxes, the floor consisted of similar bars, except that the bars were "staggered" such

that the height of adjacent bars differed by 1.6 cm. In both sets of boxes, illumination was provided by two 7.5-W incandescent bulbs mounted to the ceiling of the sound attenuation chamber. The rats entered the box through a door in the right wall. Type of box was counterbalanced over groups.

The CS was a 30-s presentation of a 3000-Hz tone (80 dBA) delivered through a 7.6 cm speaker mounted to the ceiling of the sound attenuation chamber, approximately 27 cm above the grid floor. Background noise level was 60 dBA. The US was always two 45-mg Noyes precision food pellets (Research Diets, New Brunswick, NJ) delivered 0.2 s apart at the termination of the CS. The apparatus was controlled by computer equipment located in an adjacent room.

Procedure

Magazine training. Magazine training was carried out as in Experiment 1, except that approximately 30 pellets were delivered during the session.

Conditioning. The rats then received 10 daily 90-min conditioning sessions. For 24 of the rats in each (32-rat) replication, there were eight pairings of the 30-s tone CS with the food US in each session (the mean ITI was 10.75 min, with the shortest ITI = 9.75 min). (The change in conditioning procedure from Experiment 1 was arbitrary and extends the generality of the findings.) Following conditioning, these rats were matched on their responding during the last four sessions of conditioning and assigned to groups EXT, PRF, and UNP ($ns = 16$ collapsing over replication). Group Control received the same eight US presentations but no CS. However, due to experimenter error, the Group Control rats in the second replication accidentally received two sessions of CS–US pairings and thus had to be excluded from the experiment. The results reported for Group Control therefore originate exclusively from the first replication ($n = 8$). In this experiment, Group Control was run in the same context throughout the experiment.

Extinction. Following conditioning, the rats that had received CS–US pairings received response-elimination training until the PRF group achieved a loss of responding comparable to that in the other groups. In Replication 1, this required 11 90-min sessions, and in Replication 2 it required 18. In each session, Group Control received 90 min of context exposure, with no nominal stimuli being presented. For Groups EXT, PRF, and UNP, there were 24 presentations of the tone, with a mean ITI of 3.16 min (shortest ITI = 2.50 min). For Group EXT, the tone was never paired with a US. In contrast, Group PRF received partial reinforcement and Group UNP received an explicitly unpaired procedure that involved the same number of CS and US presentations. Group UNP always received its unpaired USs in the intertrial intervals that followed trials in which Group PRF received the US. For Group UNP, the US always occurred at least 90 s after the preceding CS and at least 60 s before the next.

The PRF and UNP groups received procedures that gradually reduced the number of USs delivered in each session. In both replications, the ratio of US to CS presentations decreased from 1:8 on Days 1–4 to 1:12 on Days 5–7 and 1:24 on Days 8–11. In Replication 2, there were seven additional sessions (Days 12–18) with a 1:24 ratio. The distribution of CSs and USs in the 1:8 schedule followed the method

described in Experiment 1. In the 1:12 schedule, a US occurred in each block of 12 trials, and in the 1:24 schedule, the session's only US always occurred during either the first or second block of eight trials.

Reacquisition. Following extinction, all groups received two daily reacquisition sessions. In Session 1, the first 8 trials were CS-alone presentations designed to help guarantee the absence of spontaneous recovery on subsequent trials. Group Control received context exposure until trial positions 7 and 8, when (as before) it received two CS-alone presentations designed to habituate any unconditioned responding to the tone. All groups then received 9 reacquisition trials that included an alternating mix of reinforced and nonreinforced trials (see Bouton, 1986; Bouton & Swartzentruber, 1989). Session 2 contained 17 alternating reinforced and nonreinforced trials. The mean ITI during this phase was 4.68 min (shortest ITI = 2.50 min).

Results

Conditioning and extinction

Fig. 3 presents the data from conditioning and extinction. Interestingly, conditioning with only eight spaced trials in each session yielded very strong conditioned responding in this experiment. During the last session of conditioning, there was a difference among the groups, $F(3, 52) = 6.61$; the paired groups did not differ, $Fs < 1$, but each responded more than the control group, $Fs(1, 52) \geqslant 14.19$.

Extinction then occurred rapidly. Extinction sessions 1–11 included animals from both Replications 1 and 2, whereas Extinction sessions 12–18 included only animals
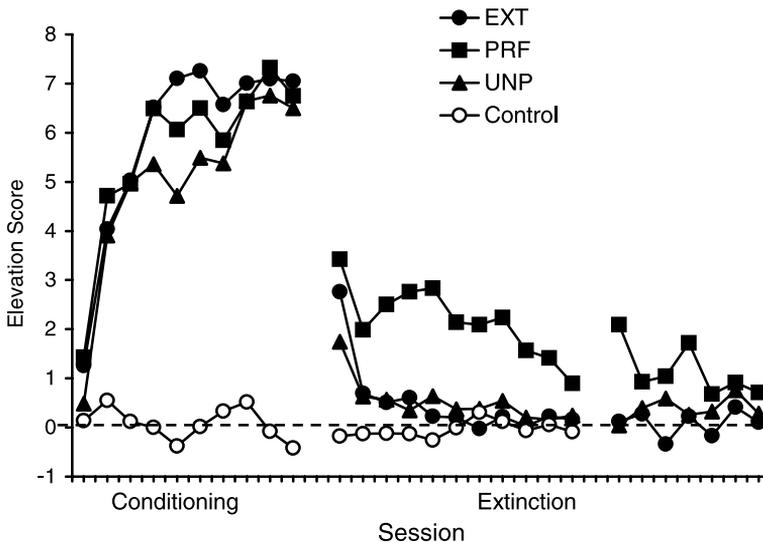

Fig. 3. Mean elevation scores during conditioning and extinction in Experiment 2. Extinction sessions 1–11 contained subjects from Replications 1 and 2, whereas sessions 12–18 contained only rats from Replication 2. (Group Control is from Replication 1.)

from Replication 2. A Group × Session × Replication ANOVA on Extinction sessions 1–11 in the groups that were represented in both replications (EXT, PRF, and UNP) revealed no effect of replication or interaction of replication with other factors, Fs < 1. We therefore collapsed over replication in a Group × Session ANOVA, which revealed main effects of Group, $F(2, 45) = 19.80$, Session, $F(10, 450) = 13.14$, and a Group × Session interaction, $F(20, 450) = 1.63$. Pairwise comparisons were performed on the first and last sessions to analyze the interaction. On Session 1, Group PRF responded more than Group UNP, $F(1, 45) = 4.35$, but neither group differed from Group EXT, $F(1, 45) \leqslant 1.59$. On Session 11, Group PRF responded more than Groups EXT, $F(1, 45) = 4.28$, and UNP, Fs$(1, 45) = 3.40$, $p = .07$. Groups EXT and UNP did not differ from one another, $F < 1$. Responding in Group PRF proved difficult to reduce to the level of that in Groups EXT and UNP. Nonetheless, by the last day of the extinction phase (Session 11 for Replication 1 and Session 18 for Replication 2), groups EXT, PRF, and UNP did not differ significantly, $F(2, 45) = 2.65$.

Analogous ANOVAs were conducted on the pre-CS scores. We again collapsed over replication in a Group × Session ANOVA that focused on Groups EXT, UNP, and PRF, which revealed main effects of Group, $F(2, 45) = 3.79$, Session, $F(10, 450) = 2.40$, and a Group × Session interaction, $F(20, 450) = 1.60$. On Session 1, there were no group differences in responding. On Session 11, Group PRF responded more than Group EXT, $F(1, 45) = 9.06$, but neither of these groups differed from Group UNP, Fs$(1, 45) \leqslant 2.33$. Despite a higher pre-CS score on Session 11, Group PRF had a significantly higher elevation score, which indicates a much higher CS score in that group. By the final extinction session (Session 11 for Replication 1 and 18 for Replication 2), there was still a difference among the groups, $F(2, 45) = 4.39$. At this time, the mean pre-CS scores for Groups EXT, PRF, UNP, and Control, respectively, were 0.75, 2.00, 1.08, and 0.47.

Reacquisition

Fig. 4 depicts responding during half-session blocks of the reacquisition sessions (trials 1–8 and 9–17 in Session 1 and trials 1–9 and 10–17 in Session 2). (The first half-session block consisted of extinction trials.) As the figure suggests, reacquisition occurred rapidly in Group EXT and slowly in Groups UNP and Control. Most important, reacquisition in Group PRF was apparently slow compared to that in Group EXT. An ANOVA on the three groups that were represented in both replications (EXT, UNP, and PRF) revealed no effects or interactions with the replication factor, Fs < 1, and we therefore collapsed over replication in a Group × Block ANOVA. This revealed significant effects of Group, $F(2, 45) = 7.44$, Block, $F(3, 135) = 24.00$, and a Group × Block interaction, $F(6, 135) = 4.94$. Planned comparisons on the data collapsing over reacquisition blocks (using the error term from those blocks) revealed that Group PRF responded less than Group EXT, $F(1, 45) = 5.06$. Group UNP responded less than both Group EXT, $F(1, 45) = 19.59$, and Group PRF, $F(1, 45) = 4.74$. The results thus indicate that while the UNP treatment caused the most dramatic interference with rapid reacquisition, the PRF treatment was effective too.
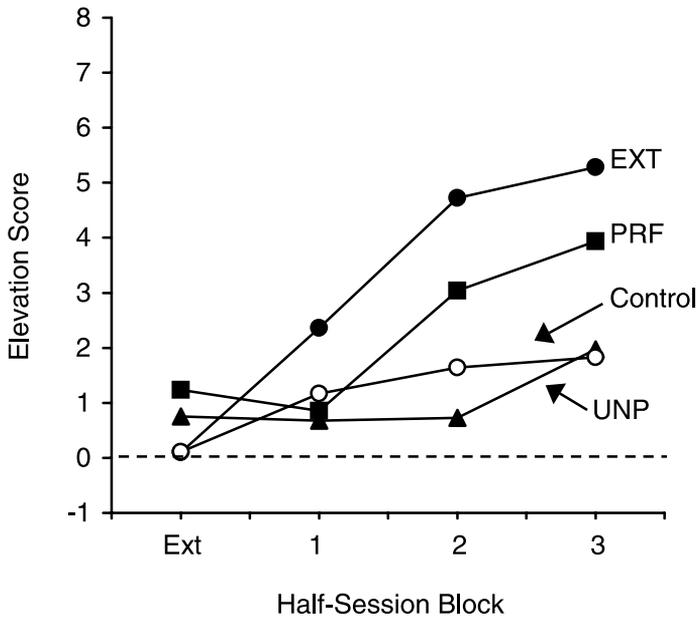
Fig. 4. Mean elevation scores during half-session blocks of the reacquisition sessions in Experiment 2. The first block represents eight nonreinforced trials. Group Control is from Replication 1.

Because there were no interactions with the Replication factor, an additional ANOVA that included Group Control (which was only represented in Replication 1) was conducted to permit comparisons of the various groups with a group that had received no previous conditioning. This ANOVA confirmed the Group, Block, and Group × Block effects indicated above, $Fs \geqslant 4.07$. Comparisons between Group Control and the other groups during the reacquisition blocks revealed that it differed from Group EXT, $F(1,52) = 10.48$, but not Group PRF, $F(1,52) = 1.71$, or Group UNP, $F(1,52) < 1$.

The differences among the groups in elevation scores in this phase were not reflected in differences in pre-CS scores. The analogous ANOVA on the three groups from both replications revealed no effects or interactions with the Replication factor, $Fs < 1$. We therefore collapsed over replication. This ANOVA revealed a main effect of Block, $F(3,135) = 22.66$, with pre-CS scores increasing over blocks. However, the Group effect and Group × Block interaction did not approach significance, $Fs < 1$. An additional ANOVA that included Group Control (Replication 1 only) confirmed the Block effect, $F(3,156) = 19.95$, but there was again no Group or Group × Block interaction, $Fs \leqslant 1.53$. Mean pre-CS responding for Groups EXT, PRF, UNP, and Control were 2.97, 3.21, 2.50, and 1.35, respectively, for the phase.

Discussion

As in Experiment 1, partial reinforcement slowed the loss of responding during the extinction phase. Unpaired USs had no such effect. Although unpaired USs in

extinction can slow the loss of responding in aversive conditioning preparations (e.g., Bouton & Bolles, 1985; Frey & Butler, 1977), the slow loss of responding in Group PRF in the present method is mainly attributable to the continued CS–US pairings. At least as important, the present experiment replicated the finding that rapid reacquisition that can occur after simple extinction (Group EXT vs. Group Control) can be slowed by a partial reinforcement procedure (Group PRF vs. Group EXT). It is noteworthy, though, that although Group PRF never differed significantly from Group Control during the reacquisition phase, it still relearned at a faster rate than a group that received unpaired training during extinction (Group UNP). The partial reinforcement procedure's interference with reconditioning was not as profound as that produced by the unpaired procedure.

The effect of the unpaired procedure on reacquisition replicates the findings of Frey and Butler (1977) in the eyeblink preparation and Rauhut et al. (2001) in conditioned suppression. There are at least three mechanisms that might contribute to this effect. First, as implied in the Introduction, according to a trial-signaling perspective the presentation of the US in extinction would break the US's exclusive connection with acquisition, and therefore reduce the potential renewal effect caused by reintroduction of the US during reacquisition. Second, presenting unpaired USs during extinction might be more effective at reducing the associative strength of the CS (Frey & Butler, 1977). For example, many models of conditioning would predict that presentation of the US in extinction would keep the associative value of the context high and therefore increase the size of associative decrements to the CS when the CS is nonreinforced in compound with the context (e.g., Rescorla & Wagner, 1972). Greater associative loss to the CS after the unpaired procedure would make it slower to recondition during the reacquisition phase. Of course, although a similar effect on context conditioning might be produced when the US is presented in the partial reinforcement procedure, it would be offset by the fact that the CS is still being paired with the US (which would maintain associative strength to the CS) and by the fact that the presence of the CS on occasions when the US is presented would tend to block or overshadow conditioning of the context. A third possible mechanism behind the effectiveness of the unpaired procedure is that it might allow the organism to habituate to the US. Such a possibility has been suggested for shock USs by Rauhut et al. (2001), although a role for US habituation may seem less likely in hungry rats receiving an occasional food-pellet US.

The fact that the unpaired extinction procedure was more effective than the partial reinforcement procedure at reducing the rate of reconditioning is not surprising, since the presence of paired trials in the partial reinforcement procedure would presumably maintain more excitation to the CS and perhaps attention to the CS as well (e.g., Kaye & Pearce, 1984; Pearce & Hall, 1980). Indeed, the apparent *positive* effect of the CS–US pairings on the rate of reacquisition (implied by the greater responding in Group PRF, which received CS–US pairings, than in Group UNP, which received the same CS and US presentations unpaired) might make the effect of partial reinforcement in extinction seem all the more striking. Despite the possibility that CS–US pairings arguably caused positive transfer with reacquisition, the partial

reinforcement procedure still reduced the rate of reconditioning. The overall pattern of results seems uniquely consistent with the trial-signaling view.

General discussion

The present experiments studied reacquisition of responding following extinction and following partial reinforcement. The results are easily summarized. First, in both experiments, acquisition after extinction was more rapid than original conditioning in a control group at a comparable point in the experiment (see Ricker & Bouton, 1996). That result is consistent with the idea that some aspect of conditioning is "saved" during extinction. Second, the loss of responding during extinction was significantly slowed by a partial reinforcement treatment in which the CS was occasionally reinforced during extinction (Experiments 1 and 2). Third, and most important, the partial reinforcement treatment slowed the rapid reacquisition that was otherwise observed after extinction. In the present experiments, the treatment that led to a slower response loss also led to a more durable type of extinction in the form of slower reacquisition.

The most straightforward account of the results follows that of Ricker and Bouton (1996), who suggested that preceding trials may become part of the "context" correlated with conditioning and extinction. Particularly when conditioning and extinction involve a large number of trials, animals may learn that reinforced trials occur in the context of other reinforced trials and nonreinforced trials occur in the context of other nonreinforced trials. As elegantly developed in sequential theory (e.g., Capaldi, 1967, 1994), different types of trials can exert discriminative control over responding on subsequent trials. Hence, when conditioning begins anew in a group that has been undergoing extinction, the reintroduction of reinforced trials can reintroduce a potent contextual stimulus that causes a renewal of conditioned responding. Partial reinforcement procedures eliminate this effect by providing an opportunity to associate reinforced trials with nonreinforced trials during the extinction phase. The results with the unpaired procedure (Experiment 2) might further suggest that the reinforcer itself, rather than reinforced trials per se, can be a powerful contextual cue for conditioning (see Bouton, Rosengard, Achenbach, Peck, & Brooks, 1993).

For many years, this laboratory has been investigating the role of context in controlling extinction performance (e.g., see Bouton, 2002, for one review). The idea that preceding trials, in addition to traditionally emphasized contextual stimuli such as the physical background and internal state, constitute part of the "context" is entirely compatible with Capaldi's (1967, 1994) sequential theory. That theory holds that responding on a given trial is determined by the animal's memory of the outcomes from preceding trials and the extent to which those memories have previously been associated with reinforcement (or with the response). Sequential theory has been enormously successful at explaining many extinction phenomena, including the partial reinforcement extinction effect (PRE), in which the loss of responding that occurs in extinction is slowed by partial reinforcement during training (e.g., see Mackintosh,

1974, for one review). According to sequential theory, partial reinforcement causes more persistent responding in extinction because the animal has learned to respond in the presence of memories of recent nonreinforced trials. The present findings can be regarded as the inverse of the partial reinforcement extinction effect. In the PRE, including nonreinforced trials in conditioning causes more generalization from conditioning to extinction, whereas in the present experiments, including reinforced trials in extinction causes more generalization from extinction to reconditioning. Interestingly, sequential theory's use of intertrial reinforcers (e.g., Capaldi, 1964) is consistent with our presentation of noncontingent USs in the unpaired procedure in Experiment 2. Here the argument was that they likewise influence the animal's memory for the outcomes of previous trials.

It is also worth noting that the theory would make a similar prediction regarding reinstatement procedures in which USs are presented noncontingently and responding recovers. If responding were tested reasonably soon after the reinstating USs, then the recent memory of the reinforcer would similarly serve as a contextual cue. Consistent with this idea, free USs during extinction have been shown to reduce the reinstating impact of free USs given after extinction (e.g., Baker, 1990).

The effect of partial reinforcement on reacquisition is less consistent with other theoretical perspectives. Models like the Rescorla and Wagner (1972) model do not anticipate rapid reacquisition following extinction because they assume that during extinction a previously conditioned stimulus loses associative strength. In contrast, the model of Kehoe (1988) correctly assumes that at least part of the original learning remains intact, but it has no basis for predicting that a partial reinforcement procedure instead of extinction will make it more difficult to access the saved association during reacquisition. Still other models, such as the Pearce and Hall (1980) model, do not assume any loss of associative strength in extinction, but instead suppose the building up of a separate inhibitory association that cancels the effect of the intact excitatory association (see also Konorski, 1948; Wagner, 1981). Unfortunately, the Pearce–Hall model also has no basis for expecting partial reinforcement to generate slower reacquisition. As noted above, its attention mechanism predicts that partial reinforcement will maintain attention to the CS and hence its conditionability during reacquisition. This makes the model predict faster reacquisition after partial reinforcement than extinction—exactly the opposite of what was presently obtained.

Sequential theory (Capaldi, 1994) and a context-retrieval view of extinction (e.g., Bouton, 1993) that includes previous trials as part of the context of conditioning and extinction are most consistent with the present results. As in some of the aforementioned models, the retrieval view does not assume that extinction destroys the original excitation; instead, a new, inhibitory, CS–US association is learned. Performance depends on which association is retrieved. Retrieval of the second-learned inhibitory association is thought to be relatively context-dependent (Bouton, 1988, 1993; Swartzentruber & Bouton, 1992; see especially Nelson, 2002, for evidence and discussion). Whereas the excitatory association can easily transfer across different contexts, the inhibitory association is best retrieved in the context in which it was learned. This approach explains the renewal effect, the recovery of responding that occurs when testing is performed in a different physical context from that in which extinction took

place (e.g., Bouton & Bolles, 1979; Bouton & King, 1983; Bouton & Peck, 1989; Bouton & Ricker, 1994). Since time is also considered a context (e.g., Bouton, 1988, 1993), it explains spontaneous recovery, the recovery of responding that takes place with the passage of time (e.g., Brooks, 2000; Brooks & Bouton, 1993; Pavlov, 1927; Robbins, 1990). In the current experiments, attempts were made to minimize recovery effects due to contextual change. Since reacquisition took place in the context in which extinction took place, the memory of the inhibitory association could have been retrieved, thus interfering with the expression of the CS–US association and generating slow reacquisition (Bouton, 1986; Bouton & Swartzentruber, 1989). However, as noted by Ricker and Bouton (1996), if the sequential learning point of view (e.g., Capaldi, 1994) is integrated with the retrieval view (Bouton, 1993), the present results can be explained. To repeat, the current results suggest that events from immediately preceding trials should be considered part of the contexts in which conditioning and extinction are learned.

We close by noting that the results have relevance for cognitive–behavior therapy. Because extinction procedures underlie many behavioral therapeutic techniques, the therapist should be aware of the evidence indicating that extinction is not unlearning. Many of the phenomena that support the view that extinction is not unlearning (reinstatement, renewal, spontaneous recovery, and rapid reacquisition) can be seen as mechanisms for relapse after therapy (e.g., Bouton, 2000, 2002). Extinction procedures that reduce such effects may be more effective than simple extinction at preventing relapse. As Bouton (2000) noted, behavior problems that result from many repeated trials in close succession may be especially vulnerable to trial-signaling effects. For example, cigarettes are often smoked in rapid succession, and drinks are often consumed in binges. As a result, previous cigarettes or previous drinks may become part of the context controlling conditioned responding. After successful extinction of cigarette smoking or drinking, an individual might smoke another cigarette or take another drink. If these trials are part of the context of smoking or drinking, renewal (i.e., relapse) may ensue. The present results suggest that a sparse partial reinforcement procedure (in which occasional cigarettes are smoked or controlled drinks are taken) may help undermine this mechanism of relapse. (The results also confirm the promise of an unpaired procedure, although it is often more difficult to visualize how this would be put into practice.) Although counterintuitive, exposure to a few CS–US pairings during exposure therapy may help ensure the success of therapy.

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