Plasticity of fear memory: a search for relapse prevention

Effting, M.

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5

Cued reacquisition trials during extinction attenuate recovery of responding upon a context switch

Effting, M., Vervliet, B. & Kindt, M. (*under revision*). Cued reacquisition trials during extinction attenuate recovery of responding upon a context switch.

Abstract

Two experiments examined whether interspersing cued reacquisition trials during extinction reduces renewal in human predictive learning. Acquisition occurred in context AX followed by extinction in context B. Cued reacquisition trials were administered in the presence of a contextual cue from acquisition (X). After simple extinction, a return to one of the contextual features from acquisition (A) produced clear renewal of the acquired contingency. The reacquisition procedure weakened the general increase of responding induced by a context switch after extinction (Experiments 1 and 2). Reacquisition conducted within a novel contextual cue (Y), which was perceptually similar to X, also attenuated recovered responding (Experiment 2). Moreover, following a reacquisition procedure, but not following simple extinction, the presence of all contextual cues from acquisition (AX) was required for evoking full-blown renewal (Experiments 1 and 2). Together, these results suggest that acquisition learning may become more context specific by exposure to cued reacquisition trials during extinction.

Introduction

Acquisition and extinction of conditioned responding seem symmetrical learning phenomena, but they are based on partially different processes. A marked difference is the sensitivity to changes in the background context: Whereas acquisition performance is largely resistant to such changes, extinction performance is easily disrupted (Bouton, 2000, 2002). For instance, when acquisition occurs in context A and extinction in context B, conditioned responding renews when the conditioned stimulus (CS) is tested in acquisition context A (e.g., Bouton & King, 1983; Vansteenwegen et al., 2005) or in a novel context C (e.g., Bouton & Bolles, 1979; Effting & Kindt, 2007). This so-called "renewal" effect has been demonstrated across species in a wide variety of paradigms, including fear conditioning (e.g., Milad, Orr, Pitman, & Rauch, 2005; Thomas, Larsen, & Ayres, 2003), appetitive conditioning (e.g., Bouton & Peck, 1989), conditioned suppression (Neumann, 2006), and human predictive learning (e.g., Rosas & Callejas-Aguilera, 2006).

One important implication of the renewal effect is that extinction does not erase the original excitatory association between the CS and the unconditioned stimulus (US). Rather, extinction is assumed to involve the formation of new learning by developing a CS-noUS association that asserts inhibitory control over the initial association (e.g., Bouton, 1993, 1994a). In addition, the renewal effect shows that this new (inhibitory) learning is disrupted by switching the context, allowing the first learned association to produce behavioural effects again (i.e., conditioned responding). Hence, extinction represents new learning that is specific to the context in which it was acquired (e.g., Bouton, 2000, 2002, 2004).

The contrast with context independent acquisition learning is striking, but it is not absolute. There is growing evidence that acquisition learning (CS-US) can also be context specific, depending on the experimental conditions. First, Rosas and colleagues (Rosas & Callejas-Aguilera, 2006; Rosas, García-Gutiérrez, & Callejas-Aguilera, 2006) showed in a human contingency learning paradigm that manipulations of the context salience can have a large impact on the generalization of acquisition learning to a novel context. Second, some studies have reported smaller ABC renewal effects compared to ABA renewal effects, indicating contextual specificity of acquisition performance (Effting & Kindt, 2007; Harris, Jones, Bailey, & Westbrook, 2000; but see Thomas et al., 2003). Notably, Harris et al. (2000) found only contextual control over conditioned responding for CSs that had been extinguished. No evidence for context specificity was observed after mere acquisition learning. This indicates that extinction training in context B caused a decrease in generalization of acquisition learning from context A to context C. One interpretation of this finding is that by simultaneously switching the context and the CS-US contingency, context A may in retrospect have been *re*considered as being important for predicting reinforcement, thereby inducing some context specificity of acquisition learning (Effting & Kindt, 2007; see Harris et al., 2000, for an alternative explanation).

There is also evidence that the context specificity of extinction is not absolute either. A number of experimental manipulations have been demonstrated to decrease renewal effects by enhancing the generalization of extinction learning (see Bouton, Woods, Moody, Sunsay, & García-Gutiérrez, 2006, for a review). Most interesting to the present study, conducting extinction in multiple contexts has sometimes been shown to reduce renewal in the context of acquisition (ABA renewal) or in a novel context (ABC renewal) (Chelonis, Calton, Hart, & Schachtman, 1999; Gunther, Denniston, & Miller, 1998; but see Bouton, García-Gutiérrez, Zilski, & Moody, 2006; Neumann, Lipp, & Cory, 2007). Arguably, multiple context extinction increases the probability that the renewal test context will share some contextual cues with the extinction contexts, thereby decreasing the context specificity of extinction (Chelonis et al., 1999; Gunther et al., 1998). This is an interesting viewpoint because it highlights the fact that a context is not one discrete stimulus, but rather a variety of disparate contextual cues. Animal research has shown that contextual cues may merge into a single context representation, but not necessarily do so (Rudy, Huff, & Matus-Amat, 2004; Rudy & O'Reilly, 2001). This opens the possibility that learning can become specific to certain contextual cues, but not to others.

This idea can be clarified by the observation of smaller ABC than ABA renewal. As stated before, by conducting extinction in context B acquisition learning may in retrospect become specific to the contextual cues of A, thereby reducing the likelihood that relevant contextual cues are shared by context C. Thus, context specificity of acquisition learning may be retrospectively induced by emphasizing the role of acquisition context cues for reinforcement. This sparks the idea that the effect of context B extinction may even be augmented by interspersing CS-US reacquisition trials in the presence of only a subset of the contextual cues from A. The predicted effect would then be that the other contextual cues from A lose their ability to elicit renewal. Interestingly, this prediction is in line with the literature on stimulus competition in human contingency learning, where it has several times been shown that the causal value of a stimulus can be changed indirectly by subsequent training with an interrelated stimulus. In backward blocking, stimuli X and Y are first presented in compound and paired with the outcome. Subsequently, stimulus X is further paired with the outcome, in the absence of stimulus Y. The typical result is a decrease in the rated value of Y as a predictor of the outcome (Dickinson & Burke, 1996; Melchers, Lachnit, & Shanks, 2004; Wasserman & Berglan, 1998). To date, however, this effect has not yet been investigated in contextual learning.

The present experiments were designed to test (1) whether renewal of predictive learning can be elicited by a subset of the contextual cues from acquisition, (2) whether renewal can be reduced by interspersing reacquisition trials during extinction in the presence of one of the contextual cues from acquisition, and (3) whether the reduction of renewal by cued reacquisition trials is restricted to the use of a contextual cue from acquisition.

Experiment 1

Experiment 1 aimed to establish and reduce renewal in predictive learning. The design of the experiment is presented in Table 5.1. There were four phases: acquisition in context AX, extinction in context B, and two renewal tests. Renewal was first assessed in a subset of contextual cues from acquisition (context A) and, subsequently, in the original acquisition context (context AX). During acquisition, one stimulus (S^+) was paired with the outcome, whereas another was not (S^-). In the extinction phase, both stimuli were no longer followed by the outcome. Participants in the control condition (EXT-only) received only extinction trials throughout extinction. By contrast, participants in the experimental condition (EXT-R) received occasionally cued reacquisition trials among extinction trials. During a cued reacquisition trial, including one presentation of each S, the S^+ was again paired with the outcome in the presence of a specific cue (X) from the acquisition context. This context cue (X) was, however, absent on extinction trials. Predictive ratings of the outcome were measured during each stimulus.

Most pertinent to our hypothesis was the response pattern between the last extinction trial in context B and the first test trial in context A as an index of renewal. It was predicted that after simple extinction (EXT-only) participants would show a renewal effect in context A. Given that cue X became a valid predictor of the S^+-outcome relationship for the reacquisition condition (EXT-R), renewal in context A (i.e., without cue X) was expected to be reduced for the EXT-R condition compared to the EXT-only condition.

Table 5.1 Experimental designs.

Exp	Condition	Acquisition	Extinction	Renewal Test 1	Renewal Test 2
1	EXT-R	AX: 10[S+-O/S-]	B: 12[S+/S-] BX: 4[S+-O/S-]	A: 3[S+/S-]	AX: 1[S+/S-]
	EXT-only	AX: 10[S+-O/S-]	B: 16[S+/S-]	A: 3[S+/S-]	AX: 1[S+/S-]
2	EXT-R	AX: 10[S+-O/S-]	B: 12[S+/S-] BX: 4[S+-O/S-]	A: 3[S+/S-]	AX: 1[S+/S-]
	EXT-R_{novel}	AX: 10[S+-O/S-]	B: 12[S+/S-] BY: 4[S+-O/S-]	A: 3[S+/S-]	AX: 1[S+/S-]
	EXT-only	AX: 10[S+-O/S-]	B: 16[S+/S-]	A: 3[S+/S-]	AX: 1[S+/S-]

Note. Letters A, B, X, and Y refer to the context manipulations consisting of a coloured computer screen (A or B) and a background sound (X or Y). The numbers specify how many trials of each type were administered. S+ and S- were the stimuli, O was the outcome.

Method

Participants

The participants were 48 psychology students (19 male, 29 female) from the University of Amsterdam receiving course credits or a small payment for participation. Their age ranged from 18.20 to 32.67 with a mean of 21.72 years (SD = 3.15). None of them was colour-blind or had previous experience with renewal experiments. Due to technical error, data of 1 participant was not included, resulting in a final sample of 47 participants. Participants were randomly assigned to either Condition EXT-R (n = 24: 10 men, 14 women) or Condition EXT-only (n = 23: 8 men, 15 women).

Stimuli

Two grey geometric shapes were used as stimuli: A circle with a diameter of 56 mm and a triangle measuring 68 mm of base and 56 mm of height. Both shapes had a 1-mm black outline. Stimuli appeared against a white slide (14.8 cm × 11.1 cm). Assignment of the shapes as S^+ and S^- was counterbalanced across participants. The outcome consisted of an emotional picture from the International Affective Picture System (IAPS, Lang, Bradley, & Cuthbert, 2005), in which pictures are rated on their valence (negative/positive) and arousal (low/high) using a 9-point Self-Assessment Manikin (SAM) (1 = negative, 9 = positive; 1 = low arousing, 9 = high arousing). Mean valence and arousal ratings for the picture (woman attacked by man with knife, # 6550) were 2.73 and 7.09, respectively. The picture measured 14.8 by 11.1 cm. Stimuli were projected in the middle of a 19-in. computer screen.

Context manipulation

Contexts were manipulated by changing the background colour of the computer screen (context cue A or B) and by turning on or off a background sound (context cue X). The colours of the computer screen (blue or red) that served as context cues A or B were counterbalanced across participants. The background sound consisted of a soundtrack that was produced by a midi-editing program (MOTU, Digital Performer 4.5). The track comprised a 4/4 drumbeat at 120 beats per minute in combination with a dominant cowbell-pattern played in 16ths. The sound was presented through two speakers (Q-TECH speaker set 2.0) next to the computer monitor.

Apparatus

Predictive ratings of the outcome were assessed online during each stimulus presentation using a pointer on a continuous rating scale. The pointer could be moved by dragging it with a mouse. Above the scale, the following question was shown: “To what extent do you expect the picture?” The scale consisted of 11 points labelled from ‘certainly not’ (0) through ‘uncertain’ (5) to ‘certainly’ (10). The scale was displayed at the bottom of the computer screen.

The experiment was run on a Pentium PC. A software program (Presentation version 10.3) controlled presentation of stimuli and recording of predictive ratings.

Procedure

Participants were tested individually in a small booth. After participants gave their informed consent, written instructions were given on the computer screen. It was explained that they would see different geometric shapes, which would sometimes be followed by a picture (outcome). Participants were instructed to predict the occurrence of the outcome on the basis of the shape. They were asked to indicate their outcome prediction during each shape by dragging a pointer on the rating scale with a mouse. Participants were required to confirm their prediction by clicking the mouse. One practice trial was then provided using a shape different from the actual experiment (i.e., a square) and no outcome. After assurance that the instructions were understood, the experimenter left the room and the participant started the experiment.

The experiment consisted of an acquisition phase, an extinction phase and two renewal test phases. In the *acquisition phase*, the relationship between S^+ and the outcome was learned. Participants received 10 trials of both stimuli (S^+ and S^-). Each trial started with a stimulus presentation. After 2 s, the rating scale appeared. Both stimulus and scale remained on the screen until a prediction of outcome occurrence was given. The outcome emerged 500 ms after S^+ offset for the duration of 1.5 s. Thus, the interval between onset of S^+ and the outcome was at least 2.5 s, with the actual time depending on the moment of responding. In case of an S^-, the outcome was replaced by presentation of a 1.5-s white slide (14.8 cm × 11.1 cm). Intertrial intervals (ITIs) were divided into a fixed pre-trial interval of 2 s and a variable post-trial interval of 2.75, 3.25 or 3.75 s with an average of 3.25 s. During trials and ITIs, the context was continuously presented. Order of trial and post-trial intervals was randomized, with the restriction that no more than two trials or post-trial intervals were of the same type. For both conditions, acquisition occurred in context AX, which consisted of coloured screen A and background sound X.

In the *extinction* phase, participants were exposed to 16 trials of each stimulus, divided into four blocks of four trials. For participants in the EXT-only condition, both stimuli (S^+ and S^-) were always presented without the outcome. Accordingly, participants learned that the S^+ was no longer followed by the outcome. Extinction trials were delivered in context B, which consisted of coloured screen B in the absence of a background sound. For participants in the EXT-R condition, the same nonreinforced stimulus presentation schedule as to the EXT-only condition was applied. However, within each block, one extinction trial was replaced by a cued reacquisition trial, resulting in a total of 12 extinction trials and 4 cued reacquisition trials. During a cued reacquisition trial, including 1 S^+ and 1 S^- presentation, the S^+ was again paired with the outcome, but not the S^-. The order of S^+ and S^- within a cued reacquisition trial was randomized. Cued reacquisition trials were presented within the combination of a specific context cue from acquisition (i.e., sound X) and the extinction context (i.e., coloured screen B). Hence, the presence of X was predictive for occurrence of the outcome after the S^+. As each trial was preceded by a pre-trial interval and followed by a post-trial interval, context cue X was initiated 2 s before onset of a reacquisition trial and remained on during the post-trial interval. The position of a cued reacquisition trial within each block was fixed. That is, trials were presented on the 3rd, 4th, 2nd, and 3rd position in blocks 1 to 4, which corresponds with trials e3, e8, e10, and e15. The parameters for stimulus, trial order, and ITIs were identical to those used in acquisition.

In the *first renewal test* phase, recovery of predictive ratings was assessed in a subset of contextual cues from acquisition (context A), that is, coloured screen A without background sound X. Each stimulus was presented for three times, none of them being followed by the outcome. In the *second renewal test* phase, recovered ratings were tested in the original acquisition context (context AX). This test consisted of one S^+ and one S^- presentation. In both test phases, the same parameters for stimulus, trial order, and ITIs as during acquisition were applied. To control for outcome omission effects (cf. Effting & Kindt, 2007; Neumann, 2006), half of the participants started extinction and both renewal test phases with an S^+ followed by an S^-, whereas the other half started with an S^- followed by an S^+. Acquisition, extinction, and renewal tests were presented without interruption.

After the experiment, the picture outcome was rated on valence and arousal levels using a paper-and-pencil version of the SAM. The scales ranged from 1 (negative/low arousing) to 9 (positive/high arousing).

Results

Statistical analyses were performed using mixed analyses of variance (ANOVA) with stimulus and trial as within-subjects factors and condition as a between-subjects factor. In all analyses, the factor stimulus included two levels (S^+ and S^-), just like the factor condition (EXT-R and EXT-only), whilst levels of the factor trial varied depending on the exact analysis. The results most pertinent to our hypothesis are reported and further examined with planned contrasts, post-hoc simple interactions and pairwise comparisons (using Bonferroni adjustment for multiple comparisons). Greenhouse-Geisser corrections were applied in case of violation of the sphericity assumption. An alpha level of .05 was used for all statistical analyses.

Outcome characteristics

The mean valence rating for the picture outcome was 2.87 (SD = 1.26) and the mean arousal rating was 5.28 (SD = 2.26). No differences were obtained between conditions with respect to outcome ratings, $F_{\text{valence}} < 1$, $F_{\text{arousal}}(1, 45) = 2.76$, p = .10.

Acquisition

Predictive ratings to trials during all phases of the experiment are shown in Figure 5.1. The figure suggests that differentiation of predictive ratings to S^+ and S^- developed gradually and similarly in both conditions. A 2 (Stimulus) × 10 (Trial: a1-a10) × 2 (Condition) ANOVA yielded a main effect of stimulus, $F(1, 45) = 406.01$, $p < .01$, and a significant Stimulus × Trial interaction, $F(5.64, 253.65) = 53.99$, $p < .01$, with the corresponding linear trend, $F(1, 45) = 243.06$, $p < .01$. Most important, no significant Stimulus × Trial × Condition interaction was obtained, $F(5.64, 253.65) = 1.08$, $p = .37$. The other effects were also not significant, *F*s < 1.

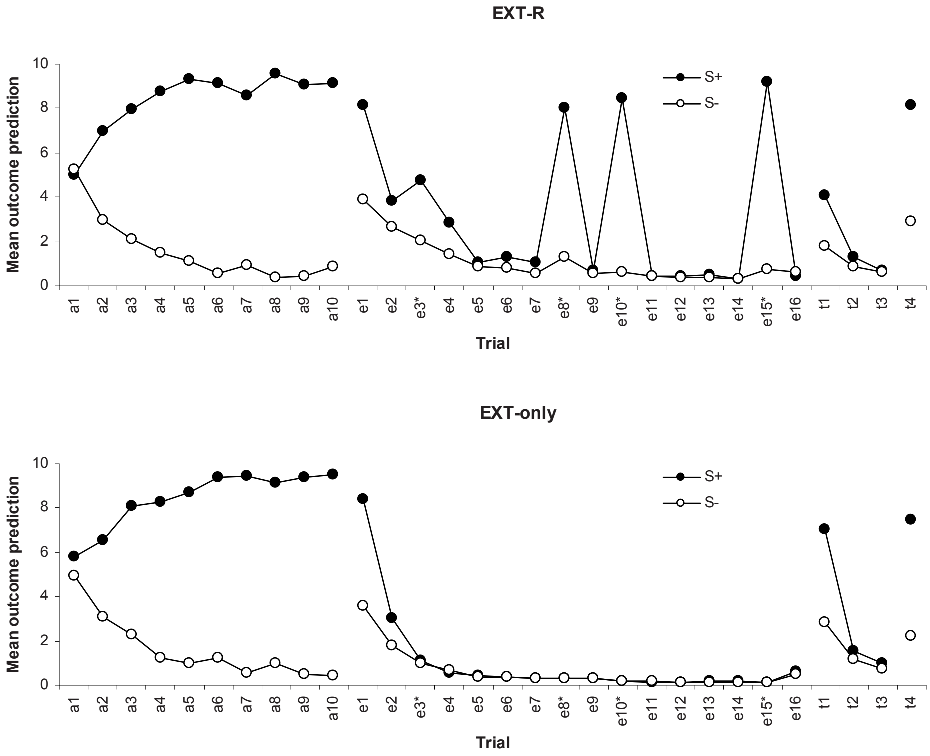

Figure 5.1 Mean outcome predictive ratings for S^+ and S^- during 10 acquisition trials (a1 to a10), 16 extinction trials (e1 to e16), and four test trials (t1 to t4) separately for the EXT-R condition (upper panel) and the EXT-only condition (lower panel) in Experiment 1. The extinction trials that were replaced by reacquisition trials for the EXT-R condition are indicated with an asterisk * (e3, e8, e10, and e15).

Generalization of acquisition

Both conditions showed a comparable decline in S^+/S^- differentiation upon changing the context between acquisition (AX) and extinction (B). Nevertheless, S^+/S^- differentiation was still present on the first extinction trial. These impressions were confirmed by a 2 (Stimulus) × 2 (Trial) × 2 (Condition) ANOVA comparing the last acquisition trial (a10) with the first extinction trial (e1). The analysis revealed main effects of stimulus, $F(1, 45) = 196.98$, $p < .01$, and trial, $F(1, 45) = 23.36$, $p < .01$, and a significant Stimulus × Trial interaction, $F(1, 45) = 35.79$, $p < .01$. Although pairwise comparisons indicated a significant decrease in S^+ ratings by a context switch, $F(1, 45) = 8.59$, $p = .01$, the difference between S^+ and S^- was highly significant at the start of extinction, $F(1, 45) = 43.85$, $p < .01$. None of the effects involving condition reached significance, *F*s < 1.

Extinction

Differential predictive ratings to S^+ and S^- progressively decreased across extinction trials in both conditions. A 2 (Stimulus) × 12 (Trial: e1-e2, e4-e7, e9, e11-e14, e16) × 2 (Condition) ANOVA found main effects of stimulus, $F(1, 45) = 31.11$, $p < .01$, and trial, $F(4.19, 188.58) = 151.56$, and a significant Stimulus × Trial interaction, $F(2.69, 121.12) = 22.13$, $p < .01$, with the corresponding linear trend, $F(1, 45) = 38.51$, $p < .01$. Pairwise comparisons indicated that no differential ratings were left on the last extinction trial, $F < 1$. No main effect of condition was observed, $F(1, 45) = 2.79$, $p = .10$. Crucially, the Stimulus × Trial × Condition interaction was not significant, $F < 1$, suggesting that the course of extinction did not differ between conditions.

Reacquisition

Participants in the EXT-R condition readily reacquired the discrimination by showing a gradual increase in ratings to S^+ relative to S^- across reacquisition trials. By contrast, ratings to S^+ and S^- decreased for participants in the EXT-only condition. Statistical analyses confirmed these observations. A 2 (Stimulus) × 4 (Trial: e3, e8, e10, and e15) × 2 (Condition) ANOVA yielded main effects of stimulus, $F(1, 45) = 96.19$, $p < .01$, and condition, $F(1, 45) = 326.66$, $p < .01$, as well as significant interactions between stimulus and trial, $F(1.99, 89.75) = 14.74$, $p < .01$, and, most important, between stimulus, trial and condition, $F(1.99, 89.75) = 15.65$, $p < .01$.

To decompose the Stimulus × Trial × Condition interaction, simple interactions (Stimulus × Trial) were performed for each condition separately. For the EXT-R condition, there was a significant Stimulus × Trial interaction, $F(2.05, 47.04) = 16.81$, $p < .01$, including the linear trend, $F(1, 23) = 36.84$, $p < .01$, suggesting that S^+, but not S^-, progressively gained predictive value for the outcome. For the EXT-only condition, the analysis yielded only a significant main effect of trial, $F(1.16, 25.44) = 9.59$, $p < .01$, indicating an overall decline in predictive ratings. Both stimuli predicted the nonoccurrence of the outcome.

Renewal in context A (EXT-only)

As demonstrating renewal in a subset of features from the acquisition context was one of the aims of the present study, renewal was analyzed separately for the simple extinction condition (EXT-only) before comparing conditions. A return to context A (without X) after extinction in context B produced a clear differential renewal effect. A 2 (Stimulus) × 2 (Trial: e10 vs. t1) ANOVA revealed the predicted effects of stimulus, $F(1, 22) = 21.51$, $p < .01$, trial, $F(1, 22) = 137.52$, $p < .01$, and the Stimulus × Trial interaction, $F(1, 22) = 18.22$, $p < .01$, the latter showing a stronger increase in predictive ratings to S^+ relative to S^- from extinction to test (i.e., differential renewal). Renewal was due to higher S^+ than S^- ratings on the first test trial, $F(1, 22) = 19.94$, $p < .01$, whereas responding was not differentiated on the last extinction trial, $F(1, 22) = 2.24$, $p = .15$.

Renewal in context A (EXT-only vs. EXT-R)

A differential renewal effect was evident upon changing the context from extinction (B) to test (A), which did not differ significantly between conditions. However, a reacquisition procedure reduced the general increase in predictive ratings induced by a context switch compared to a simple extinction procedure.

These impressions were supported by a 2 (Stimulus) × 2 (Trial: e16 vs. t1) × 2 (Condition) ANOVA, which revealed significant main effects of stimulus, $F(1, 45) = 29.94$, $p < .01$, trial, $F(1, 45) = 110.28$, $p < .01$, and condition, $F(1, 45) = 6.98$, $p = .01$. The significant Stimulus × Trial interaction, $F(1, 45) = 34.43$, $p < .01$, reflects a stronger increase in S^+ than S^- ratings upon a context change. Nevertheless, comparisons revealed that S^+ ratings as well as S^- ratings significantly increased across contexts, $F(1, 45) = 109.54$, $p < .01$, and $F(1, 45) = 23.52$, $p < .01$, respectively. Importantly, the Trial × Condition interaction was significant, $F(1, 45) = 9.04$, $p < .01$, indicating a weaker increment in ratings for the reacquisition condition as compared to the simple extinction condition, irrespective of stimulus type. Pairwise comparisons yielded no group differences on the last extinction trial ($M_{\text{EXT-R}} = 0.52$; $M_{\text{EXT-only}} = 0.58$), $F < 1$, whereas ratings on the first test trial were significantly weaker for the EXT-R condition than for EXT-only condition ($M_{\text{EXT-R}} = 2.95$; $M_{\text{EXT-only}} = 4.95$), $F(1, 45) = 12.10$, $p < .01$. The interaction most pertinent to our hypotheses (Stimulus × Trial × Condition) was, however, not significant, $F(1, 45) = 2.00$, $p = .16$, suggesting no differences between conditions regarding the differential renewal effect. Thus, presenting cued reacquisition trials during extinction reduced the increase of predictive ratings to stimuli in general.

Renewal in context AX

Transition from the extinction context (B) to test in the original acquisition context (AX) produced similar renewal effects in both conditions. This was confirmed by the statistical analyses: A 2 (Stimulus) × 2 (Trial: e16 vs. t4) × 2 (Condition) ANOVA revealed no condition main effect, $F(1, 45) = 1.21$, $p = .28$, but there were main effects of stimulus, $F(1, 45) = 57.33$, $p < .01$, and trial, $F(1, 45) = 156.43$, $p < .01$. The interaction between stimulus and trial was significant, $F(1, 45) = 65.96$, $p < .01$, reflecting a larger increase in S^+ than S^- ratings from extinction to test. Most importantly, the extent of renewal was similar for both conditions as indicated by a nonsignificant Stimulus × Trial × Condition interaction, $F < 1$.

Renewal for S^+ in context A vs. context AX

Activation of acquisition performance (i.e., S^+-outcome relationship) depended on the test context (A vs. AX) following a reacquisition procedure (EXT-R), but not following simple extinction (EXT-only). This was confirmed by a 2 (Trial) × 2 (Condition) ANOVA comparing S^+ ratings in context A (t1) with context AX (t4). This analysis yielded a main effect of trial, $F(1, 45) = 17.27$, $p < .01$, indicating higher ratings in context AX than in context A, and a Trial × Condition interaction, $F(1, 45) = 11.17$, $p < .01$. The interaction reflected that predictive ratings significantly increased from context A to context AX for the EXT-R condition, $F(1, 45) = 28.72$, $p < .01$, whereas the difference was not significant for the EXT-only condition, $F < 1$.

Discussion

Experiment 1 demonstrates that a return to a subset of contextual cues from acquisition, after simple extinction in another context, was sufficient to produce a clear renewal effect. This was an important precondition to assess the effectiveness of the reacquisition procedure. Most importantly, administering reacquisition trials (during extinction) in the presence of one acquisition context cue (X) reduced the ability of the other acquisition context cue (A) to produce renewal. The reduction was not differential: The increase in predictive ratings to stimuli in general was weakened for the reacquisition condition (EXT-R) compared to the simple extinction condition (EXT-only).

Moreover, following a reacquisition procedure (EXT-R), the extent of recovered responding was context specific: Context AX elicited higher predictive ratings to S^+ than context A. By contrast, similar recovered ratings were obtained in contexts A and AX after a traditional extinction training (EXT-only). In addition, no differences in recovered ratings were observed between conditions in context AX. Hence, the presence of context cue X appears to be crucial for the full recovery of outcome prediction to S^+ after reacquisition training (with X).

A possible explanation for the present findings is that the administration of cued reacquisition trials resulted in the formation of a direct association between context cue X and the outcome (Rescorla & Wagner, 1972). An alternative explanation would come in terms of occasion setting. During reacquisition training, participants may have acquired a hierarchical relationship, in which context cue X sets the occasion for S^+ to be reinforced (Holland, 1986; Ross & Holland, 1981). In either way, the absence of cue X at test in context A would explain the attenuation of outcome predictions.

Additionally, and irrespective of the exact mechanism, reacquisition training may have induced a revaluation of the significance of contextual cues. That is, participants may have retrospectively inferred that context cue A was a weak predictor for the outcome. As stated in the introduction, such an effect would resemble backward blocking, a phenomenon that has been frequently observed in human causal judgment studies (e.g., Dickinson & Burke, 1996; Melchers et al., 2004; Wasserman & Berglan, 1998). To recap, backward blocking refers to the observation that the causal status of a cue can decline by additional learning experiences of an interrelated cue. For instance, Wasserman & Berglan (1998) demonstrated that following conditioning of a compound XY in a first phase, reinforcing one cue (X) of the compound in a second phase reduces the causal judgment of the other, nonpresented cue (Y). For backward blocking to occur, it is stated that cues must have been previously associated (Larkin, Aitken, & Dickinson, 1998; Melchers et al., 2004; Wasserman & Berglan, 1998).

Although backward blocking has only been demonstrated for Pavlovian excitatory stimuli, processes of blocking may also occur in contextual learning. Applied to the current study, learning that cue X signals reinforcement may retrospectively block the ability of cue A to elicit renewal, on the precondition that context cues X and A were simultaneously present during acquisition. By implication, reacquisition with a novel context cue (Y) should not result in blocking of acquisition context cue A, as these context cues (A and Y) were never associated. Thus, if backward blocking accounts for the observed effect, a reduction of renewal is expected following reacquisition with an acquisition context cue, but not following reacquisition with a novel context cue. This issue was examined in Experiment 2.

Experiment 2

Experiment 2 was designed to elucidate the role of backward blocking in attenuating renewal. Two reacquisition conditions were included. Condition EXT-R received reacquisition trials in the presence of an acquisition context cue (X), while for Condition EXT-R_{novel} reacquisition occurred within a novel context cue (Y). Condition EXT-only received merely extinction trials. At test in context A, reduced renewal was predicted for Condition EXT-R relative to Condition EXT-only. If this effect is caused by retrospective blocking of context cue A, only Condition EXT-R, but not Condition EXT-R_{novel}, is expected to show reduced renewal in context A. In that case, none of the conditions are predicted to demonstrate a reduction of renewal at test in original acquisition context AX.

Method

Participants

Seventy-two students from the University of Amsterdam (20 male, 52 female) with a mean age of 23.01 years (*SD* = 5.23; range 17.78 – 42.05) participated in return for course credits or a small payment. None of the participants was colour-blind and all were naïve to renewal experiments. Assignment of participants to the three conditions was at random: EXT-R (*n* = 24: 6 men, 18 women), EXT-R_{novel} (*n* = 24: 7 men, 17 women) and EXT-only (*n* = 24: 7 men, 17 women).

Stimuli, context manipulation, apparatus, and procedure

Stimuli, context manipulation, apparatus, and procedure were identical to Experiment 1, except for the following changes. In Experiment 2, the outcome consisted of a 500-ms white noise of 95 dB (A) with instantaneous rise time (Vansteenwegen et al., 2005). A loud noise outcome was selected as future experiments are planned within a fear conditioning paradigm. In Experiment 2, the rating scale was changed in the way that participants were asked to predict the occurrence of the loud noise.

As illustrated by Table 5.1, participants of all conditions received acquisition trials in context AX (coloured screen A and sound X) and extinction trials in context B (coloured screen B). For the EXT-R condition, reacquisition took place in the presence of an acquisition context cue (sound X) and the extinction context (coloured screen B). For the EXT-R_{novel} condition, reacquisition occurred within a novel context cue (sound Y) and the extinction context (coloured screen B). The EXT-only condition received only extinction trials. Similar to Experiment 1, renewal was tested in context A (coloured screen A) followed by a test in the original acquisition context AX (coloured screen A and sound X). X and Y consisted of two sounds: the fast sound from Experiment 1 and a slow sound both played at 55 dB. The slow sound was produced by writing a 4/4 metronome drumbeat at 110 beats per minute in combination with a dominant closed hi-hat sound that was played every ¼ note (MOTU, Digital Performer 4.5). Afterwards, the sound track was pitch-shifted down two octaves in order to enhance differentiation from the fast sound. Which of the sounds served as X and Y was counterbalanced across participants. In Experiment 2, all auditory stimuli were presented through Monacor MD-4600 headphones. During the experiment, all participants received twice a 1-min break: halfway the acquisition phase and after three quarter of the extinction phase (cf. Alvarez, Johnson, & Grillon, 2007).

After completion of the test phase, participants were asked to rate the pleasantness of the white noise outcome on an 11-point scale ranging from -10 (*unpleasant*) to +10 (*pleasant*) and the intensity of the white noise on a 5-category scale (*weak*, *moderate*, *intense*, *enormous*, and *unbearable*).

Results

The same statistical analyses were used as in Experiment 1, except that the factor condition had three levels (EXT-R, EXT-R_{novel}, and EXT-only). To examine the interactions most pertinent to our hypotheses, Helmert's contrasts were planned to compare conditions regarding potential stimulus or trial main effects or a Stimulus × Trial interaction (Field, 2005, Appendix A.6). In one contrast, the reacquisition conditions were compared with the simple extinction condition (EXT-R and EXT-R_{novel} combined vs. EXT-only). In a second contrast, the reacquisition conditions were directly compared (EXT-R vs. EXT-R_{novel}).

Outcome characteristics

The mean rating score for outcome pleasantness was -6.47 (SD = 2.65) and participants characterized the outcome as intense (M = 3.11, SD = 0.60). There were no differences between conditions in the way they rated the outcome, Fs < 1.

Acquisition

Figure 5.2 depicts mean predictive ratings across all trials of the experiment. The figure shows a gradual increase in differentiation between S^+ and S^- ratings. The course of acquisition did not differ between conditions. This was confirmed by a 2 (Stimulus) × 10 (Trial: a1-a10) × 3 (Condition) ANOVA, which revealed main effects of stimulus, $F(1, 69) = 594.67$, $p < .01$, trial, $F(6.32, 436.15) = 2.55$, $p = .02$, and the crucial Stimulus × Trial interaction, $F(5.71, 393.63) = 69.19$, $p < .01$, with the corresponding linear trend, $F(1, 69) = 359.25$, $p < .01$. There was neither a condition main effect, $F(2, 69) = 1.01$, $p = .37$, nor a Stimulus × Trial × Condition interaction, $F < 1$.

Generalization of acquisition

Although a context switch after acquisition produced a similar decline in S^+/S^- differentiation for all conditions, differential responding was still present in the novel context. A 2 (Stimulus) × 2 (Trial: a10-e1) × 3 (Condition) ANOVA yielded main effects of stimulus, $F(1, 69) = 341.73$, $p < .01$, and trial, $F(1, 69) = 22.24$, $p < .01$, as well as a Stimulus × Trial interaction, $F(1, 69) = 75.96$, $p < .01$. Subsequent pairwise comparisons indicated a decrease of S^+ ratings from the last acquisition trial to the first extinction trial, $F(1, 69) = 20.23$, $p < .01$, but reliable S^+/S^- discrimination at the start of extinction, $F(1, 69) = 49.37$, $p < .01$. Crucially, conditions did not differ from one another with regard to their generalization decrement, as reflected by a nonsignificant Stimulus × Trial × Condition interaction, $F(2, 69) = 1.82$, $p = .17$. No main effect of condition was observed, $F < 1$.

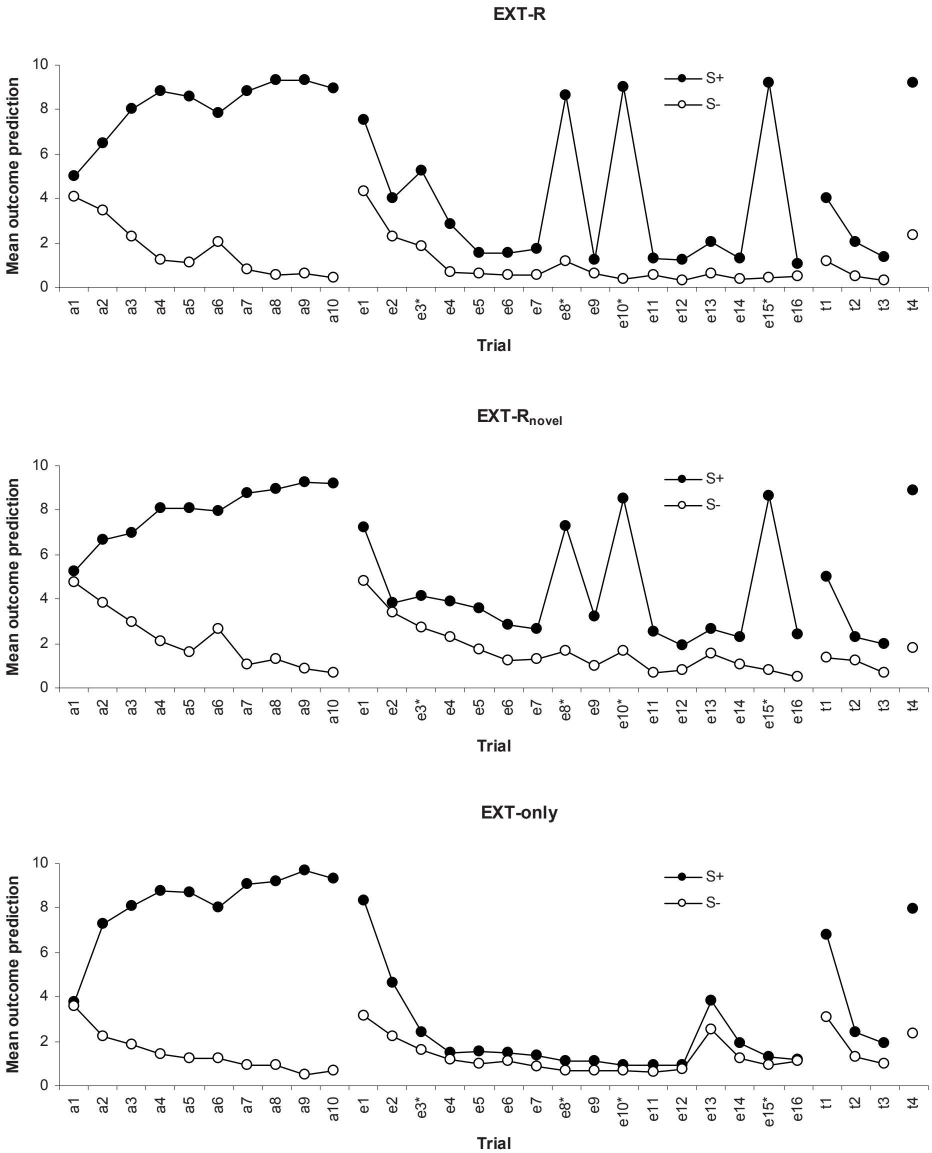

Figure 5.2 Mean outcome predictive ratings for S^+ and S^- during 10 acquisition trials (a1 to a10), 16 extinction trials (e1 to e16), and four test trials (t1 to t4) separately for the EXT-R condition (upper panel), the EXT-R_{novel} condition (middle panel) and the EXT-only condition (lower panel) in Experiment 2. The extinction trials that were replaced by reacquisition trials for the reacquisition conditions (EXT-R and EXT-R_{novel}) are indicated with an asterisk * (e3, e8, e10, and e15).

Extinction

Differentiation in predictive ratings progressively declined across extinction trials. Figure 5.2 suggests, however, that extinction was complete for the EXT-R and EXT-only conditions, but not for the EXT-R_{novel} condition. A 2 (Stimulus) × 12 (Trial: e1-e2, e4-e7, e9, e11-e14, e16) × 3 (Condition) ANOVA yielded significant main effects of stimulus, $F(1, 69) = 48.81$, $p < .01$, and trial, $F(4.98, 343.67) = 88.67$, $p < .01$, but not of condition, $F(2, 69) = 2.10$, $p = .13$. There were also a Trial × Condition interaction, $F(9.96, 343.67) = 2.59$, $p = .01$, a Stimulus × Trial interaction, $F(3.81, 262.91) = 9.68$, $p < .01$, and, crucially, a Stimulus × Trial × Condition interaction, $F(7.62, 262.91) = 3.53$, $p < .01$.

To examine the pattern of extinction in the three conditions subsequent ANOVAs (Stimulus × Trial) were performed for each condition. They revealed that S^+/S^- differentiation significantly decreased across trials for Conditions EXT-R, $F(2.79, 64.20) = 2.82$, $p = .05$, and EXT-only, $F(3.46, 79.52) = 18.35$, $p < .01$, but not for Condition EXT-R_{novel}, $F(3.10, 71.26) = 1.44$, $p = .24$. In the latter condition, ratings to S^+ and S^- showed a similar decline during extinction, as indicated by a main effect of trial, $F(4.76, 109.37) = 22.74$, $p < .01$. Subsequent pairwise comparisons on the last extinction trial confirmed that discriminative responding was left for Condition EXT-R_{novel}, $F(1, 23) = 7.42$, $p = .01$, while differential ratings were extinguished for Conditions EXT-R, $F(1, 23) = 1.68$, $p = .21$, and EXT-only, $F < 1$. Note that the curve in Figure 5.2 around the 13th extinction trial (e13) reflects an increase in predictive ratings upon a 1-min break.

Reacquisition

The reacquisition conditions (EXT-R, EXT-R_{novel}) readily reacquired discriminative responding to S^+ and S^-, whereas ratings declined for the simple extinction condition (EXT-only). Moreover, presentation of an acquisition cue (X) elicited larger discriminative responding than a novel cue (Y) during the first reacquisition trials, indicating that these sounds were perceived differentially. A 2 (Stimulus) × 4 (Trial: e3, e8, e10, and e15) × 3 (Condition) ANOVA produced significant effects of stimulus, $F(1, 69) = 361.96$, $p < .01$, condition, $F(2, 69) = 50.60$, $p < .01$, a Stimulus × Trial interaction, $F(2.38, 164.27) = 45.13$, $p < .01$, a Stimulus × Condition interaction, $F(2, 69) = 77.02$, $p < .01$, a Trial × Condition interaction, $F(4.15, 143.22) = 7.49$, $p < .01$, and, most importantly, a Stimulus × Trial × Condition interaction, $F(4.76, 164.27) = 15.04$, $p < .01$. Follow-up tests (Stimulus × Trial) compared ratings to S^+ and S^- across trials for each condition. These tests confirmed that for both reacquisition conditions differential ratings gradually increased, as indicated by significant interactions, $F_{\text{EXT-R}}(2.09, 47.99) = 22.16$, $p < .01$, $F_{\text{EXT-Rnovel}}(3, 69) = 32.47$, $p < .01$, and linear trends, $F_{\text{EXT-R}}(1, 23) = 42.96$, $p < .01$, $F_{\text{EXT-Rnovel}}(1, 23) = 61.93$, $p < .01$. For Condition EXT-only, ratings declined across trials, as reflected by a main effect of trial, $F(1.54, 35.47) = 9.04$, $p < .01$.

To examine whether reacquisition with an acquisition cue (X) differed from reacquisition with a novel cue (Y), the Stimulus × Trial × Condition was further decomposed by conducting simple 2 (Stimulus) × 3 (Condition) interactions for each trial separately. The analyses revealed that conditions varied for differential ratings at each level of trial, $F_{e3}(2, 69) = 5.19$, $p = .01$, $F_{e8}(2, 69) = 34.39$, $p < .01$, $F_{e10}(2, 69) = 84.40$, $p < .01$, and $F_{e15}(2, 69) = 104.88$, $p < .01$, respectively. Subsequent contrasts showed, not surprisingly, that S^+/S^- differentiation was larger following reacquisition (EXT-R, EXT-R_{novel}) compared to normal extinction (EXT-only) on each of the trials, $t_{e3}(69) = -2.19$, $p = .03$, $t_{e8}(69) = -8.02$, $p < .01$, $t_{e10}(69) = -12.71$, $p < .01$, and $t_{e15}(69) = -14.41$, $p < .01$. However, S^+/S^- discrimination was also larger by using an acquisition cue (X) than a novel cue (Y) for reacquisition on the first three trials, $t_{e3}(69) = -2.36$, $p = .02$, $t_{e8}(69) = -2.11$, $p = .04$, $t_{e10}(69) = -2.68$, $p = .01$, but not on the last trial, $t_{e15}(69) = -1.48$, $p = .14$. Thus, while cue X (EXT-R) produced initially larger discriminative responding than cue Y (EXT-R_{novel}), this difference had disappeared by the final reacquisition trial.

Renewal in context A (EXT-only)

Testing in context A after extinction in context B caused a clear renewal effect for the EXT-only condition. A 2 (Stimulus) × 2 (Trial: e16 vs. t1) ANOVA found main effects of stimulus, $F(1, 23) = 36.65$, $p < .01$, and trial, $F(1, 23) = 52.60$, $p < .01$. Most importantly, the Stimulus × Trial interaction was significant, $F(1, 23) = 22.33$, $p < .01$, showing a stronger increase for S^+ ratings than for S^- ratings across contexts. Pairwise comparisons indicated no differentiation at the end of extinction, $F < 1$, but higher ratings to S^+ than to S^- at test, $F(1, 23) = 30.26$, $p < .01$.

Renewal in context A (EXT-only, EXT-R, and EXT-R_{novel})

A return to context A produced a differential renewal effect, which was not reliable different between conditions. However, a reacquisition procedure weakened the general increase in responding induced by a context switch compared to a traditional extinction procedure, regardless the context cue that was used for reacquisition. A 2 (Stimulus) × 2 (Trial: e16 vs. t1) × 3 (Condition) ANOVA revealed significant main effects of stimulus, $F(1, 69) = 61.70$, $p < .01$, trial, $F(1, 69) = 76.47$, $p < .01$, and condition, $F(2, 69) = 4.49$, $p = .02$. There was also a Stimulus × Trial interaction, $F(1, 69) = 27.13$, $p < .01$, indicating a greater increase in outcome predictions to S^+ than S^- across contexts. Pairwise comparisons showed that the increase was significant for S^+, $F(1, 69) = 63.23$, $p < .01$, but also for S^-, $F(1, 69) = 24.81$, $p < .01$. The Stimulus × Trial × Condition interaction was, however, not significant, $F(2, 69) = 1.42$, $p = .25$, suggesting no group differences regarding the differential renewal effect.

The main analysis further yielded a significant Trial × Condition interaction, $F(2, 69) = 5.90$, $p < .01$, suggesting that conditions differed with regard to the general increase in ratings after a context change. Planned contrasts indicated that this increase was attenuated for the reacquisition conditions combined compared to the simple extinction condition, $t(69) = -3.43$, $p < .01$, while the reacquisition conditions did not differ from each other, $t < 1$. Separate analyses for each trial revealed that overall ratings differed significantly between conditions on the first test trial ($M_{\text{EXT-R}} = 2.60$; $M_{\text{EXT-Rnovel}} = 3.18$; $M_{\text{EXT-only}} = 4.93$), $F(2, 69) = 7.71$, $p < .01$, but not on the last extinction trial ($M_{\text{EXT-R}} = 0.79$; $M_{\text{EXT-Rnovel}} = 1.45$; $M_{\text{EXT-only}} = 1.13$), $F < 1$. Ratings on the first test trial were higher for Condition EXT-only compared to Condition EXT-R, $p < .01$, and Condition EXT-R_{novel}, $p = .02$, while Conditions EXT-R and EXT-R_{novel} did not differ from one another, $p = 1.00$. This suggests that both reacquisition procedures impeded increases in outcome predictions upon a context switch after extinction, regardless whether the context cue was novel or was part of the acquisition context.

The fact that extinction was incomplete for the EXT-R_{novel} condition (see Figure 5.2) may have contributed to the reduction of responding following reacquisition, because of a ceiling effect. Therefore, we performed a post-hoc renewal analysis for participants showing at least 50% of extinction, calculated by the difference in ratings to S^+ on e1 and e16 (e.g., Norrholm et al., 2006). Participants who met this criterion (EXT-R: $n = 22$, EXT-R_{novel}: $n = 18$, and EXT-only: $n = 21$) displayed neither differential responding nor group differences regarding differential responding on the last extinction trial, as confirmed by nonsignificant effects of stimulus, $F(1, 58) = 2.03$, $p = .16$, and the Stimulus × Condition interaction, $F(2, 58) = 1.19$, $p = .31$. The renewal analysis for "extinguishers" revealed similar results as the main analysis: A reacquisition procedure attenuated the general increase in responding from extinction to test, irrespective of the cue used for reacquisition. This was confirmed by the ANOVA, which yielded a Stimulus × Trial interaction, $F(1, 58) = 48.25$, $p < .01$, as well as a Trial × Condition interaction, $F(2, 58) = 8.71$, $p < .01$. Contrasts on the latter interaction indicated a weaker increase in ratings after reacquisition compared to simple extinction, $t(58) = -4.03$, $p < .01$, whereas the increase was similar for reacquisition with a novel cue and an acquisition cue, $t < 1$. No Stimulus × Trial × Condition interaction was found, $F(2, 58) = 1.26$, $p = .29$. Thus, also when conditions showed a similar extent of extinction, the increase of responding was still reduced following reacquisition relative to simple extinction.

Renewal in context AX

As suggested by Figure 5.2, conditions showed similar differential renewal effects upon a return to the original acquisition context AX. Statistical analyses confirmed this impression. A 2 (Stimulus) × 2 (Trial: e16 vs. t4) × 3 (Condition) ANOVA revealed main effects of stimulus, $F(1, 69) = 218.83$, $p < .01$, and trial, $F(1, 69) = 202.05$, $p < .01$. Also, a significant Stimulus × Trial interaction was found, $F(1, 69) = 123.80$, $p < .01$, indicating a stronger increase in predictive ratings for S^+ than for S^-. Importantly, the Stimulus × Trial × Condition interaction was not significant, $F < 1$, suggesting that conditions demonstrated comparable renewal effects. No main effect of condition was observed, $F < 1$.

Renewal for S^+ in context A vs. context AX

Renewed prediction of the outcome to S^+ was contextually controlled following a reacquisition procedure (EXT-R, EXT-R_{novel}), but not following traditional extinction (EXT-only). A 2 (Trial: t1 vs. t4) × 3 (Condition) ANOVA yielded a main effect of trial, $F(1, 69) = 48.19$, $p < .01$, indicating an increment in ratings from context A (t1) to context AX (t4), and a significant Trial × Condition interaction, $F(2, 69) = 5.87$, $p < .01$. Contrasts demonstrated that the increment in ratings was more pronounced after a reacquisition procedure (EXT-R, EXT-R_{novel}) than after normal extinction (EXT-only), $t(69) = 3.26$, $p < .01$, while similar increments were observed following reacquisition with an acquisition cue and a novel cue, $t(69) = 1.07$, $p = .29$. Pairwise comparisons for each condition showed a significant increase in ratings for Conditions EXT-R and EXT-R_{novel}, $F(1, 69) = 37.14$, and 20.98, respectively, ps < .01, but not for Condition EXT-only, $F(1, 69) = 1.82$, $p = .18$. Thus, contextual control over acquisition performance was only evident when participants experienced cued reacquisition trials during extinction.

Discussion

The results of Experiment 2 replicate and extend those of Experiment 1. A return to a subset of contextual cues from acquisition (A), after extinction in another context (B), evoked a clear renewal effect. A reacquisition procedure during extinction reduced again the general increase in ratings upon a switch from context B to context A. This effect was observed even though a more intense outcome was used compared to Experiment 1. Unexpectedly, however, attenuation was independent of the reacquisition context cue's relationship to the acquisition context: A novel context cue was as effective as an acquisition context cue. Furthermore, following both reacquisition procedures, the presence of all contextual cues from acquisition (including cue X) was crucial for evoking full blown renewal. By contrast, after a conventional extinction procedure, no such contextual control was obtained. For this condition, equal levels of renewed responding were observed, regardless whether only a subset or all features from the acquisition context were presented. The implications of these results are discussed below.

General discussion

The present study tested whether renewal could be established in a subset of contextual cues from acquisition and whether this renewal effect could be reduced by interspersing cued reacquisition trials during extinction. For reacquisition, reinforced trials were administered in the presence of a contextual cue either from acquisition or a novel cue. The results can be summarized as follows. First, after normal extinction, clear renewal was observed upon returning to one of the contextual features from acquisition (Experiments 1 and 2). Second, the reacquisition procedure reduced renewal, providing that the reacquisition context cue was not present at test. The reduction was not differential, however, meaning that the increase in predictive ratings to S^+ and S^- was equally attenuated (Experiments 1 and 2). Third, a reacquisition procedure attenuated the increase of responding upon a context change after extinction regardless of whether the contextual feature for reacquisition was novel or was part of the acquisition context (Experiment 2). Fourth, following a reacquisition procedure during extinction, but not following simple extinction, the presence of all contextual cues from acquisition (including cue X) was critical for evoking full-blown renewal. In sum, the results seem to suggest that exposure to cued reacquisition trials during extinction protects extinction performance against the disruptive effects of context changes.

Renewal after simple extinction

Several facts about the renewal effect after simple extinction are worth noting. First, the results show that a negatively valenced picture can produce renewal in contingency judgments when used as an outcome, adding to the range of stimuli employed in human renewal studies, such as loud noises (e.g., Vansteenwegen et al., 2005) and mild electric stimuli (Effting & Kindt, 2007). Second, the context of testing (A or AX) had no influence on the degree of renewal. Hence, acquisition performance could be activated by only a subset of features that made up the acquisition context. Third, the observation of renewal adds to the body of evidence in contingency learning (e.g., Paredes-Olay & Rosas, 1999; Rosas & Callejas-Aguilera, 2006) and suggests that similar mechanisms may underlie human contingency learning and Pavlovian conditioning (De Houwer & Beckers, 2002).

It must be noted that the exact mechanism underlying renewal is unclear here. One plausible explanation is that retrieval of the second information that was learned about the cue (S^+-no outcome), but not first learned information (S^+-outcome), was gated by contextual stimuli (e.g., Bouton, 2004; Nelson, 2002). Accordingly, a context switch after extinction promotes responding appropriate to the first learned association, regardless of the test context. However, other mechanisms may also account for the observed recovery of responding (see Lovibond, Preston, & Mackintosh, 1984). Renewal might be the result of summation between the excitatory value of the acquisition context and the remaining stimulus excitation. The decline of ratings observed with a context change after acquisition may imply the formation of excitatory context-outcome associations during conditioning. On the other hand, the finding that S^+ ratings were more affected than S^- ratings by a return to the acquisition context is less consistent with an explanation of contextual excitation. Another possibility is that renewed responding reflects a release from inhibition. When extinction occurs in a different context than acquisition, the extinction context may become inhibitory, which in turn “protects” the S^+ from extinction (e.g., Lovibond, Davis, & O'Flaherty, 2000; Rescorla, 2001). Increased responding to the S^+ at test could then be explained as responding that was never extinguished. The available data cannot rule out this possibility as no direct evaluation of the associative value of contexts was performed. Alternatively, renewal can also be the effect of the combination of these processes. Although the mechanism underlying renewal was not the focus of the present study, this brief account of possibilities may shed a light on the working of the reacquisition procedure.

Renewal reduction after a reacquisition procedure

To our knowledge, it is the first time that attenuation of recovered responding has been observed by reinforcing the target cue during an extinction phase. Previously, it has been demonstrated in rodents that renewal could be thwarted by intermingling outcome alone trials among extinction trials (Rauhut, Thomas, & Ayres, 2001, Exp 2 and 4; Thomas, Longo, & Ayres, 2005). An important characteristic of these studies is that presentations of stimuli and outcome occurred in a noncontiguous relationship, also known as an explicitly unpaired procedure. By contrast, in the present study, delivery of the outcome was always signalled by the target cue (S^+) and conditional on the presence of a contextual feature. The only study that prevented renewal by a cued reinforcement procedure, reinforced a cue other than the target cue during extinction (Rauhut et al., 2001, Exp 3 and 4).

Note that the difference in the number of extinction trials for the two conditions (16 in EXT-only vs. 12 in EXT-R) could not have contributed to the attenuation effect by the reacquisition procedure. Several studies have shown that the transfer of extinction across contexts improves as the number of extinction trials increases (Denniston, Chang, & Miller, 2003; Rosas & Callejas-Aguilera, 2006; Tamai & Nakajima, 2000; but see Rauhut et al., 2001). Therefore, if anything, the current procedure works against the hypothesis, such that extinction learning in the condition that received more nonreinforced S^+ exposures (i.e., EXT-only) would have been expected to be less disrupted by context changes. The reverse, however, was observed in both experiments.

The observation of reduced ratings at test in context A may suggest that responding became under contextual control (X) by our reacquisition procedure. In this perspective, the finding of intact renewal in the original acquisition context (AX) was important, as it makes at least two alternative explanations less likely. First, the ability of the reacquisition procedure to reduce responding could be the result of enhanced extinction learning. Presenting nonreinforced trials in the presence of reinforced trials may have caused stronger S^+-no outcome associations compared to a simple extinction procedure (e.g., Rauhut et al., 2001). The fact that S^+ was still able to elicit full responding in context AX is in contrast with this explanation. Second, reduced responding at test in context A may reflect enhanced retrieval of extinction learning. A procedure that intermixes reinforced trials and nonreinforced trials may make the extinction phase more similar to the acquisition phase (Bouton, Woods, & Pineño, 2004; Woods & Bouton, 2007). It follows that testing in the context of acquisition retrieves extinction learning more easily, which would then interfere with the expression of acquisition performance. Again, however, such an explanation would also predict reduced responding in context AX, which was not observed.

Instead of affecting extinction learning, the reacquisition procedure may have modified acquisition learning. The fact that responding improved throughout reacquisition training (Experiments 1 and 2) implies additional learning about the S^+-outcome relationship, such as learning about contextual cues. Related to this, the observed decline in generalization of acquisition may indicate that acquisition learning was already contextually controlled to some extent prior to extinction, which perhaps increased the susceptibility to further contextualization. One possibility is that a direct association between context cue X and the outcome was formed during reacquisition. In both experiments, feature X was a good predictor of the outcome in the reacquisition condition (EXT-R). Alternatively, participants may have acquired a hierarchical structure, in which context cue X signals that S^+ will be reinforced. In that case, context cue X would have properties similar to those of positive occasion setters (see Holland, 1992; Swartzentruber, 1995, for reviews). Occasion setting is normally observed in serial feature positive discrimination training with discrete cues (A→X+/ X-). In such discriminations, cue A controls responding to X independently of its own association with the outcome. There is indeed some evidence that contexts can serve as occasion setters (Bouton & Swartzentruber, 1986; Swartzentruber, 1991). Although differing to the locus of their contextual control, both explanations share the view that the presence of cue X is necessary for eliciting conditioned responding. This would support the notion that reacquisition training induced context specificity of acquisition performance. The absence of X at test in context A may then explain the observed reduction in the recovery of responding. Irrespective of the exact mechanism, the results suggest that cue X has retrospectively blocked the ability of cue A to produce renewal.

Reacquisition with a novel contextual cue

The role of backward blocking was further explored in Experiment 2. Theoretical accounts of backward blocking state that two cues should have been trained in compound (and associated) for later retrospective revaluation to occur (e.g., Dickinson & Burke, 1996). For Condition EXT-R_{novel}, in which reacquisition took place in the presence of a novel contextual cue (sound Y), nothing could have been retrospectively inferred about the elemental features of the acquisition context (e.g., coloured screen A) regarding S^+ reinforcement: Y and A had never occurred together and, hence, were never associated. As such, no or at least less reduction of renewal in context A was predicted for Condition EXT-R_{novel} compared to Condition EXT-R.

The finding of equal attenuation of increased responding after reacquisition with a novel cue (EXT-R_{novel}) and an acquisition cue (EXT-R) was, therefore, unexpected and intriguing. One explanation may be that participants in the EXT-R_{novel} condition simply failed to discriminate between the sound from acquisition (X) and the novel sound (Y), which would imply no difference between Conditions EXT-R and EXT-R_{novel}. However, the fact that presenting sound Y (EXT-R_{novel}) produced smaller discriminative responding (S^+/S^-) than sound X (EXT-R) on the first reacquisition trials suggests that these sounds were perceived differentially. Additionally, the finding that extinction was complete in Condition EXT-R but not in Condition EXT-R_{novel} may also point towards a qualitative difference between conducting reacquisition with a novel cue compared to a cue from acquisition. Incomplete extinction for the EXT-R_{novel} condition, however, may have confounded the renewal results, artificially reducing the increase of responding upon a context switch for this condition. Nevertheless, a post-hoc analysis for samples that showed a similar extent of extinction revealed exactly the same pattern of findings.

Hence, the results of a comparable reduction for Conditions EXT-R_{novel} and EXT-R seem not in line with a hypothesis of backward blocking, unless one would assume a process of generalization. In the EXT-R_{novel} condition, a different (Y) but same modality context cue (i.e., sound) predicted reinforcement during reacquisition, which may have generalized to the sound from acquisition (X). Thus, the presence of sounds in general may have become relevant for activation of acquisition performance, which in turn may have blocked the predictive value of screen A for signaling the S^+-outcome relationship. If this is the case, the present test of a backward blocking account is not optimal because the null hypothesis (i.e., no difference between the reacquisition conditions) could not be easily rejected. Nevertheless, in that case, the results are still of interest, indicating that recovered responding can also be weakened by using a contextual feature that is perceptually similar to a feature from acquisition.

Nondifferential reduction

Contrary to expectation, the reduction by the reacquisition procedure was not specific to the S^+. That is, participants showed an equally strong reduction for S^+ ratings as for S^- ratings. Before interpreting this result, one could ask why predictive ratings to the S^- increased in the first place for the simple extinction condition. As this stimulus was never paired with the outcome, the increase cannot be understood as a restoration of the learned relationship between S^- and the outcome. The disruptive effect of context changes on control stimuli is, however, a familiar phenomenon in human differential (CS^+/CS^-) conditioning studies (Effting & Kindt, 2007; Neumann, 2006). As argued by Neumann (2006), this increase may reflect the effects of learning about the CS^+. When the CS^+ is no longer followed by the US after switching the context (i.e., either on the first extinction trial or the first test trial), participants become uncertain about the CS^- with respect to nonreinforcement, which augments responding. The finding of reduced S^- ratings after reacquisition in the present study may, therefore, be interpreted in terms of increased certainty that the S^- was not going to be followed by the outcome. Thus, while presenting cued reacquisition trials might protect the extinguished S^+ for the disrupting effects of context changes, the same may be true for the S^-.

In summary, interspersing cued reacquisition trials during extinction trials attenuated general recovered responding induced by a context change after extinction. Attenuation of responding appeared to be independent of whether reacquisition occurred with a contextual cue from acquisition or a novel but perceptual similar cue. Hence, the present results lead to the perhaps counterintuitive conclusion that further (cued) reinforcement of the target cue during extinction can enhance the generalization of extinction effects over contexts.