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### **Paper:**

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Running head: PARTIAL REINFORCEMENT

Partial reinforcement of avoidance and resistance to extinction in humans

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## Abstract

In anxiety, maladaptive avoidance behavior provides for near-perfect controllability of potential threat. There has been little laboratory-based treatment research conducted on controllability as a contributing factor in the transition from adaptive to maladaptive avoidance. Here, we investigated for the first time whether partial reinforcement rate, or the reliability of avoidance at controlling or preventing contact with an aversive event, influences subsequent extinction of avoidance in humans. Five groups of participants were exposed to different partial reinforcement rates where avoidance cancelled upcoming shock on 100%, 75%, 50%, 25% or 0% of trials. During extinction, all shocks were withheld. Avoidance behavior, online shock expectancy ratings and skin conductance responses (SCRs) were measured throughout. We found that avoidance was a function of relative controllability: higher reinforcement rate groups engaged in significantly more extinction-resistant avoidance than lower reinforcement groups, and shock expectancy was inversely related with reinforcement rate during avoidance acquisition. Partial reinforcement effects were not evident in SCRs. Overall, the current study highlights the clinical relevance of laboratory-based treatment research on partial reinforcement or controllability effects on extinction of avoidance.

*Key words:* avoidance; partial reinforcement; extinction; controllability; anxiety.

Anxiety disorders are highly prevalent (Kessler, Berglund, Demler, Merikangas & Walters, 2005), with an estimated global lifetime prevalence rate of 7.3% (Baxter et al., 2013) and annual costs exceeding €74 billion in Europe alone (Gustavsson et al., 2011). Anxiety disorders are characterized by excessive avoidance of real and perceived threat (American Psychiatric Association, 2013). In experimental psychopathology research, the Pavlovian fear conditioning paradigm is widely adopted to study the acquisition and unlearning of avoidance (Vervliet & Raes, 2013; LeDoux, 2014). During fear conditioning, an aversive unconditioned stimulus (US) (e.g., an electric shock) is paired with a neutral conditioned stimulus (CS+), while another stimulus (CS-) is paired with the absence of the US. Presentations of the CS+, but not the CS-, come to induce conditioned fear responses (CRs) akin to clinical anxiety symptoms such as increased physiological arousal. Avoidance learning can then be studied in several ways in the laboratory (LeDoux, Moscarello, Sears, & Campese, 2016). For instance, in signaled active avoidance procedures, a response such as bar pressing, performed in the presence of the CS+ minimizes or prevents contact with the aversive US (Higgins & Morris, 1984; LeDoux et al., 2016; Lovibond, Saunders, Weidemann, & Mitchell, 2008). Once learned, avoidance may be subject to extinction by withholding all US presentations. As avoidance is now unnecessary (since all shock is withheld), responding eventually extinguishes (Baum, 1970; Kryptos, Effting, Kindt, & Beckers, 2015; Lovibond, 2006; Riccio & Silvestri, 1973), although the persistence of avoidance in extinction has been reported (e.g., Malloy & Levis, 1988; Solomon, Kamin, & Wynne, 1953; Williams & Levis, 1991).

The therapeutic implications of experimental psychopathology research on avoidance arise when avoidance becomes the excessive and default way of coping with potential threat. Charting this transition from adaptive to maladaptive avoidance, and identifying potential factors which may contribute to the persistence of avoidance, are important issues in

laboratory-based treatment research. Indeed, the shift to maladaptive avoidance so often seen in the anxiety disorders means that clients fail to learn that threat cues may not predict impending danger; their avoidance behavior may thus become resistant to extinction (LeDoux et al., 2016; Lovibond, Mitchell, Minard, Brady, & Menzies, 2009; Volders, Meulders, de Peuter, Vervliet, & Vlaeyen, 2012). Extinction of maladaptive avoidance is one of the treatment goals in exposure therapy for anxiety (Barlow, Raffa, & Cohen, 2002; Scheveneels, Boddez, Vervliet, & Hermans, 2016; Vervliet, Craske, & Hermans, 2013), yet, to date, there has been minimal research conducted with humans on extinction of avoidance (Dunsmoor, Niv, Daw, & Phelps, 2015; LeDoux et al., 2016; Riccio & Silvestri, 1973). Little is known, then, about factors responsible for the resistance to extinction of maladaptive avoidance.

Here, we investigated extinction of avoidance and the role played by controllability in avoidance (i.e., reinforcement rate) on subsequent resistance to extinction. The study of reinforcement rate or partial reinforcement effects is common across appetitive and non-appetitive learning, yet each domain makes contrasting predictions about the effects on responding during the (unsigned) shift to extinction. In the domain of appetitive conditioning, a partially reinforced response is known to extinguish less rapidly than a continuously reinforced response when the source of reinforcement is discontinued in extinction (Catania, 2013); an outcome referred to as the partial reinforcement extinction effect (Nevin, 1988). Appetitive approaches to behavior change therefore incorporate partial reinforcement to facilitate subsequent resistance to extinction (e.g., Higbee, Carr, & Patel, 2000; Kazdin & Polster, 1973; Lerman & Iwata, 1996). In non-appetitive domains, such as avoidance learning, partial reinforcement involves manipulating the effectiveness of the operant response at preventing the US (Davenport, Olson, & Olson, 1971). Generally, when avoidance has been partially reinforced, responding during extinction (when shock is

withheld) is less resistant to extinction than avoidance acquired under conditions of continuous reinforcement (Galvani, 1971; Olson, Davenport, & Kamichoff, 1971). Thus, contrasting effects of partial reinforcement in extinction are predicted by each domain: in appetitive conditioning, partially reinforced appetitive behavior will be *more* resistant to extinction, while in non-appetitive learning, partially reinforced avoidance behavior will be *less* resistant to extinction than continuously reinforced avoidance behavior.

Until now, the effects of partial reinforcement on the acquisition and extinction of avoidance has largely been the focus of research with nonhumans (e.g., Davenport et al., 1971; Galvani, 1971, 1973; Marsh & Paulson, 1968; Olson, 1971; Olson et al., 1971; Solomon et al., 1953). Marsh and Paulson (1968), for instance, exposed groups of goldfish to either continuous or partial reinforcement of avoidance before extinction in which shock was omitted on all trials and where CS termination occurred following avoidance. Unpredictably, it was found that partial reinforcement increased resistance to extinction. However, response rates were highest for the continuous reinforcement group throughout the study, suggesting some resistance to extinction in that group, and it is likely that methodological factors such as delayed CS termination and the number of escape responses made in the presence of shock (on non-avoided trials) may have contributed to this outcome. Subsequent nonhuman research on partial reinforcement effects in avoidance sought to develop the “proper procedure” (Davenport et al., 1971, p.9) for studying extinction of avoidance. Such a procedure should, it was claimed, involve “making a response ineffective in producing the reinforcing consequence that was provided during acquisition” (Olson et al., 1971, p.12). Davenport et al. (1971) compared groups of rats exposed to partial reinforcement (0%, 25%, 50%, 75%, or 100%) on this revised extinction of avoidance procedure in which responding was no longer effective at preventing shock. Davenport et al. found that acquisition of avoidance was a function of reinforcement rate with a lower rate leading to slower acquisition

(see also, Galvani, 1971) but found no evidence of a differential effect on avoidance responding in extinction. Finally, Olson et al. (1971) compared groups of rats given 0%, 50% and 100% reinforcement and replicated the finding that responding during acquisition was a direct function of rate of reinforcement but did find that groups differed during extinction, with reduced resistance to extinction in the 100% group as compared to the 50% or 0% groups.

Recently, in an analog study of coping with chronic pain conducted with healthy human participants, Meulders, Franssen, Fonteyne and Vlaeyen (2016) manipulated the probability of receiving painful electric shock and the effort involved in avoidance of shock. For the experimental group, the fastest and easiest response trajectory (moving a 3 degrees-of-freedom robotic arm) always resulted in shock, while shock could be avoided on 50% or 100% of occasions with either moderate or extreme effort, respectively. Participants in a yoked group received the same reinforcement schedule (shocks) regardless of their behavior. Following acquisition, an extinction test phase was conducted where no shocks were delivered (i.e., CS extinction). The experimental group demonstrated acquisition of avoidance behavior by deviating more from the easiest/quickest response trajectory than the yoked group. Moreover, Meulders et al. found that the experimental group showed resistance to extinction by continuing to avoid more than the yoked group during extinction, despite the response effort involved (see also, Rattel, Miedl, Blechert, and Wilhelm, 2017; van Meurs, Wiggert, Wicker, and Lissek, 2014).

Research on partial reinforcement of avoidance in humans and nonhumans has thus far employed only intensely aversive (e.g., Olson et al., 1971) or painful shocks (Meulders et al., 2016). To date, however, little is known about the role of partial reinforcement on the acquisition and extinction of avoidance in humans, using, by definition, mildly aversive shocks, where only one of the methodological factors described above (i.e., avoidance

extinction procedures where the US is withheld) has been examined. Here, we sought to investigate in humans whether partial reinforcement of avoidance influences resistance to CS extinction.

In clinical settings, one of the goals is to highlight that not every CS+ is followed by a US and that indiscriminate avoidance may be unnecessary. The effects of partial reinforcement of CS-US pairings on conditioned fear and extinction have been well studied (e.g., Allen, Myers, & Servatius, 2014; Grady, Bowen, Hyde, Totsch, & Knight, 2015), but less is known about the effects of partial reinforcement of avoidance in cases where excessive avoidance has become the default way of coping and which may thus be more difficult to treat. Indeed, the clinical relevance of partial reinforcement effects on avoidance extinction centers around the observation that there is never a sense of perfect controllability in clinical anxiety disorders, quite the contrary (Amat, Baratta, Paul, Bland, Watkins, & Maier, 2005; de Berker et al., 2016; Hartley, Gorun, Reddan, Ramirez, & Phelps, 2014; Maier & Watkins, 1998). For instance, in social anxiety disorder, a socially anxious individual will possess various behavioral strategies to avoid threatening events within a social context, yet none will have 100% certainty (e.g., not looking people in the eye does not always avoid being talked to). Similarly, in panic disorder, avoiding supermarkets may decrease the probability of experiencing a panic attack, but the individual may always experience a panic attack nonetheless. Finally, an example of the clinical relevance of controllability in post-traumatic stress disorder is that avoiding certain situations may decrease the probability of memory intrusions and reliving the traumatic event, without erasing the probability altogether.

Partial reinforcement of avoidance and resistance to extinction may thus be involved in the etiology and maintenance of anxiety disorders. According to this view, the initial effectiveness of avoidance at preventing contact with aversive events may subsequently determine the persistence of maladaptive avoidance when aversive events are withheld. The

resistance to extinction of avoidance may then, at least in part, be a function of prior controllability. In this way, experimental procedures that investigate avoidance learning under conditions of perfect controllability may miss clinically relevant processes (LeDoux et al., 2016). One strategy to examine avoidance under conditions of relative uncontrollability is by systematically varying the reinforcement rate during avoidance conditioning as potential contributing factor in the transition from adaptive to maladaptive avoidance. The question then is whether partial reinforcement will produce avoidance patterns that resemble clinical avoidance patterns; that is, excessive and/or extinction-resistant avoidance.

The present study tested groups of participants exposed to different partial reinforcement rates during avoidance (100%, 75%, 50%, 25% or 0%) before extinction where avoidance could still occur but all shock was withheld. First, during fear conditioning, all participants were presented with a CS+ that was always paired with shock and a CS- which was never paired with shock. Next, during avoidance, different groups of participants were told they would have the opportunity to cancel upcoming shock by pressing the spacebar in the presence of an avoidance cue. Shock never followed CS- presentations, regardless of avoidance. Importantly, reinforcement rates varied across groups; of all the CS+ trials, avoidance was scheduled to be effective at cancelling scheduled shock across 100%, 75%, 50%, 25% or 0% of trials, depending on group. During CS extinction, regardless of group, the avoidance cue was present throughout, avoidance responses could be made, and all shocks were withheld regardless of behavior. Outcome measures included skin conductance responses (SCRs), avoidance responses and trial by trial shock expectancy ratings.

Based on previous findings (Davenport et al., 1971; Galvani, 1971; Olson et al., 1971), we predicted acquisition of avoidance on CS+ trials to be a function of reinforcement rate; that is, a higher, more reliable (effective) avoidance response will result in higher response rates across phases than partially reinforced avoidance. We further expected

differences in avoidance to be most evident between the 0% and 100% groups, with response rates predicted to be higher in the 100% group across acquisition and CS extinction phases. Overall then, we hypothesized that when shock is withheld, and thus avoidance is unnecessary, partially reinforced avoidance will be less resistant to extinction than continuously reinforced avoidance.

## Methods

### Participants

Participants were recruited from Swansea University. A sample size calculation (Erdfelder, Faul, & Buchner, 1996) with power ( $1 - \beta$ ) set at 0.95,  $\alpha = 05$ , two-tailed, and effect size of 0.4, recommended a minimum sample of 162 (32 participants per group). A total of 185 participants (131 females, aged 18-40 years ( $M = 21.67$ ,  $SD = 5.72$ )) took part. Exclusion criteria consisted of: (I) age range outside of 18-40 years old, (II) history of any physical condition possibly affected by the electrocutaneous stimulus (e.g. epilepsy, heart-related conditions and severe migraines) (III) current use of psychoactive medication. Two participants were excluded as they fell outside the age range and fifteen participants were excluded (8 technical problems, 4 failed to comply with the instructions and 3 withdrawals), resulting in a total of 168 participants eligible for analysis. Participants were assigned to one of the five groups: the *100% reinforcement rate* group ( $N = 37$ , 23 women), *75% reinforcement rate* group ( $N = 35$ , 21 women), *50% reinforcement rate* group ( $N = 32$ , 22 women), *25% reinforcement rate* group ( $N = 32$ , 22 women) and the *0% reinforcement rate* group ( $N = 32$ , 18 women) with equivalent mean age ( $F < 1$ ). Written consent was obtained at the outset and participants were compensated with either course credits or a £10 voucher at the end of the study. This study was approved by the Department of Psychology Ethics Committee, Swansea University.

### Apparatus and Stimuli

Stimuli consisted of two CSs (CS+ and CS-) and an avoidance cue. The CSs were grey squares and grey triangles presented against a white background in the middle of the screen. The grey triangle had a width and height of 2.5 cm, while the grey square had a width and height of 2 cm. Both shapes were counterbalanced as either CS+ or CS-. The avoidance cue consisted of a line of text, “The spacebar is now available”, shown at the top of the screen during all CS presentations (Figure 1). Stimuli were presented on a 17" computer screen with a 60 Hz refresh rate and the task was programmed in *OpenSesame* (Mathôt, Schreij & Theeuwes, 2012).

\*\*\*Insert Figure 1 About Here\*\*\*

The US was a 250 ms electric shock; intensity of the current was individually adjusted. The US was generated using a STM200 stimulator (BIOPAC Systems, Santa Barbara, USA) and administered through a surface electrode (MLADDF30 bar electrode with two 9 mm contacts spaced 30 mm apart). Electrode gel was applied to the right forearm and the electrode held in place with a Velcro band.

SCR was measured through two Ag/AgCl electrodes coated with non-hydrating gel attached to the middle phalanges on the index and middle fingers and interfaced with the MP150 (BIOPAC Systems, Santa Barbara, USA). The SCR signal was sampled at 1000Hz with a notch filter of 10Hz. The computer, monitor and all additional hardware received power through a medical grade isolation transformer in compliance with safety standards.

### **Procedure**

On arrival at the lab, participants first filled in a consent form and then had electrodes for SCR recording and shock administration applied. Participants then completed a shock-calibration procedure where the current was initially set at 35 mV and increased or decreased in steps of 2.5 mV depending on participants' ratings. The maximum shock level was 100 mV. Participants were told to state the intensity of the shock in terms of how uncomfortable

they found it. When a shock level was deemed ‘uncomfortable but not painful’ twice consecutively, it was used for that participant.

Following the shock calibration, participants were given explicit instructions on screen regarding the shock contingencies (see Supplementary Materials). They were also informed that on some trials they would have the opportunity to press the spacebar and cancel the impending shock when the message ‘The spacebar is now available’ appeared. This message served as the avoidance cue. Additionally, to aid concentration, the room lights were dimmed and participants listened to white noise via headphones.

The experiment consisted of three phases: *fear conditioning*, *avoidance* and *CS extinction*. For all trials in all phases, a fixation cross was presented for 7-11 s followed by the CS presentation (10 s). After the first 3 s, a rating scale about the expectancy of an impending electric shock at the end of the current trial appeared underneath the CS. The ratings scale consisted of a Likert scale ranging from 0 (“*I certainly expect no shock*”) to 10 (“*I certainly expect a shock*”). Participants responded by pressing the left mouse button to select the chosen number. The expectancy scale was removed following a rating or on CS termination (see Figure 1). The intertrial interval (ITI) was 6 s.

During the *fear conditioning* phase, each CS was presented twice in a quasi-random order (i.e., 2 CS+ trials and 2 CS- trials). All CS+ trials were coupled with the US, which occurred at stimulus offset.

The *avoidance* phase consisted of 12 CS+ trials and 12 CS- trials. During this phase, the avoidance cue appeared 1 s after CS presentation and lasted for 2 s regardless of whether or not the avoidance response (pressing the spacebar) was performed. While the avoidance cue appeared on all trials, the avoidance response was only effective in cancelling shock during the CS+ (CS- trials were never followed by shock US). The reinforcement rate or reliability of the avoidance response at cancelling shock varied across groups; the effective

and ineffective trials were determined randomly for each participant. In the 100% group, participants could cancel shock after every CS+ trial if they made the avoidance response during each trial. For the other groups, avoidance was partially effective at cancelling upcoming shock (i.e., there were 9/12 avoidable trials in the 75% group, 6/12 avoidable trials in the 50% group, 3/12 avoidable trials in the 25% group, and zero avoidable trials in the 0% group). The absence of avoidance on CS+ trials was always followed by shock, regardless of group.

During the *CS extinction* phase, which happened without interruption and was identical for all groups, no shocks were delivered. This phase consisted of 48 trials in total, 24 of CS+ and CS-, respectively.

After the final trial, the experimenter reentered the room, SCR and shock electrodes were removed, and participants were debriefed and compensated. The session lasted approximately 45 minutes.

### **Data analysis**

Skin conductance data was processed using *AcqKnowledge* software (BIOPAC Systems, Santa Barbara, USA) and SCRs were calculated as the first peak to occur within 0.5 to 5 s after CS onset. Prior to data analysis, SCRs were range-corrected per participant and square root transformed across all phases. Fourteen participants were excluded from SCR analyses as they were identified as ‘non-responders’ (>90% zero responses over the experiment). Statistical analyses for SCRs were conducted on the remaining 154 participants; 30 in the 0% group, 26 in the 25% group, 30 in the 50% group, 34 in the 75% group and 34 in the 100% group. Mean ratings of shock expectancy following the CS+ and CS- were calculated for each phase. Mixed ANOVA were conducted where shock expectancy had been made on every trial. Shock expectancy was also analyzed as two different variables (Avoided and Not Avoided) depending on the presence or absence of the avoidance response

during avoidance and CS extinction phases, respectively. Mean proportion of avoidance was determined by scoring avoidance responses as 1 (with 0 for non-responses) and averaging per trial, CS and group. Means of the total number of avoidance responses were also calculated per group and per CS for correlational tests. Shock expectancy ratings, SCR and avoidance responses were analyzed per phase. To reduce noise, shock expectancy ratings, avoidance response proportion scores and SCRs were binned per two trials. Greenhouse-Geisser corrections were applied where sphericity was not met. Due to the violation of normality by the questionnaire data and frequent occurrence of tied data, correlations between questionnaire scores and mean number of avoidance responses were examined using Kendall's Tau-B correlation as opposed to Spearman's Rho (Bonett, 2008; Chen & Popovich, 2002). Bonferroni correction was applied to all post hoc tests.

## Results

### *Fear conditioning*

All participants underwent Pavlovian fear conditioning. As expected, a 5 x 2 mixed ANOVA revealed that both shock expectancy ratings ( $F_{CS(1,157)} = 525.34, p < .001, \eta_p^2 = .77$ ; Figure 2A) and SCR ( $F_{CS(1,146)} = 42.25, p < .001, \eta_p^2 = .45$ ; Figure 2B) were higher for CS+ than CS-. Because CS+ and CS- contingencies were explicitly instructed, we did not check for contingency awareness.

\*\*\*Insert Figure 2 About Here\*\*\*

### *Avoidance*

During the avoidance phase, avoidance was possible across all trials and the extent to which it was effective varied across groups. To determine whether avoidance varied across the different reinforcement groups, the proportion of avoidance responses were compared per group, CSs and over time. A 5 (Group) x 2 (CS) x 6 (Trial bin) mixed ANOVA revealed a significant three-way interaction ( $F_{Group \times CS \times Trial\ bin(13.90, 566.2)} = 1.91, p = .02, \eta_p^2 = .05$ ). To

further investigate avoidance behavior per CS, avoidance responses during CS+ and CS- trials were analyzed separately.

For CS+ trials, a 5 (Group) x 6 (Trial bin) mixed ANOVA revealed a significant interaction ( $F_{\text{Group} \times \text{Trial bin}} (13.08, 532.84) = 3.00, p < .001, \eta_p^2 = .07$ ), indicating differential avoidance responding on CS+ trials between the various groups and over the course of acquisition. Planned contrasts confirmed that avoidance on CS+ trials differed only between the 100% and 0% groups ( $p < .001$ ) and 25% ( $p = .04$ ), respectively. Avoidance did not differ between the 100% group and either the 50% or 75% reinforcement groups ( $p$ 's  $> .05$ ). Furthermore, trend analyses of avoidance responding per group revealed a significant linear ( $p < .001$ ) and quadratic ( $p < .01$ ) decrease as a function of reinforcement rate (Figure 3A). Pairwise comparisons (with Bonferroni-corrected  $\alpha = 0.008$ ) revealed differences in avoidance on CS+ trials between the 0% group and the 25%, 50% and 75% groups ( $p$ 's  $< .002$ ), respectively. Perhaps surprisingly, avoidance responses for the 25%, 50% and 75% groups did not differ ( $p$ 's  $> .008$ ).

For CS- trials, there was a significant main effect of Trial ( $F_{(3.23, 527.21)} = 3.63, p = 0.01, \eta_p^2 = .02$ ), but not of Group and there was no significant interaction ( $F$ 's  $\leq 1.48, p$ 's  $> .05$ ). This indicates a general decrease in avoidance responding during safety cue presentations over the course of avoidance acquisition.

\*\*\*Insert Figure 3 About Here\*\*\*

A 5 x 2 x 6 mixed ANOVA for shock expectancy ratings largely followed the same trend as the proportion of avoidance with ratings differing by groups, CSs and time ( $F_{\text{Group} \times \text{CS} \times \text{Trial bin}} (13.78, 561.32) = 7.21, p < .001, \eta_p^2 = .15$ ). To investigate shock expectancy ratings per CS, avoidance responses during CS+ and CS- trials were analyzed separately. For CS+ trials, a 5 (Group) x 6 (Trial bin) ANOVA revealed a significant interaction ( $F_{\text{Group} \times \text{Trial bin}} (14.06, 572.78) = 6.77, p < .001, \eta_p^2 = .14$ ), indicating that participants' shock expectancy ratings diverged

over time as a function of reinforcement rate (Figure 4). Planned contrasts revealed ratings of CS+ trials differed between the 100% group and the 0%, 25% and 50% groups ( $p$ 's < .001), respectively, but not between the 100% and 75% groups ( $p$  > .05). Furthermore, trend analyses revealed a significant linear increase ( $p$  < .001) from the 100% to the 0% reinforcement group; that is, as predicted, expectancy ratings increased as reinforcement rate decreased. Pairwise comparisons (with Bonferroni-corrected  $\alpha$  = 0.008) revealed that the 0% group, and 50% and 75% groups, all differed ( $p$ 's < .01), as did the 25% and 75% groups ( $p$  < .001), and the 50% and 75% group ( $p$  < .001), respectively.

For CS- trials, there was a significant main effect of Trial ( $F_{(4.10, 668.30)} = 6.29$ ,  $p = 0.001$ ,  $\eta_p^2 = .04$ ), but not of Group and no significant interaction ( $F$ 's  $\leq 1.16$ ,  $p$ 's > .05). This indicates that, like avoidance, a general decrease in shock expectancy ratings occurred over time for all groups (Figure 4).

\*\*\*Insert Figure 4 About Here\*\*\*

To investigate whether shock expectancy ratings reflected perceived effectiveness of the avoidance response, mean shock expectancy ratings of trials with a successful avoidance response (*Avoided*) and no avoidance response (*Not Avoided*) were compared. Due to unequal data sample size, one-way ANOVAs with weighted means were used (Table 1). Shock expectancy ratings for both *Avoided* and *Not Avoided* trials were significantly different for CS+ ( $F$ 's  $\geq 5.65$ ,  $p$ 's < .001,  $\eta^2 \geq .21$ ) and both trial types displayed a linear increase in ratings from 100% to 0% reinforcement rate (see Supplementary Materials).

Shock expectancy ratings for both *Avoided* and *Not Avoided* trials were similar for CS- ( $F$ 's < 1,  $p$ 's > .05) (Table 1). Post hoc tests showed that, for CS+ *Avoided* trials, the 0%, 25% and 50% groups did not have differential shock expectancy ( $p$ 's > .05), but each group did differ from the 75% and 100% reinforcement group ( $p$ 's < .001), respectively. On *Not*

Avoided trials, shock expectancy ratings were similar for all groups except between the 100% and 0% reinforcement groups ( $p < .001$ ).

\*\*\*Insert Table 1 About Here\*\*\*

SCR differed between groups and CSs ( $F_{\text{Group} \times \text{CS}}(4, 149) = 2.87, p = .03, \eta_p^2 = .07$ ) but not over time ( $F_{\text{Group} \times \text{CS} \times \text{Trial bin}}(4, 704.9) = 1.51, p > .05$ ). A significant main effect of Trial ( $F_{(4, 65, 692.6)} = 16.26, p > .001, \eta_p^2 = .10$ ) indicates there was a general decrease in SCR over time. Pairwise comparisons revealed only a significant difference between the 0% group and the 25% group for the CS+ ( $p = .04$ ); however, this did not survive correction ( $\alpha = 0.005$ ). There were no further differences between groups for CS+ and CS- ( $p$ 's  $> .05$ ) indicating that partial reinforcement effects were not visible in SCRs during avoidance.

#### *CS extinction*

Following avoidance, participants were exposed to CS extinction trials without interruption. A 5 (Group)  $\times$  2 (CS)  $\times$  12 (Trial bin) mixed ANOVA showed that the proportion of avoidance decreased over time ( $F_{\text{Trial bin}}(4.98, 806.5) = 9.62, p < .001, \eta_p^2 = .06$ ). There were significant group differences between CSs ( $F_{\text{Group} \times \text{CS}}(4, 163) = 8.43, p < .001, \eta_p^2 = .17$ ), but these differences were not evident over time ( $F_{\text{Group} \times \text{CS} \times \text{Trial bin}}(26.02, 1060) = .71, p > .05$ ) indicating a general effect of reinforcement rates on avoidance in extinction. The proportion of avoidance responses for CS+ trials during extinction followed a similar trend as seen during avoidance (Figure 3B). Follow up ANOVAs showed group differences for CS+ trials ( $F_{(4, 163)} = 7.35, p < .001, \eta_p^2 = .15$ ) with a similar linear ( $p < .001$ ) and quadratic ( $p < .01$ ) decrease (Figure 3B), but not for CS- trials ( $F_{(4, 163)} < 1, p > .05$ ). Post hoc comparisons (with Bonferroni-corrected  $\alpha = 0.005$ ) revealed significant differences in avoidance responding for CS+ trials between the 0% reinforcement group and the 50%, 75% and 100% groups ( $p$ 's  $< .001$ ), respectively, but not between the 0% group and the 25% group ( $p > .005$ ). Avoidance responses for the 25%, 50%, 75% and 100% groups did not differ ( $p$ 's  $> .005$ ).

This indicates that during CS extinction avoidance responding was consistent and sustained for reinforcement groups of 50% and higher.

Cumulative proportion of avoidance for each group clearly illustrates the similar response patterns between the 50%, 75% and 100% groups (Figure 5). Importantly, each group's cumulative avoidance response pattern differed over time and between CSs ( $F_{\text{Group} \times \text{CS} \times \text{Trial bin}} (4.17, 169.93) = 8.00, p < .001, \eta_p^2 = .16$ ), further indicating differential avoidance responding based on reinforcement rate.

\*\*\*Insert Figure 5 About Here\*\*\*

A 5 x 2 x 12 mixed ANOVA for shock expectancy ratings during extinction revealed a significant interaction between groups, CSs and trial ( $F_{\text{Group} \times \text{CS} \times \text{Trial bin}} (18.11, 733.5) = 7.51, p < .001, \eta_p^2 = .16$ ) indicating that shock expectancy decreased over trials but at different trajectories in the groups and by CSs. Further 5 (Group) x 12 (Trial bin) mixed ANOVAs showed significantly different expectancy ratings between groups during extinction ( $F_{\text{Group} \times \text{Trial bin}} (17.55, 710.71) = 10.19, p < .001, \eta_p^2 = .20$ ) on CS+ trials, but not on CS- trials ( $F_{\text{Group} \times \text{Trial bin}} (21.99, 890.74) = 1.05, p > .05$ ) (Figure 4). Follow up 2 x 12 ANOVAs for CS+ trials showed that expectancy ratings differed between the 0% and 75% and 100% reinforcement groups ( $F$ 's  $\geq 21.19, p$ 's  $\leq .001, \eta_p^2$ 's  $\geq .25$ ), respectively, and approached trend level significance between the 0% and 50% reinforcement groups ( $F_{\text{Group} \times \text{CS} \times \text{Trial bin}} (4.06, 247.63) = 3.62, p = .007$ ). The 25% reinforcement group differed from the 75% and 100% groups ( $F$ 's  $\geq 8.43, p$ 's  $\leq .001, \eta_p^2$ 's  $\geq .12$ ), respectively, as did the 50% reinforcement group and the 75% and 100% groups ( $F$ 's  $\geq 8.83, p$ 's  $\leq .001, \eta_p^2$ 's  $\geq .12$ ), respectively. Together, these results show decreasing shock expectancy as a function of reinforcement rate (Figure 4); the decrease in shock expectancy ratings was most pronounced in lower reinforcement groups, indicating fear extinction learning, whereas the higher reinforcement groups' expectancy of shock remained low during extinction.

To further investigate whether this decline in expectancy was a result of differential rate of fear extinction learning, we compared ratings made on Avoided and Not Avoided trials. One-way ANOVA revealed that the groups differed on CS+ trials with avoidance ( $F_{(4,142)}=4.47, p=.002, \eta^2=0.11$ ), with a significant linear trend ( $p<.01$ ). Thus, shock expectancy ratings decreased linearly from 0% to 100% reinforcement rate. Post hoc tests confirmed that only the 100% group and the 25% and 50% groups differed ( $p$ 's  $\leq .002$ ). Importantly, groups did not differ on non-avoidance trials ( $F_{(4,142)}=2.40, p>.05$ ). Shock expectancy ratings did not differ on CS- trials ( $F$ 's  $<1, p$ 's  $>.05$ ).

Finally, SCR differed between groups and CSs ( $F_{\text{Group} \times \text{CS}}(4, 149) = 4.39, p=.002, \eta_p^2 = .11$ ), but not over the time course of extinction ( $F_{\text{Group} \times \text{CS} \times \text{Trial bin}}(40.05, 1491) = 1.09, p>.05$ ). A main effect of Trial ( $F_{(9.62, 1432)} = 1.94, p=.04, \eta_p^2 = .01$ ) indicates there was a general decrease in SCRs over time. Follow up tests revealed no differences between groups for both CS+ and CS- ( $p$ 's  $>.05$ ), suggesting no discernible reinforcement rate effects in SCRs during CS extinction.

#### *Individual differences in avoidance*

As individual differences in anxiety vulnerability include female sex (Sheynin et al., 2014), we examined whether sex differences influenced avoidance behavior. Independent samples  $t$ -tests (Bonferroni corrected  $\alpha = .025$ ) showed that, for the 0% reinforcement rate group only, females made significantly more avoidance responses in the presence of CS+ during both avoidance (males:  $M=0.35, SD=0.38$ ; females:  $M=0.66, SD=0.32$ ;  $t(30)= 2.51, p = .018, d=0.88$ ) and CS extinction phases (males:  $M=0.17, SD=0.33$ ; females:  $M=0.56, SD=0.44$ ;  $t(30)= 2.81, p = .009, d=1.00$ ). No other individual differences were found for any of the remaining groups (see Supplementary Materials).

## Discussion

The present study investigated the effects of partial reinforcement of avoidance on the resistance to extinction of avoidance in humans during test trials where the aversive event no longer occurred. Like previous research with nonhumans (Galvani, 1971; Olson et al., 1971), we found avoidance rates for the danger cue (CS+) to be a function of reinforcement rate: avoidance responses were most prevalent and sustained in the higher reinforcement rate groups. During avoidance, a gradient-like profile in avoidance responding was evident. We found pronounced differences in the proportion of trials with avoidance between the 100% and 0% groups, while the 100%, 75% and 50% groups did not differ. Shock expectancy ratings largely corroborated this behavioral gradient as participants' expectancies diverged similarly over time as a function of reinforcement rate (Figure 4). Avoidance during CS extinction remained relatively constant across groups as higher reinforcement groups continued to make more avoidance responses to the danger cue than lower reinforcement groups. Shock expectancy ratings, however, drastically changed during CS extinction for lower reinforcement groups: the 0%, 25% and 50% groups all exhibited a sharp decline in expectancy, while the 75% and 100% groups' ratings exhibited a more moderate decline (Figure 4 and Table 1). Taken together, the present study constitutes evidence for avoidance responses and shock expectancy ratings related to reinforcement rate during CS extinction in humans.

There are several noteworthy findings to discuss. First, the decline in expectancy ratings in the 0% and 25% reinforcement groups was likely the result of these participants having a greater chance of noticing the context shift during CS extinction (i.e., when no shocks following the danger cue regardless of behavior). Since avoidance responses remained low during both phases, it is possible that the change in expectancy ratings reflected a shift from realizing the ineffectiveness of making an avoidance response to realizing that shocks

would no longer occur. Second, the decline in expectancy ratings in the 50% reinforcement group similarly suggested awareness of the transition to the CS extinction phase; however, unlike the 0% and 25% reinforcement groups, avoidance responses in the 50% group remained high and indistinguishable from both the 75% and 100% reinforcement group (Figure 3B). Persistent avoidance responding, while unnecessary, may indicate a “better safe than sorry” (Lommen, Engelhard, & van den Hout, 2010) or “anxiety conservation” approach (Solomon & Wynne, 1954). Third, as both the 75% and 100% group exhibited neither a change in avoidance responding nor shock expectancy across phases, it is possible these participants were less able to discriminate the transition between phases; continued avoidance may have provided ‘protection from extinction’ (Lovibond et al., 2009). Of course, it is possible that these groups did discriminate the onset of extinction and simply persisted in much the same way as the 50% group described above. This is unlikely, however, given the elevated avoidance responding during extinction and the striking difference in expectancy ratings between trials with and without avoidance (i.e., Not Avoided trials received higher expectancy ratings than Avoided trials; Table 1). Thus, it appears that continuous reinforcement (100%) or near-continuous reinforcement (75%) was most resistant to extinction, while the lowest reinforcement groups (50%, 25% and 0%) were least resistant to extinction. Finally, avoidance responding to the CS- along with shock expectancy ratings were universally low and similar across all groups and phases. This indicates robust differentiation, established during fear conditioning, about which stimuli predicted the presence and absence of the US. That there should be any avoidance responding at all during the CS- is not unusual (Kryptos et al., 2015; Lommen et al., 2010), but it is noteworthy that the rate of avoidance to the CS- seemed inversely related to reinforcement rate for both phases (Figure 3). This suggests that experiences of uncontrollability may generalize to other stimuli, such as safety stimuli, and evoke avoidance as well. It is also noteworthy that

expectancy ratings closely corresponded with avoidance behavior: we found differences between groups and by CSs and time across avoidance and CS extinction phases.

It is apparent, then, that the availability of differentially effective opportunities to engage in avoidance across the groups modulated the likelihood with which participants expected shock – that is, expectancy increased as reinforcement rate decreased. The present study, for the first time, shows modulation of expectancy as a function of reinforcement rate. Expectancy was recorded after the option to engage in avoidance (Figure 1) and in the same format across all trials (from fear conditioning to avoidance extinction). Thus, while the necessity or effectiveness of avoidance changed from learning to extinction for all groups, save for the 100% group, the conditions under which ratings were made about the likelihood of shock occurring remained unchanged. Despite this, ratings clearly tracked behavior and once again indicate that trial-by-trial expectancy ratings are a useful proxy measure of fear capable of detecting the modulating effects of avoidance (Cameron, Schlund, & Dymond, 2015; Dymond, Schlund, Roche, De Houwer, & Freegard, 2012; Vervliet & Indekeu, 2015).

As outlined in the Introduction, the present study is relevant to research from non-appetitive domains on the partial reinforcement extinction effect (PREE), whereby exposure to partial reinforcement of avoidance schedules leads to less resistance to extinction than continuous reinforcement (Galvani, et al., 1971; Olson et al., 1971). There are, however, some important differences between the present approach and past findings on the PREE, most which have been obtained with nonhumans. Previous research on partial reinforcement has, for instance, employed ‘classical’ extinction consisting of CS-alone trials and where avoidance results in CS termination and with escape permitted from the US on non-avoidance trials (Davenport et al., 1971; Galvani, 1971; Olson et al., 1971). In our study with humans, the US was omitted on all extinction trials and there was no CS or US termination response requirement. Avoidance responses made in the presence of the CSs were simply recorded and

the cue was removed when scheduled (Figure 1). Indeed, research with humans on avoidance generally and the PREE specifically has not tended to employ CS termination procedures (Dymond & Roche, 2009; Krypotos et al., 2015; but see, Avcu, Jiao, Myers, Beck, Pang, and Servatius, 2014). Our findings suggest that CS termination may in fact not be necessary to demonstrate the PREE with avoidance behavior in humans in a CS-alone extinction test phase without US escape responses.

Unlike the CS extinction trials of the present study, Davenport and Olson (1968) first employed a non-traditional extinction procedure in which the avoidance response no longer lead to US omission (Baum, 1970). That is, the aversive event was non-eliminable (Lattal, St. Peter, & Escobar, 2013) - it continued to occur regardless of behavior. In research with rodents, Davenport, Coger and Spector (1970) found reliable rates of avoidance extinction were like those seen with appetitive reward extinction. Galvani (1971) found that gerbils made significantly less avoidance when the operant response could not prevent occurrence of shock than traditional extinction. In research with humans, response prevention procedures involving CS-no CS extinction trials in the absence of avoidance availability result in rapid extinction of avoidance and trigger a return of fear when they either do (Vervliet & Indekeu, 2015) or do not (Lovibond et al., 2009) alternate across test trials with CS extinction. Indeed, as avoidance behavior itself may induce either return of fear (Vervliet & Indekeu, 2015) or fear towards a novel stimulus (Engelhard, van Uijen, Seters & Velu, 2015), response prevention is central to successful exposure-based therapy. The present study adds another argument for the necessity for response prevention: partial reinforcement of at least 50% leads to avoidance acquisition and sustained avoidance responding like continuous reinforcement. Furthermore, expectancy ratings for the 50% group suggest that participants were aware of the CS extinction, yet continued to make avoidance responses. It is also possible that participants interpreted the changed contingencies during CS extinction to

indicate that the effectiveness of avoidance had in fact increased; that is, the lack of the US throughout this phase may have contributed to participants' erroneous interpretations that their avoidance was responsible for the continued absence of the US. As a clinical analog, our findings suggest that avoidance behavior can be acquired under circumstances *without* perfect controllability (as is often modelled in laboratory tasks) and lead to clinical avoidance which is excessive and resistant-to-extinction. In the context of the present study, it will be important for future translational research to investigate how to optimize both partial reinforcement and avoidance extinction learning processes during clinical exposure treatment (see, Craske, Treanor, Conway, Zbozinek & Vervliet, 2014; Scheveneels et al., 2016). For instance, a future study could test whether, after the CS extinction phase, if participants are again presented with the CS+ but in the absence of the possibility to avoid, US expectancy returns to high levels (Vervliet & Indekeu, 2015). Such a demonstration would allow one to distinguish between interpretations of each group's motivation to avoid during the CS extinction phase.

The study of partial reinforcement effects on extinction of avoidance permits a consideration of other issues relevant to clinical problems. For instance, it may offer a new perspective on the transition from adaptive to maladaptive avoidance by emphasizing the potential benefits and pitfalls of stressor controllability, which, if left unchecked, can become chronic and impair daily life. Specifically, "it is the element of controllability, which puts the brakes on reactive defensive behaviors, that makes active avoidance useful. Animals and people who are able to engage in active avoidance may constitute the population of resilient individuals." (LeDoux et al., 2016, p.32). It is known that emotional or stressor controllability leads to resilience to stress (e.g., Lucas et al., 2014). Resilience, then, may lie in knowing when avoidance is and is not necessary, and in restraining impulses to engage in maladaptive avoidance as the default way of coping with potential threat and uncertainty. It may entail

tolerating occasional threat and showing willingness to “wait and see”. But, a ‘tipping point’ is soon reached (Schlund et al., 2016) whereby maladaptive avoidance becomes the norm and controllability shifts to being “all or nothing”. Our findings indicate that partially reinforced avoidance behaviors (i.e., with a reinforcement rate, or controllability index, of 50% or lower) are less resistant to extinction than avoidance which has had a more reliable history of stressor controllability, and may represent a useful threshold to study the transition from adaptive to maladaptive avoidance. Hence, the results of the current study could provide a case for pre-clinical research that avoidance is better examined under partial reinforcement to model the sense of impaired controllability that cuts across the anxiety disorders.

Our finding indicating specific individual differences in avoidance supports animal models of anxiety vulnerability highlighting the resistance to extinction of avoidance (e.g., Servatius, Jiao, Beck, Pang, & Minor, 2008). Here, we found that anxiety-vulnerable female participants in the group for which avoidance was never effective at preventing shock (i.e., the 0% group) engaged in more avoidance than males throughout the entire study (Sheynin, Beck, Servatius, & Myers, 2014). This exaggerated level of maladaptive avoidance persisted even when shock no longer occurred and avoidance was hence unnecessary. The present findings demonstrate an interaction between a known anxiety vulnerability factor (female sex) and 0% reinforcement rate on subsequent resistance to extinction of (maladaptive) avoidance. Further research is needed to delineate the interaction with other reinforcement parameters and psychological traits, such as experiential avoidance (Chawla & Ostafin, 2007; Gámez, Chmielewski, Kotov, Ruggero, & Watson, 2011; Hayes, Wilson, Gifford, Follette, & Strosahl, 1996), which has been found to modulate avoidance in healthy individuals (van Meurs et al., 2014).

The present study has some limitations. First, partial reinforcement effects were not visible in SCR, which may have been caused by movement artifacts. We measured first

interval responses (FIR) as the first peak between 0.5-5 ms after CS presentation; however, the avoidance cue was introduced 1 s after the CS. It is possible, therefore, that the significant Group x CS finding was influenced by participants performing the avoidance response rather than by any physiological arousal elicited during CS presentation. As SCR often follows a similar pattern to US expectancy ratings, future research should be capable of detecting partial reinforcement effects with a longer FIR recording parameter (Vervliet & Indekeu, 2015). Second, there was an unequal number of US exposures across the groups. To ensure groups are matched for US exposure prior to extinction, future research should seek to employ either triadic or yoked control designs (Meulders et al., 2016). Related findings from research employing triadic designs has highlighted that extinction may be augmented by active avoidance. For example, stressor controllability, operationalized as exposure to escapable shock, which can be avoided, and inescapable shock, which cannot, is well known to augment extinction in nonhumans (Barratta et al., 2007) and humans (Hartley et al., 2014). Hartley et al. observed that a session of escapable shocks enhanced extinction and eliminated spontaneous recovery when conducted several days prior to fear learning, extinction and spontaneous recovery testing (Hartley et al., 2014). It would be helpful therefore to extend this approach to create a variant of the present design in which one group was able to avoid shock according to a schedule and compared with another group matched for number of shocks but with no option to avoid.

In conclusion, the current study highlights the clinical relevance of investigating partial reinforcement effects on avoidance behavior in extinction (Dunsmoor et al., 2015; Krypotos et al., 2015). It is known from clinical practice that avoidance is not always effective, yet nonetheless it can remain persistent and difficult to treat. Approaching the study of a clinically relevant issue in this way not only increases ecological validity of the experimental psychopathology account of fear and avoidance (Vervliet & Raes, 2013) but

may also better guide treatment of excessive avoidance in anxiety disorders and build bridges between basic research and clinical application.

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### Figure Captions

*Figure 1.* Study design. (A): Schematic overview of the experimental design. All groups underwent all three phases. Stimuli consisted of grey squares and triangles, counterbalanced as either CS+ or CS-. Groups differed by how effective avoidance was in cancelling the upcoming US (electric shock). Reinforcement rates were 100%, 75%, 50%, 25% and 0%. (B): Schematic overview of the trial structure and timings of a CS+ trial during the avoidance phase.

*Figure 2.* Participants made clear distinctions between CS+ and CS- during Pavlovian fear conditioning. (A) Participants had higher shock expectancy ratings for the CS+ than CS- and (B) similarly exhibited greater skin conductance responses (SCRs) for the CS+ than CS-. Error bars are SEM.

*Figure 3.* Proportion of avoidance responses is related to reinforcement rate. Participants in lower reinforcement groups made less avoidance responses during avoidance (A) and CS extinction (B) than higher reinforcement groups for CS+. Error bars are SEM.

*Figure 4.* Participants rated shock expectancy differently between reinforcement groups. For illustrative purposes, the left panel shows CS+ and the right panel shows CS- ratings, respectively. Expectancy ratings during avoidance (Av\_1 to Av\_6) showed that shock expectancy was rated significantly higher in lower reinforcement groups. During the CS extinction phase (Ex\_1 – Ex\_12), a significantly sharper decrease in shock expectancy ratings is visible in the lower reinforcement groups. Error bars are SEM.

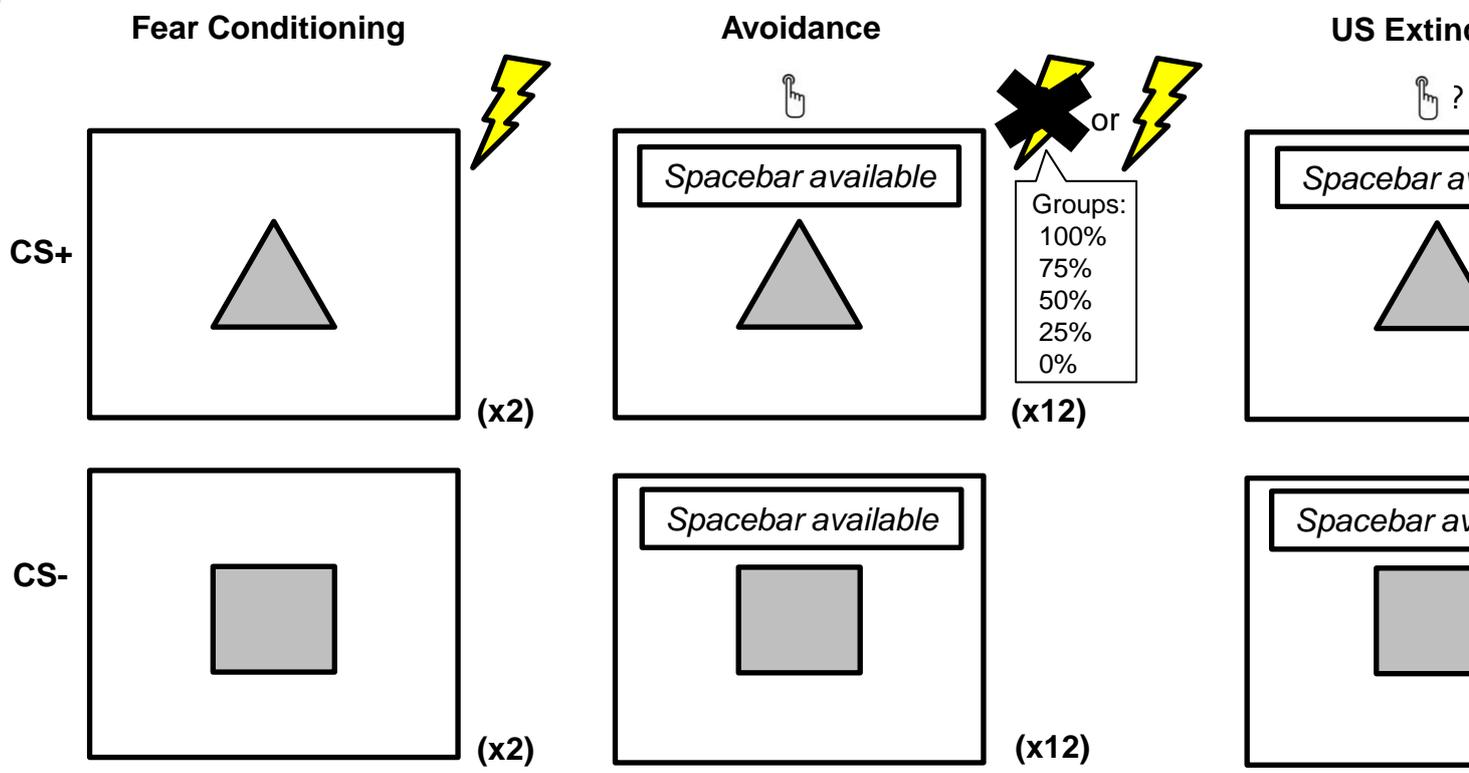
*Figure 5.* Cumulative avoidance in extinction shows group differences over time and between CSs. For illustrative purposes, the left panel shows CS+ and the right panel shows CS- trials.

**Table(s)**

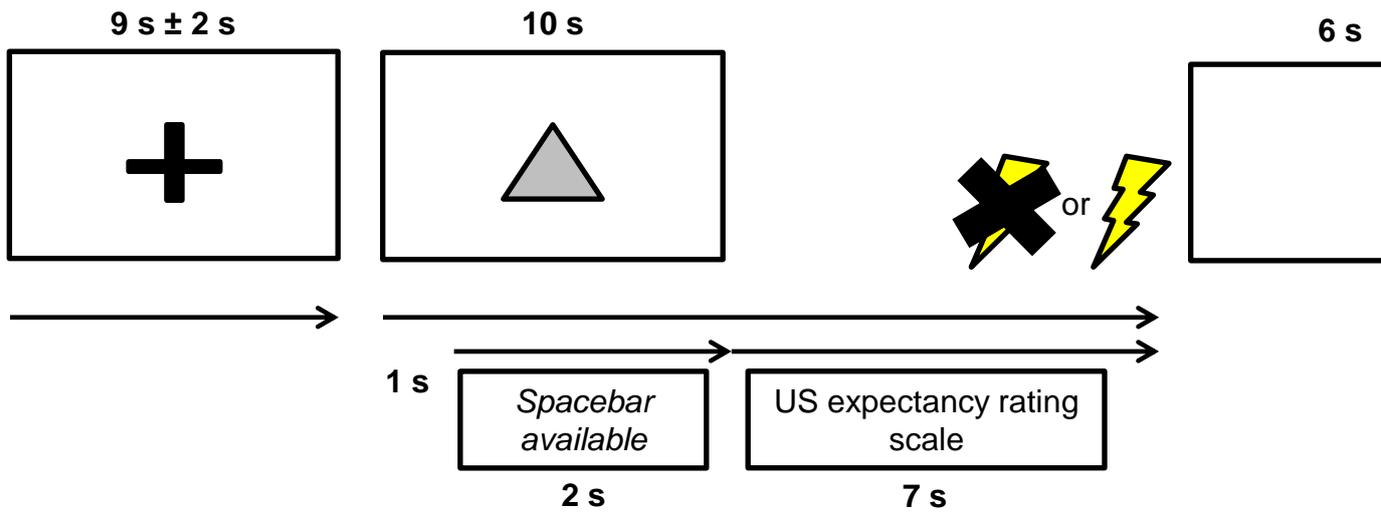
*Table 1.* Mean (SD) shock expectancy ratings on avoided and not avoided trials and the Av:NAv (Avoided:Not Avoided) ratio for CS+ and CS- during avoidance acquisition and US extinction across groups (100%, 75%, 50%, 25%, 0%). Note that the ratio is calculated for 12 trials during avoidance acquisition and 24 trials during US extinction, respectively.

		<b>Group</b>				
		100%	75%	50%	25%	0%
<b>Avoidance Acquisition</b>		<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
	Avoided	3.20 (2.53)	3.56 (2.69)	6.80 (2.02)	7.41 (2.14)	7.45 (2.38)
<b>CS+</b>	Not Avoided	5.83 (3.47)	7.41 (2.95)	8.10 (3.09)	8.01 (2.04)	9.38 (1.36)
	<i>Av:NAv Ratio</i>	<i>10.8:1.2</i>	<i>10.3:1.7</i>	<i>10.6:1.4</i>	<i>9.0:3.0</i>	<i>6.3:5.7</i>
	Avoided	2.49 (2.87)	1.38 (1.94)	1.73 (2.09)	0.89 (1.55)	1.02 (2.28)
<b>CS-</b>	Not Avoided	0.74 (1.27)	1.29 (2.17)	0.54 (1.05)	0.77 (1.40)	0.60 (1.20)
	<i>Av:NAv Ratio</i>	<i>1.7:10.3</i>	<i>3.0:9.0</i>	<i>3.7:8.3</i>	<i>3.2:8.8</i>	<i>3.9:8.1</i>
<b>US Extinction</b>						
	Avoided	1.94 (2.35)	2.75 (2.87)	4.01 (2.88)	4.43 (2.54)	3.19 (2.16)
<b>CS+</b>	Not Avoided	3.60 (3.19)	5.37 (2.80)	4.84 (2.77)	3.24 (2.87)	2.93 (2.29)
	<i>Av:NAv Ratio</i>	<i>19.3:4.7</i>	<i>19.6:4.4</i>	<i>19.1:4.9</i>	<i>15.4:8.6</i>	<i>9.4:14.6</i>
	Avoided	0.91 (1.70)	1.91 (3.29)	1.35 (2.22)	0.66 (1.51)	0.68 (1.32)
<b>CS-</b>	Not Avoided	0.51 (1.15)	0.63 (1.29)	0.66 (1.58)	0.42 (1.05)	0.44 (0.77)
	<i>Av:NAv Ratio</i>	<i>2.8:21.2</i>	<i>4.5:19.5</i>	<i>4.6:19.4</i>	<i>4.8:19.2</i>	<i>6.0:18.0</i>

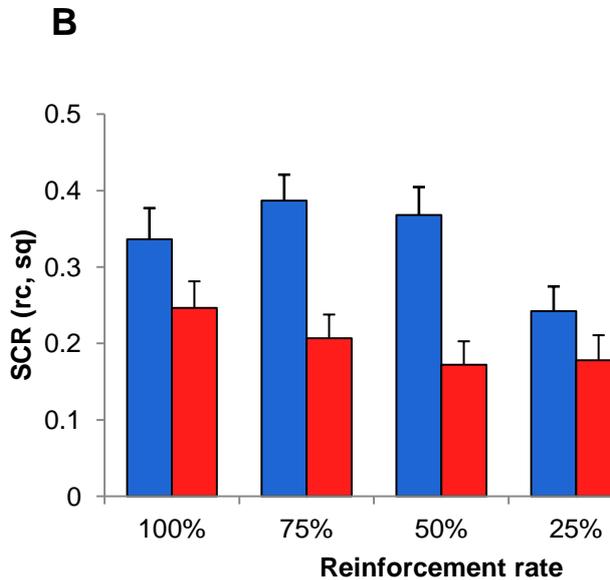
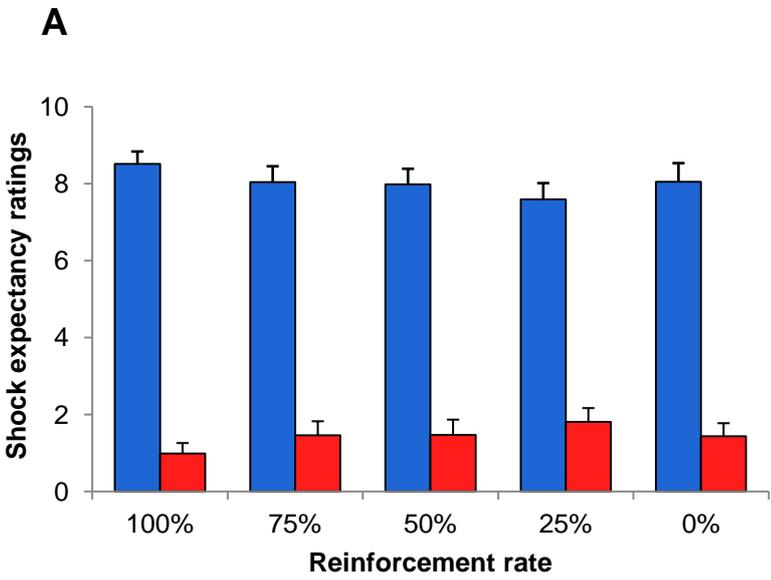
Figure(s)  
A)



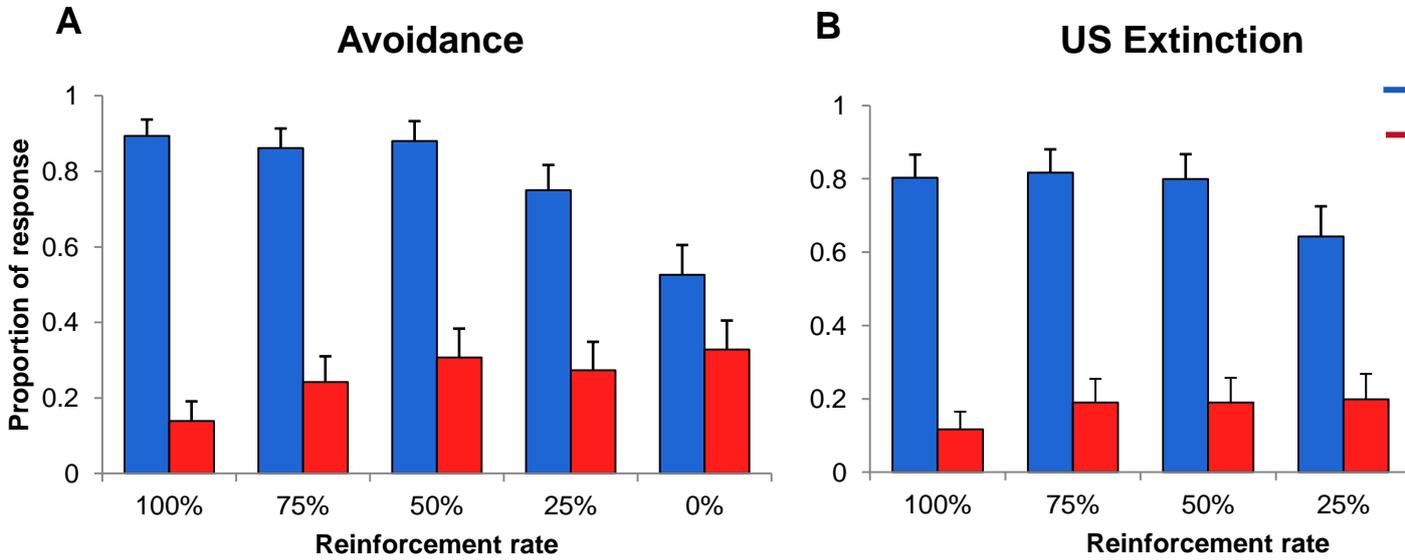
B)



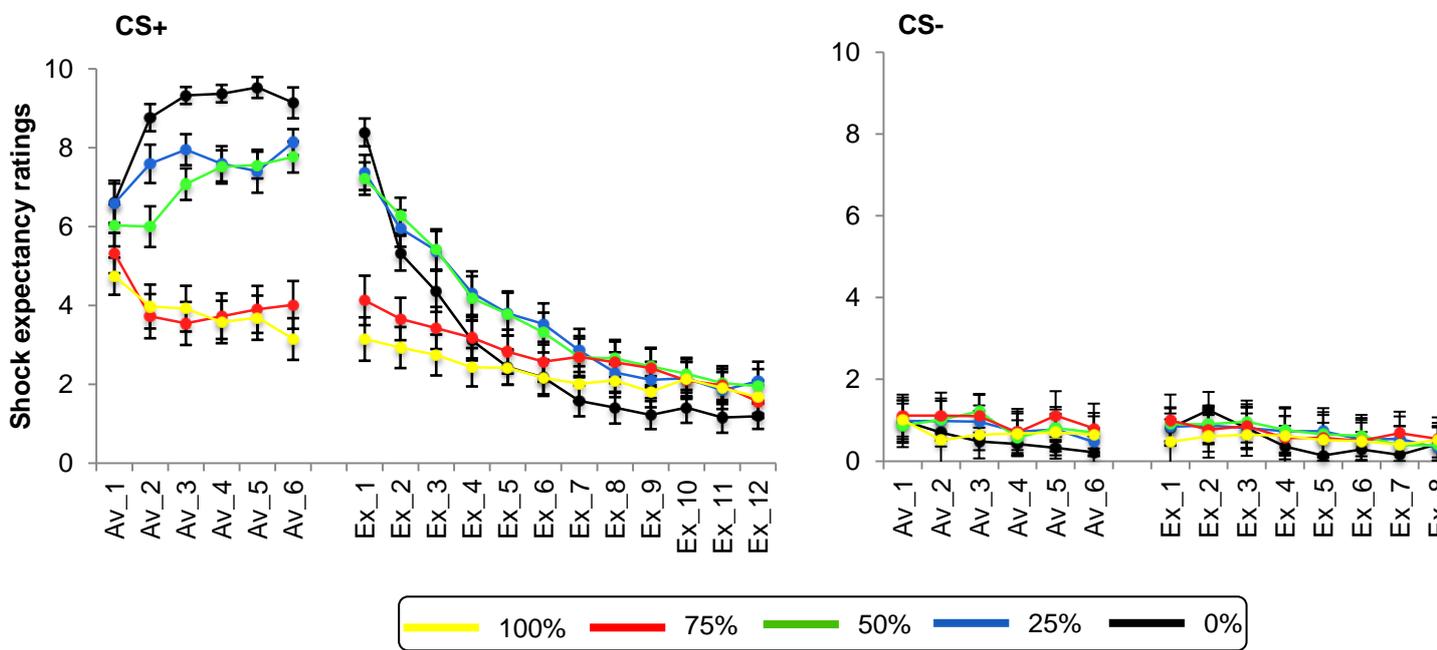
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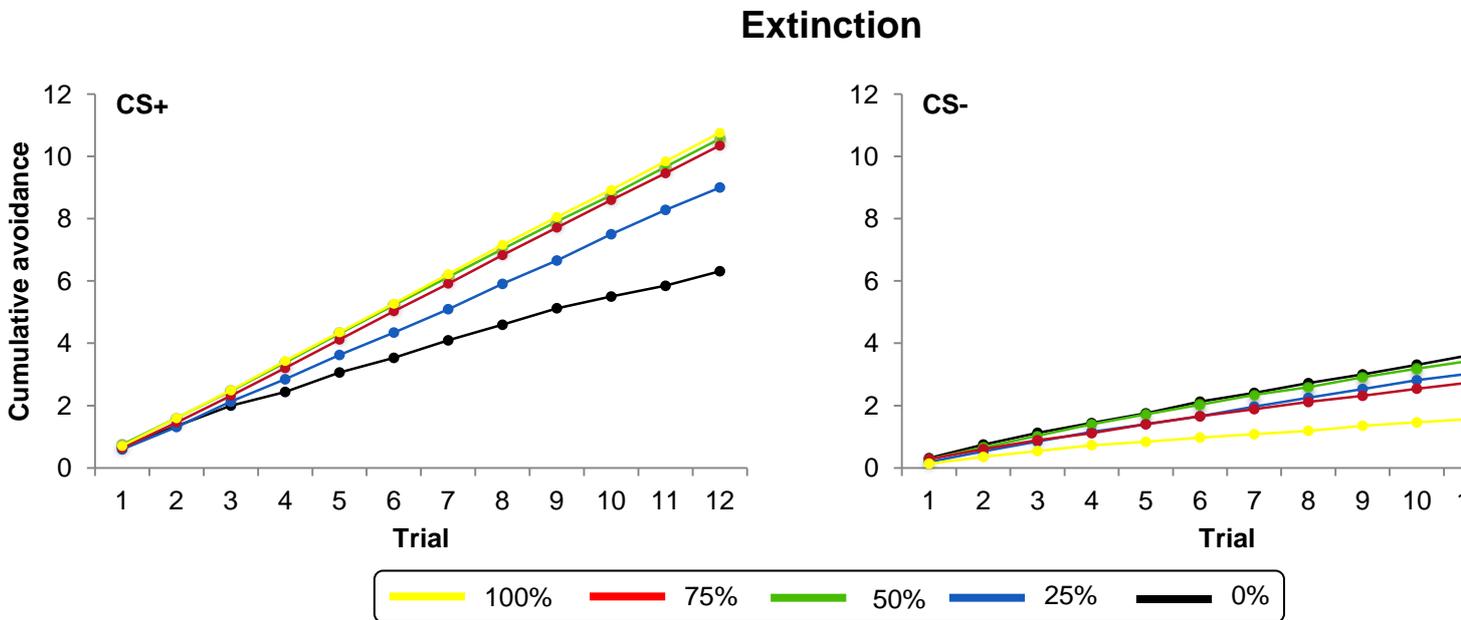
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