

Novelty-Facilitated Extinction: Providing a Novel Outcome in Place of an Expected Threat Diminishes Recovery of Defensive Responses

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ABSTRACT

BACKGROUND: Experimental extinction serves as a model for psychiatric treatments based on associative learning. However, the effects of extinction are often transient, as evidenced by postextinction return of defensive behaviors. From a therapeutic perspective, an inherent problem with extinction may be that mere omission of threat is not sufficient to reduce future threat uncertainty. The current study tested an augmented form of extinction that replaced, rather than merely omitted, expected threat outcomes with novel nonthreat outcomes, with the goal of reducing postextinction return of defensive behaviors.

METHODS: Thirty-two healthy male Sprague-Dawley rats and 47 human adults underwent threat conditioning to a conditioned stimulus paired with an electrical shock. Subjects then underwent a standard extinction protocol with shock omitted or an augmented extinction protocol wherein the shock was replaced by a surprising tone. Tests of postextinction recovery occurred 24 hours later in the absence of the tone.

RESULTS: Replacing the shock with a novel nonthreat outcome, as compared with shock omission, reduced postextinction recovery (freezing in rats and anticipatory skin conductance responses in humans) when tested 24 hours later. Self-reported intolerance of uncertainty was positively correlated with recovery following standard extinction in humans, providing new evidence that postextinction recovery is related to sensitivity to future threat uncertainty.

CONCLUSIONS: These findings provide cross-species evidence of a novel strategy to enhance extinction that may have broad implications for how to override associative learning that has become maladaptive and offer a simple technique that could be straightforwardly adapted and implemented in clinical situations.

Keywords: Anxiety, Arousal, Electrodermal, Fear, Pavlovian, Regulation

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Without effort or intention, individuals retain information associated with highly aversive experiences. In extreme cases, this leads to persistent intrusive memories and unwanted physiological responses to cues associated with the event. Investigations on how to mitigate the psychological and physiological impact of negative events borrows heavily from research on extinction of classical threat (fear) conditioning, whereby the omission of an aversive event reduces defensive behaviors, like increases in sympathetic arousal and freezing. Laboratory research routinely shows, however, that defensive behaviors return postextinction (1–3). That learned defensive behaviors return even in laboratory experiments with healthy subjects reveals that threat conditioning is a powerful form of learning and that extinction is a rather unsatisfactory way to acquire safety. As the principles of extinction continue to serve as a model for clinical treatments like exposure therapy (4,5), there is strong motivation to discover innovative behavioral techniques to prevent postextinction return of defensive behaviors.

The weakness of extinction may be owed to a number of evolutionary and environmental factors (6,7). One limiting factor is that extinction does not eliminate the association between a conditioned stimulus (CS) and an unconditioned stimulus (US). Instead, extinction is a form of retroactive interference in which the new safety association competes for expression against the original threat association (6,8). This secondary association is fragile, as evidenced by the return of conditioned responses (CR) following the passage of time (spontaneous recovery), following presentation of the US (reinstatement), or when cues are encountered outside the extinction context (renewal) [see (9) for review]. Preventing the return of CRs remains a challenge (10). Models that conceptualize extinction as another form of associative learning propose that animals are provoked to learn by the surprising absence of the US (8,11). However, omission does not guarantee an effective learning signal. This is especially true in relapse following exposure treatment, where highly feared outcomes are repeatedly disconfirmed but continue to be expected following treatment, e.g., a persistent fear of dying in

an airplane crash after exposure therapy for fear of flying. In other words, the mere absence of the US is not sufficient to provoke a durable safety memory.

Another limit to extinction is that US omission can render the meaning of the CS ambiguous (12). That is, the CS takes on an additional meaning where it no longer predicts the US (or predicts no US). Resolving this ambiguity tends to favor expression of the original memory, perhaps since this association was learned first and/or is simply more salient than the extinction memory. For example, expression of threat conditioning readily generalizes to related cues and across multiple contexts, whereas extinction tends to be confined to the extinguished cue in the extinction context (12–14). The unexpected absence of the US could also promote a general sense of future threat uncertainty. If so, then individuals who have difficulty coping with uncertainty may be especially prone to return of defensive behaviors following extinction.

In the present study, we reasoned that extinction could be straightforwardly and effectively augmented if the aversive US was instead replaced by a surprising nonthreat outcome. Here, an expected electric shock was replaced by a novel and affectively neutral tone. We predicted that replacing shock with a novel outcome would reduce postextinction spontaneous recovery more effectively than shock omission alone for two principal reasons. First, unlike the mere absence of the shock, a novel outcome should be more effective at generating a mismatch between the predicted and received outcome, therefore signaling a clear change in the environment to promote the acquisition of new learning (8,15). Second, a novel perceptible outcome should help resolve some ambiguity generated by shock omission by providing a more substantive alternative association for the CS than no shock.

It is important to note up front certain methodological similarities to another form of outcome interference: counterconditioning. In counterconditioning, the outcome switches between opposing reinforcement qualities (appetitive and aversive) and thus opposing behavioral responses (approach and avoidance). Counterconditioning serves as a model for some behavior therapies (16,17), but contemporary research on aversive-to-appetitive counterconditioning in humans is scant (18,19). However, there is ample evidence in rats showing strong return of defensive CRs following counterconditioning (20–25). Unlike counterconditioning, the current protocol replaces the US with a surprising stimulus that does not reinforce any overt behavior.

The effect of this modified extinction protocol was assessed 24 hours after extinction in rats (experiment 1) and humans (experiment 2), with the prediction that a novel nonthreat outcome would diminish spontaneous recovery. We additionally explored for the first time whether individual differences in self-reported intolerance of uncertainty predicts postextinction recovery in humans.

METHODS AND MATERIALS

Experiment 1

Animal Subjects. Thirty-two male Sprague-Dawley rats (Hilltop Lab Animals, Scottsdale, Pennsylvania) were used in experiment 1. Further details regarding the animal subjects

and threat conditioning procedures are included in [Supplement 1](#).

Rodent Threat Conditioning Procedures. Two contexts were created (A and B) and made distinct with visual, tactile, and olfactory cues. Subjects were placed in context A on the first day of the study (Figure 1A), wherein the front panel light was illuminated for 30 seconds and co-terminated in the delivery of a 1-second .7 mA footshock on 100% of trials. The acquisition session included five trials spaced apart by an approximate 180-second intertrial interval. Two minutes following the last trial, subjects were removed from the chambers and returned to the colony for the remainder of the day.

Subjects were randomly assigned to one of two groups that differed only in regard to the type of extinction training: extinction through shock omission (EXT) or extinction modified by a surprising and novel nonthreat outcome in place of the shock, a procedure we refer to as novelty-facilitated extinction (NFE). Rats in both groups were placed in context B on day 2 of the study. Subjects in the EXT group received only the 30-second light presentation. For NFE subjects, the final 10 seconds of the light presentation were accompanied by a 5-kHz tone. This session included 30 trials separated by 15

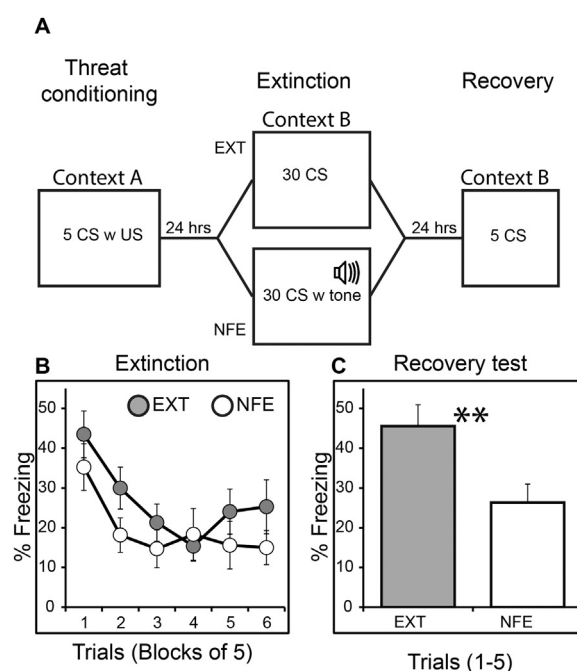


Figure 1. (A) Procedure for experiment 1 in rats. Two groups underwent identical differential threat conditioning to initiate freezing to a conditioned stimulus (CS) paired with an electric shock unconditioned stimulus (US). Twenty-four hours later in a new context, one group underwent standard extinction in which the US was omitted on CS trials, while another group underwent a modified extinction procedure in which the US was replaced by a novel nonaversive tone. Spontaneous recovery was tested for both groups 24 hours later in the extinction context. (B) Freezing during extinction in the two groups was equivalent. (C) The novelty-facilitated extinction (NFE) group showed significantly less evidence of recovery 24 hours later than the standard extinction group. $**p < .01$; error bars reflect standard error. CS duration was 30 seconds. EXT, extinction through shock omission.

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