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Reactivated Memories Compete for Expression After Pavlovian Extinction

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Abstract

We view the response decrement resulting from extinction treatment as an interference effect, in which the reactivated memory from acquisition competes with the reactivated memory from extinction for behavioral expression. For each of these memories, reactivation is proportional to both the strength of the stimulus-outcome association and the quality of the facilitatory cues for that association which are present at test. Here we review basic extinction and recovery-from-extinction phenomena, showing how these effects are explicable in this associative interference framework. Moreover, this orientation has and continues to dictate efficient manipulations for minimizing recovery from extinction. This in turn suggests procedures that might reduce relapse from exposure therapy for a number of psychological disorders. Some of these manipulations enhance the facilitatory cues from extinction that are present at test, others strengthen the extinction association (i.e., CS-no outcome), and yet others seem to work by a combination of these two processes.

Keywords

exposure therapy; extinction; interference; recovery from extinction; relapse

1. Pavlovian Extinction and its Recovery

In a Pavlovian conditioning preparation, a target cue (X) acquires control over a response through its pairings with an outcome (O) that unconditionally elicits responding. For example, in a fear conditioning preparation, rats display a conditioned fear response in the presence of a tone (i.e., X) after having received tone-shock (i.e., X→O) pairings; this fear response is unconditionally elicited by shocks but not by tones. Moreover, the behavioral control acquired through stimulus pairings is reduced when X is repeatedly presented in the absence of O (i.e., X→noO), a phenomenon known as experimental extinction (Pavlov, 1927). In the fear conditioning preparation described above, the conditioned fear response elicited by the tone after acquisition training is reduced if the tone is repeatedly presented in the absence of shock. Contrary to some early theorizing concerning extinction (e.g., Rescorla & Wagner, 1972), nonreinforced presentations of X (i.e., extinction treatment) do

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not erase the X—O association formed during acquisition training, as Pavlov originally proposed (1927; see also, Konorski, 1967). Instead, it creates a new inhibitory-like association between X and O (i.e., $X \rightarrow \text{noO}$), the retrieval of which is believed to be context specific in nature (e.g., Bouton, 1993). When experimental subjects are tested outside of the context of extinction, or after a long retention interval, they usually exhibit partial recovery of extinguished associations, suggesting that the X—O association is kept largely intact despite the formation of an X—noO association during extinction treatment. Consequently, factors other than erasure of the X—O association are primarily responsible for the decrease in responding after extinction treatment.

One associative phenomenon usually cited as evidence against the erasure hypothesis of extinction is the renewal effect (e.g., Bouton & Bolles, 1979). Following extinction treatment of an excitatory cue X (i.e., $X \rightarrow \text{noO}$ treatment after $X \rightarrow \text{O}$ training), weak conditioned responding is evidenced if X is tested in the context in which extinction took place (i.e., behavior indicative of the X—noO association is expressed). But considerable recovery of expression of the X—O association is evidenced if X is tested outside the context of extinction. This type of recovery from extinction occurs under at least three circumstances. First, following extinction of X in a context different than the one used during acquisition training (i.e., $[X \rightarrow \text{noO}]_B$ treatment after $[X \rightarrow \text{O}]_A$ training, with A and B representing different physical contexts), responding to the extinguished X is observed if testing occurs back in the acquisition context (i.e., ABA renewal; e.g., Bouton & Bolles, 1979; Rauhut et al., 2001). Second, following extinction of X in a context different than the one used during acquisition training, responding to the extinguished X is observed if testing occurs in a third context (i.e., ABC renewal; e.g., Bouton & King, 1983; Laborda, Witnauer, et al., 2011). Finally, when acquisition and extinction occur in the same context (i.e., $[X \rightarrow \text{noO}]_A$ treatment after $[X \rightarrow \text{O}]_A$ training), responding to the extinguished X is sometimes observed (albeit weakly) if testing occurs in a second context (i.e., AAB renewal; e.g., Bouton & Ricker, 1994; Laborda, Witnauer, et al., 2011). Despite the existence of a number of different theoretical explanations of the renewal effect, a change from the physical context of extinction seems to be the essential manipulation for this type of recovery to occur.

Similar recovery occurs when a long delay is imposed between extinction treatment and testing even when testing occurs in the physical context of extinction; this is referred to as spontaneous recovery (e.g., Brooks & Bouton, 1993; Pavlov, 1927). Following extinction treatment of an excitatory cue X (i.e., $X \rightarrow \text{noO}$ treatment after $X \rightarrow \text{O}$ training), weak conditioned responding is evidenced if X is tested soon after extinction (i.e., behavior indicative of the X—noO association is expressed). But response recovery is evidenced if X is tested long after extinction (i.e., behavior indicative of the X—O association is expressed). Introducing a long delay between extinction and testing (which arguably creates a temporal context at test different from that of extinction; e.g., Bouton, 2010) seems to be the essential manipulation for this type of recovery to occur. Many studies have demonstrated that this recovery is not due to an increase in the interval between acquisition and testing (e.g., Laborda & Miller, 2011, 2012).

Importantly, Rosas and Bouton (1998; see also Rosas et al., 2001) reported data in which renewal and spontaneous recovery summated in a conditioned taste aversion preparation with rats, producing more recovery of the extinguished conditioned responses than either recovery-from-extinction phenomenon alone. These results are of importance to researchers interested in developing potential applications of extinction treatment. A preparation in which renewal and spontaneous recovery summate seems to be a more naturalistic model of the relapse in clinical situations observed following exposure therapy. Such recovery often occurs when patients confront the exposed stimulus (e.g., a phobic object or an alcohol-

related cue) in a context different than the psychological clinic in which treatment took place (i.e., renewal) and after a time has elapsed since the end of treatment (i.e., spontaneous recovery). In line with Bouton's (e.g., 2010) assumption that organisms have a sense of temporal contexts in which different events occur analogous to their apparent sense of physical contexts in which different events occur, and with the role given to facilitatory cues in the account presented here (see section 3), conjoint changes in the physical and temporal contexts of extinction should in general produce a stronger return of the extinguished CRs than either physical or temporal changes alone.

Recently, Laborda and Miller (2012; Experiment 1) evaluated whether changing the physical context between extinction and testing summates with introducing a long delay between extinction and testing to produce strong recovery in a fear conditioning preparation with rats. Following acquisition training and extinction treatment in different contexts (i.e., $[X \rightarrow \text{noO}]_B$ treatment after $[X \rightarrow O]_A$ training); rats tested in the extinction context following a short delay between extinction treatment and testing displayed low conditioned responding (i.e., behavior consistent with extinction), rats tested in a neutral context after a short delay following extinction treatment displayed some recovery of conditioned responding (i.e., ABC renewal); rats tested in the extinction context after a long delay from extinction treatment also displayed some recovery of conditioned responding (i.e., spontaneous recovery); and finally, rats tested in a neutral context after a long delay from extinction treatment displayed a stronger recovery of conditioned responding than rats tested after a context shift or after a long delay from extinction alone (i.e., ABC renewal plus spontaneous recovery). These results extended Rosas and Bouton's (1998) findings and evidenced the additive effect of recovery-from-extinction phenomena in a fear conditioning preparation.

2. Some Theoretical Views on Pavlovian Extinction and Recovery From Extinction

Several associative theories provide explanations of extinction and subsequent recovery from extinction. For example, the Rescorla-Wagner (1972) model predicts that during acquisition training in Context A all cues present become excitatory (e.g., the target cue X and Context A). Then, during extinction treatment in Context B, the X—O association is partially erased, but complete erasure is prevented because Context B becomes inhibitory (given that O is expected based on X but not present during extinction treatment; e.g., McConnell & Miller, 2010). At test in Context A, subjects display renewed fear responding caused by the addition of the excitation of the acquisition context and the remaining excitation of the extinguished X. Subjects tested in the context of extinction do not display significant fear responding because the inhibitory status of the context negatively summates with the residual excitatory strength of X. In similar ways, the model can also explain ABC and some instances of AAC renewal. This account (as well as the rest of the accounts described here) fails to account for spontaneous recovery without assuming that temporal cues are part of the contexts.

Another associative approach is presented by the sometimes-competing retrieval model (SOCR; Stout & Miller, 2007), the mathematical implementation of the extended comparator hypothesis (Denniston et al., 2001). For this family of models, contiguity is necessary and sufficient for an association to be formed, and responding at test depends on a comparison between the strength of the X—O association relative to the strengths of other stimuli that were present during training with CS X (e.g., the context). Specifically, responding is assumed to be a direct function of the degree to which X signals an increase in the likelihood of the US over that of these background cues alone. According to the model, during extinction treatment two things occur; the X—O association formed during

acquisition is partially erased (thus any recovery from extinction should not be complete) and the association between X and the context is strengthened. This fortified X-context association then indirectly down modulates responding to X at test. Although this model predicts some context-shift effects that evade other models (e.g., Laborda, Witnauer, et al., 2011), it does not anticipate the basic renewal effect (e.g., $ABB < ABA$). However, accepting associative summation between test contexts and cues, SOCR provides an account of renewal similar to that of the Rescorla-Wagner (1972) model. Recent research has supported this view, suggesting that associative summation at test and the acquisition of conditioned inhibition by the extinction context are potential mechanisms that contribute to renewal (Laborda, Polack, et al., 2012; Polack et al., 2012; but see Nelson et al., 2011).

According to Pearce's (1987) configural associative model, following acquisition training, the target cue X and the context of acquisition (A) comprise a single configured cue (i.e., [X and Context A]) that becomes associated with the outcome (O). Then, during extinction treatment, partial excitation from acquisition generalizes to the configured cue formed by X and the context of extinction (B), which, given the absence of O during extinction treatment, encourages the development of an inhibitory association between the configured extinction cue (i.e., [X and Context B]) and O. If X is tested back in the acquisition context, the excitation of the acquisition-configured cue (i.e., [X and Context A]) is expressed (i.e., ABA renewal) with a partial decrease in strength due to some generalization of inhibition from the extinction-configured cue (i.e., [X and Context B]).

Another approach to extinction and its recovery suggests that the X—noO association formed during extinction treatment produces associative interference (e.g., Bouton, 1993; see also Miller & Escobar, 2002, for a variant of this account). From Bouton's (1993) perspective, extinction treatment produces an inhibitory-like X—noO association that is more context specific than the X—O association learned during acquisition training, and that retroactively interferes with the expression of the acquisition memory at test. A central reason that the extinction memory is more sensitive to context shifts than the acquisition memory is that extinction learning creates ambiguity (because it contradicts the information acquired with respect to X during acquisition training), which promotes encoding of the memory of noO as an exception that can be predicted by contextual cues (i.e., the context of extinction becomes a negative facilitatory cue; e.g., Holland, 1983; Rescorla, 1985). Then, when testing occurs outside of the extinction context, the extinction memory is not activated and behavior indicative of acquisition is expressed. Recent research has found that it is more the ambiguity-creating nature of extinction memories than their inhibitory-like nature that is responsible for them being context specific (e.g., Sissons & Miller, 2009). Furthermore, renewal and spontaneous recovery after interference are observed in the absence of inhibitory training (e.g., Miguez et al., 2011).

Recently, Rosas et al. (2006) have modified Bouton's (1993) account by proposing somewhat different circumstances that can lead extinction learning to become context specific. For them, it is not the ambiguity generated by the extinction treatment that promotes context specificity, but anything that makes organisms pay attention to the context (e.g., ambiguity resolution, previous experience focusing attention on the context, instructions to pay attention to the context, informational value of the context, and the salience of the context relative to the target cue). In this framework, renewal occurs because ambiguity encourages organisms to attend to and encode contextual features along with the extinction memory. As discussed elsewhere (Miller & Laborda, 2011), Bouton's and Rosas et al.'s approaches successfully anticipate basic spontaneous recovery and renewal. However, their accounts ignore the effects of the relative strengths of the X—O and X—noO associations on responding.

3. Reactivated Memories Compete at Test

Recently, Miller and Laborda (2011) suggested, like Bouton (1993), that extinction and its recovery could be understood as instance of retroactive associative interference. From their point of view, after extinction treatment, conditioned responding at test is determined by a comparison between the reactivated memory from acquisition (RMA) and the reactivated memory from extinction (RME; see Figure 1). Each of the reactivated memories is assumed to reflect the product of a) the facilitatory cues (i.e., stimuli that enhance the potential of a cue to reactivate the memorial representation of an outcome with which it is associated; e.g., Holland, 1983; Rescorla, 1985) presented at test for that memory and b) the strength of the stored associations (i.e., X—O association from acquisition and X—noO association from extinction). The emphasis on the strengths of the two associations distinguishes this view from Bouton's, which ignores differences in the strengths of the two competing memories. More generally, any type of associative interference can be viewed as the result of a competition process in which reactivated memories contest with one another for behavioral expression at test. Each of the memories competing for expression would be proportional to the strength of the interfering/interfered associations and to the effectiveness of the facilitatory cues from each association that are present at test. For Miller and Laborda (2011), behavior indicative of the X—noO association (i.e., weak responding at test) is elicited when the RME is stronger than the RMA. Conversely, behavior indicative of the X—O association (i.e., strong responding at test including more recovery from extinction) is elicited when the RMA is stronger than the RME. In our view, simple averaging of expected outcomes from acquisition and extinction does not determine responding at test. Instead, the stronger retrieved memory (i.e., RMA or RME) seems to inhibit expression of the weaker reactivated memory, which is similar to the mechanism proposed by Anderson et al. (1994) to explain the results of their experiments concerning retrieval-induced forgetting. This approach seems to better describe recovery from extinction, given that simple averaging of memory strengths would tend to underestimate the amount of recovery that is actually observed (i.e., adding expected outcomes from acquisition and extinction would predict only weak recovery, if any). Such active inhibition of the weaker association is functional because the subject has experienced reinforcement and nonreinforcement, not weak reinforcement which averaging would predict. Hence, one of these two outcomes should be expected.

To explain why the X—noO association from extinction seems to be more context specific than the X—O association from acquisition, Miller and Laborda suggested (in agreement with the general ideas proposed by Bouton [1993] and Rosas et al. [2006]) that the ambiguous information received during extinction treatment focuses the subject's attention on the context of extinction, thereby causing it to be better encoded than the context of acquisition. This makes the extinction context a better facilitatory cue than the acquisition context (see section 3.1.2), which is expected to play a lesser role given that during acquisition training the degree of ambiguity is generally lower than during extinction treatment, although there is likely some ambiguity even during acquisition based on the acquisition context being present during both reinforcement and the nonreinforced intertrial intervals).

The applied relevance of this approach is that recovery-from-extinction phenomena can be attenuated by manipulations that enhance the RME (by increasing the facilitatory cues from extinction present at test and by strengthening the X—noO association). Thus, this general account of extinction and its recovery can be useful in guiding the search for manipulations to reduce recovery from extinction and relapse after exposure therapy (for a review, see Laborda, McConnell, et al., 2011).

3.1. Reactivated memory from acquisition (RMA)

As noted above, Miller and Laborda's (2011) account of extinction proposes that the effectiveness of the RMA in controlling responding at test is determined in part by both the strength of the acquisition association and the facilitatory cues from acquisition present at test. To illustrate, we here describe some empirical examples concerning the role of these factors in responding after extinction treatment.

3.1.1. Strength of the X—O association formed during acquisition—The role of the strength of the X—O association on responding after extinction treatment has been largely ignored when theorizing about extinction and its recovery, in favor of other factors, such as the facilitatory role of the extinction context on these effects (e.g., Bouton, 1993). However, most researchers would agree that the strength of the X—O association plays a role in determining responding after nonreinforced treatment. According to Miller and Laborda (2011), enhancing the X—O association should increase the RMA, which is then stronger when it enters into the comparison process with the RME to determine responding. A stronger RMA should favor responding indicative of the acquisition memory at test (i.e., slower decreases in responding and/or more recovery from extinction than an appropriated control condition). A number of experimenters have explored whether the strength of the acquisition association influences responding during and after extinction treatment (e.g., Hill & Wallace, 1967; Spence et al., 1963; Wilton & Strongman, 1967). For instance, Spence et al. manipulated the strength of the acquisition memory, while keeping the strength of the extinction memory and the facilitatory cues from both acquisition and extinction constant. In Spence et al.'s conditioned eyelid experiment, college students received few (32) or many (64) acquisition trials, each consisting of the presentation of a tone (i.e., X) that coterminated with an air puff administered in the right eye (i.e., O). Immediately following this training, some participants received nonreinforced presentations of X (i.e., extinction). As can be seen in Figure 2A, on the first extinction trial, participants who received few and many acquisition trials did not differ in the level of conditioned responding to X (i.e., conditioned eyelid response); however, on the second and third nonreinforced trials and thereafter, participants who received more acquisition trials displayed higher levels of responding to X (i.e., slower extinction), suggesting that the strength of the X—O association directly influences responding after extinction treatment. Similarly, Todd et al. (2012; Experiment 2) recently reported that rats that received a large number of acquisition sessions (12 × 32-min sessions of barpressing for food in a variable interval 30 s schedule) in an appetitive instrumental renewal paradigm exhibited more ABA and ABC renewal than rats that received only a few acquisition sessions (4 instead of 12 barpressing sessions).

3.1.2. Facilitatory cues from acquisition present at test—In addition to the strength of the X—O association, the facilitatory cues (e.g., Holland, 1983; Rescorla, 1985) from acquisition that are present at test are also expected to influence the RMA, albeit not an influence as strong as the influence of facilitatory cues from extinction on the RME. Facilitatory cues are seemingly best established in circumstances in which there is ambiguity, such as when extinction treatment follows acquisition. Given that there is less ambiguity during acquisition training, the acquisition context may play only a modest role as a facilitatory cue at test. That is, X may reactivate the representation of O primarily as a function of the strength of the X—O association even in the absence of facilitatory cues from acquisition. However, all other things being equal, we should be able to assess the efficacy of the facilitatory cues from acquisition in responding at test.

Indeed, some reports suggest that manipulating the facilitatory cues from acquisition can in fact have an effect on behavior at test. For example, in Gunther et al.'s (1998) Experiment 2, rats received extinction treatment in multiple contexts (3) after acquisition training in 1 or 3

other contexts. Then, at test in a neutral context, subjects that received acquisition training in multiple contexts displayed more responding than subjects that received the same number of acquisition trials in a single context (i.e., stronger ABC renewal). These results suggest that increasing the number of contexts in which acquisition trials take place increases the facilitatory cues from acquisition that are present at test in a neutral context, encouraging responding indicative of the X—O association. Similarly, Todd et al. (2012; Experiment 4) recently reported that rats that received the same total number of acquisition sessions distributed in one or two contexts differed in the level of ABC renewal displayed after extinction treatment in a single context (see Figure 2B). Rats trained in two acquisition contexts exhibited stronger responding at the renewal test than rats trained in a single acquisition context, supporting the view that increasing the contexts of acquisition facilitates generalization from the acquisition to the test context. Moreover, subjects trained in two contexts exhibited slower rates of extinction than subject trained in a single context, which arguably implies that acquisition training in two contexts facilitated generalization of the acquisition memory to other contexts and/or that this type of training strengthened the memory of acquisition. Likely, both processes are involved when training in two instead of one context.

In situations in which the facilitatory cues from acquisition and from extinction are similar (as when acquisition and extinction occur in the same context and/or extinction occurs soon after acquisition), and the acquisition and extinction memories are also of comparable strengths, whether behavior indicative of the X—O or the X—noO association is expressed at test becomes a question of whether the subject can discriminate between the two sets of facilitatory cues (e.g., Capaldi & Neath, 1995).

3.2. Reactivated memory from extinction (RME)

Miller and Laborda's (2011) account of extinction proposes that the effectiveness of the RME in controlling responding at test is determined in part by both the strength of the extinction association and the facilitatory cues from extinction present at test. To illustrate, we here describe some empirical examples concerning the role of these factors in responding after extinction treatment.

3.2.1. Strength of the X—noO association formed during extinction—Just as the strength of the X—O association created during acquisition training influences responding after extinction treatment (see section 3.1.1), the strength of the X—noO association formed during extinction also has a role in determining responding to an extinguished cue. A number of studies have shown that a stronger X—noO association (made stronger by various means) encourages responding indicative of extinction at test (e.g., Denniston et al., 2003; Tamai & Nakajima, 2000; Urcelay et al., 2009; for a clinical parallel, see Powers et al., 2010). For instance, Denniston et al. manipulated the strength of the extinction memory by increasing the number of extinction trials, while keeping the acquisition memory strength and the facilitatory cues from acquisition and extinction constant in their critical groups. According to Miller and Laborda (2011), enhancing the X—noO association should increase the RME, which then is stronger when it enters to the comparison process with the RMA to determine responding at test. A stronger RME should favor responding indicative of nonreinforcement and result in less recovery from extinction. In Denniston et al.'s Experiment 1, all rats received fear conditioning in Context A, followed by extinction treatment in Context B. Groups Mod-Ext (ABB) and Mod-Ext (ABC) received a moderate number of extinction trials (160), while Group Mass-Ext (ABC) received a massive number of extinction trials (800). Finally, the ABB group was tested for responding in the context of extinction (B) and the ABC groups were tested in a neutral but familiar context (C). As can be seen in Figure 3A, after a moderate number of extinction trials, subjects tested in the

extinction context (i.e., Group Mod-Ext [ABB]) displayed reduced responding compared with a group in which testing occurred in a neutral context (i.e., Group Mod-Ext [ABC]). This effect was produced in part by testing subjects of the Mod-Ext (ABB) group in the context of extinction, under the influence of strong facilitatory cues from that treatment. Of central interest, less ABC renewal was evidenced with a massive number of extinction trials than with a moderate number of them (i.e., Group Mass-Ext [ABC] < Group Mod-Ext [ABC]), a manipulation that presumably strengthened the memory of extinction (X—noO). Likely, these results are also due to massive extinction occurring in several different temporal contexts, encouraging generalization to yet other temporal contexts.

Along similar lines, Urcelay et al. (2009) manipulated the strength of the extinction memory by spacing the extinction trials, while keeping the acquisition memory strength and the facilitatory cues from acquisition and extinction constant in their critical groups. Arguably, spacing the nonreinforced presentations of the target cue should enhance what is learned during extinction (just as spaced reinforced trials enhance what is learned during acquisition; e.g., Barela, 1999), thereby augmenting the RME, which promotes responding indicative of the X—noO association at test. Alternatively, this manipulation can also be seen as extinction in multiple *temporal* contexts, which encourage generalization to other temporal contexts, enhancing the RME and promoting low responding at test. Urcelay et al. tested whether spacing the extinction trials would decrease recovery from extinction after a physical (i.e., renewal) and a temporal (i.e., spontaneous recovery) context change from extinction treatment. As expected, after fear conditioning of an auditory cue in rats, spaced extinction trials (600-s intertrial intervals [ITI]) were more effective in decreasing either renewal or spontaneous recovery than massed extinction trials (6-s ITI), consistent with the expected role of the strength of the X—noO association on responding after extinction treatment.

3.2.2. Facilitatory cues from extinction—In addition to the strength of the X—noO association, the facilitatory cues from extinction present at test are also expected to influence the RME. Given the inherent ambiguity of an extinguished cue (which has been sequentially reinforced and then nonreinforced), strong facilitatory properties should be acquired by the context of extinction (where ambiguity is created) and other cues present during extinction treatment (e.g., Bouton, 1993). These facilitatory properties are expected to play an important role in determining responding to the cue after extinction (e.g., Bouton, 1993; Rosas et al., 2006), which has been supported by a number of experimental studies (e.g., Brooks & Bouton, 1993, 1994; Gunther et al., 1998; Laborda, Miguez, et al., 2012). In these studies, facilitatory cues from extinction have been manipulated while the memory strengths from acquisition and extinction, and the facilitatory cues from acquisition presented at test have been kept constant. The typical control group from renewal studies can be viewed as an example of the role of facilitatory cues from extinction reducing responding at test, as exemplified when comparing ABA and ABC renewal to a ABB control condition, where the B context at test serves as a facilitatory cue for the extinction memory.

In an interesting set of articles, Brooks and Bouton (1993, 1994) found that ABA renewal and spontaneous recovery were both reduced when a facilitatory cue from extinction (in this case an extinction cue) was presented at test. More specifically, when Brooks and Bouton presented a non-target cue during extinction treatment, this extinction cue was later able to reduce the strong responding expected at test, given that testing occurred back in the acquisition context after extinction in a different context (Brooks & Bouton, 1994) or after a long delay from extinction (Brooks & Bouton, 1993).

In related research, Gunther et al. (1998; Experiment 1) tested whether incrementing the number of contexts in which extinction takes place (while keeping other parameters

constant) would decrease recovery after a physical context change (see Figure 3B). In line with Miller and Laborda's (2011) views, extinction of a cue in multiple contexts should increase the number of potential facilitatory cues from extinction that are present at test, thereby effectively enhancing context generalization. As expected, after fear conditioning of an auditory cue in rats, extinction training in three different contexts (Group Ext-Mult) was more effective in decreasing ABC renewal than the same number of extinction trials in a single context (Group Ext-Sing). Similarly, Laborda, Miguez, et al. (2012; Experiment 2) tested whether spacing the extinction *sessions* would decrease recovery from extinction in a situation in which renewal and spontaneous recovery summate to produce strong recovery. Spacing the extinction sessions should increase the number of potential facilitatory cues from extinction to a different temporal test context (i.e., enhanced temporal context generalization). As expected, after fear conditioning of an auditory cue in rats, spaced extinction sessions (7-d intersession interval) were more effective in decreasing conjoint renewal and spontaneous recovery than were massed extinction sessions (10-m intersession interval). Alternatively, these manipulations (extinction in many different contexts) might work by freeing extinction learning from control by facilitatory cues, instead of merely increasing generalization.

3.3. Compounding techniques to enhance the RME

Recently, two series of studies have found that independent behavioral techniques to prevent the recovery from extinction will summate. As can be seen in Figure 4A, Laborda and Miller (2012; Experiment 2) have reported an experiment in which extinction in multiple contexts (Group Mod-Ext/Ext-Mult) and massive extinction training (Group Mass-Ext/Ext-Sing) attenuated strong recovery arising from conjoint renewal and spontaneous recovery. This extends Gunther et al.'s (1998) and Denniston et al.'s (2003) results. More importantly, when both techniques were used together, recovery from extinction was further reduced (Group Mass-Ext/Ext-Mult). As can be seen in Figure 4B, along similar lines Laborda, Miguez, et al. (2012; Experiment 3) have reported an experiment in which spacing the extinction *trials* (Group Mass-ExtSessions/Spac-ExtTrials) and spacing the extinction *sessions* (Group Spac-ExtSessions/Mass-ExtTrials) attenuated conjoint renewal and spontaneous recovery. Note that different mechanisms presumably underlie these two effects as spacing extinction trials results in more time in the extinction context, presumably extinguishing associations to that context, whereas when extinction sessions are spaced, the added time is not spent in the extinction context. More importantly, when both techniques were used together, strong recovery from extinction due to conjoint renewal and spontaneous recovery was further reduced (Group Spac-ExtSessions/Spac-ExtTrials). These reports further support the idea that strengthening the extinction memory (by increasing the number of extinction trials and by spacing the extinction trials) and increasing the potential facilitatory cues from extinction present at the moment of testing (by increasing the number of physical and temporal contexts in which extinction takes place) summate to reduce recovery from extinction more than either technique alone (Miller & Laborda, 2011).

4. Final Remarks

In this article, evidence supporting an interference account of extinction and its recovery has been presented. As proposed by Miller and Laborda (2011), it appears that responding after extinction training is determined by a comparison at test of the reactivated memory of extinction and the reactivated memory of acquisition. Centrally, each of these memories appears to be proportional to the strength of the stored stimulus-outcome association (X—O from acquisition and X—noO from extinction) and the effectiveness of facilitatory cues present at test. Accordingly, manipulations that (arguably) enhance the X—O association (e.g., Spence et al., 1967), and treatments that increase the facilitatory cues from acquisition present at test (e.g., Todd et al., 2012), both promote responding indicative of acquisition.

Similarly, manipulations that (arguably) enhance the X—noO association (e.g., Denniston et al., 2003) and treatments that (arguably) increase the facilitatory cues from extinction present at test (e.g., Gunther et al., 1998) both promote responding indicative of extinction. Moreover, manipulations that seem to enhance the X—noO association and treatments that seem to increase the facilitatory cues from extinction at test have been shown to summate to enhance responding indicative of extinction (e.g., Laborda, Miguez, et al., 2012; Laborda & Miller, 2012).

Importantly, the general interference account of extinction and its recovery described and supported in the present article has and continues to suggest manipulations for attenuating recovery from extinction, thereby recommending treatments to reduce relapse after exposure therapy (see Laborda, McConnell, et al., 2011).

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Highlights

>The response decrement resulting from extinction treatment can be viewed as an interference effect, in which the reactivated memory from acquisition competes with the reactivated memory from extinction for behavioral expression. >Reactivation of each memory is proportional to both the strength of the stimulus-outcome association and the quality of the facilitatory cues for that association which are present at test. > This suggests procedures that might reduce relapse from exposure therapy for a number of psychological disorders. Some of these manipulations enhance the facilitatory cues from extinction that are present at test, others strengthen the extinction association (i.e., CS-no outcome), and yet others seem to work by a combination of these two processes.

Figure 1.

Diagram of Miller and Laborda's interference account of extinction and its recovery (adapted from R.R. Miller, M.A. Laborda, 2011. *Curr. Dir. Psychol. Sci.* 20, 325–329). Responding at test is determined by a comparison between the reactivated memory from acquisition (RMA; which is proportional to the strength of the X—O association and the facilitatory cues from acquisition present at test) and the reactivated memory from extinction (RME; which is proportional to the strength of the X—noO association and the facilitatory cues from extinction present at test).

Figure 2.

A) Percentage of conditioned eyelid responses to the target cue during the first eleven extinction trials. Few = group that received 32 acquisition trials. Many = group that received 64 acquisition trials. See text for further details (adapted from K.W. Spence, E.F. Rutledge, J.H. Talbott, 1963. *J. Exp. Psychol.* 66, 286–291). B) Mean barpress response per minute in the extinction and renewal contexts. One Acq Ctx = subjects that received acquisition training in a single context. Two Acq Ctx = subjects that received acquisition training in two contexts. See text for further details (adapted from T.P. Todd, N.E. Winterbauer, M.E. Bouton, 2012. *Experiment 4. Learn. Behav.* [in press]).

Figure 3.

A) Mean log time to complete 5 cumulative seconds of licking in the presence of the target cue. Mod-Ext = 160 extinction trials. Mass-Ext = 800 extinction trials. ABB = subjects tested in the context of extinction treatment. ABC = subjects tested in a neutral context. See text for further details (adapted from J.C. Denniston, R.C. Chang, R.R. Miller, 2003. Experiment 1. *Learn. Motiv.* 34, 68–86). B) Mean log time to complete 5 cumulative seconds of licking in the presence of the target cue in a neutral context. Ext-Sing = group that received extinction treatment in a single context. Ext-Mult = group that received extinction treatment in 3 different contexts. See text for further details (adapted from L.M. Gunther, J.C. Denniston, R.R. Miller, 1998. Experiment 1. *Behav. Res. Ther.* 36, 75–91).

Figure 4.

A) Mean log time to complete 5 cumulative seconds of licking in the presence of the target cue in a neutral context after a long delay from extinction treatment. Mod-Ext = condition that received 162 extinction trials. Mass-Ext = condition that received 810 extinction trials. Ext-Sing = condition that received extinction treatment in a single context. Ext-Mult = condition that received extinction treatment in 3 different contexts. See text for further details (adapted from M.A. Laborda, R.R. Miller, 2012. Experiment 2. Manuscript submitted for publication). B) Mean log time to complete 5 cumulative seconds of licking in the presence of the target cue in a neutral context after a long delay following extinction treatment. Mass-ExtSessions = condition that received massed extinction sessions. Spac-ExtSessions = condition that received spaced extinction sessions. Mass-ExtTrials = condition that received massed extinction trials. Spac-ExtTrials = condition that received

spaced extinction trials. See text for further details (adapted from M.A. Laborda, G. Miguez, R.R. Miller, 2012. Experiment 3. Manuscript submitted for publication).