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Relapse processes after the extinction of instrumental learning: Renewal, resurgence, and reacquisition

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Abstract

It is widely recognized that extinction (the procedure in which a Pavlovian conditioned stimulus or an instrumental action is repeatedly presented without its reinforcer) weakens behavior without erasing the original learning. Most of the experiments that support this claim have focused on several “relapse” effects that occur after Pavlovian extinction, which collectively suggest that the original learning is saved through extinction. However, although such effects do occur after instrumental extinction, they have not been explored there in as much detail. This article reviews recent research in our laboratory that has investigated three relapse effects that occur after the extinction of instrumental (operant) learning. In renewal, responding returns after extinction when the behavior is tested in a different context; in resurgence, responding recovers when a second response that has been reinforced during extinction of the first is itself put on extinction; and in rapid reacquisition, extinguished responding returns rapidly when the response is reinforced again. The results provide new insights into extinction and relapse, and are consistent with principles that have been developed to explain extinction and relapse as they occur after Pavlovian conditioning. Extinction of instrumental learning, like Pavlovian learning, involves new learning that is relatively dependent on the context for expression.

There is now a broad consensus that extinction, the procedure in which a Pavlovian conditioned stimulus (CS) or an instrumental action or response occurs repeatedly without its reinforcer, generally decreases learned behavior without erasing the original learning. The consensus is based largely on a growing body of evidence indicating that an extinguished response can readily return with certain treatments or manipulations—and has thus been “saved” through extinction (e.g., Bouton, 2004). We have suggested that, instead of creating unlearning, extinction gives the Pavlovian CS or the instrumental action a new second “meaning” that is stored in memory along with the first, thus creating a CS or action whose current meaning is ambiguous (e.g., Bouton, 1988, 2002, 2004). And like the response evoked by an ambiguous verbal stimulus (i.e., a word with more than one meaning), the response observed after extinction pivots on what the current context retrieves.

Most of the evidence that supports this claim comes from studies of extinction after Pavlovian conditioning. That research, which has been reviewed in several recent papers (e.g., Bouton & Woods, 2008; Myers & Davis, 2007; Laborda, McConnell, & Miller, 2011),

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has emphasized several key results that have become central to our understanding of extinction. For example, in the *renewal effect*, extinguished responding returns if the context is changed after extinction (e.g., Bouton & Bolles, 1979a; Bouton & King, 1983). Renewal implies that extinction performance is not permanent, and that it depends on the context. In *reinstatement*, extinguished responding returns if the unconditioned stimulus (US) is presented by itself before the CS is tested again (e.g., Rescorla & Heth, 1975). Because reinstatement depends on the US being presented in the same context in which the CS is subsequently tested (e.g., Bouton, 1984; Bouton & Bolles, 1979b; Bouton & King, 1983), it is another context effect; casually speaking, the animal responds to the CS again if it expects the US in the contemporary context. In *spontaneous recovery*, extinguished responding returns if time elapses after extinction. That result can be understood as a renewal effect that occurs when the CS is tested outside extinction's *temporal* context (e.g., Bouton, 1988, 1993). And in *rapid reacquisition*, extinguished responding can return abruptly if CS-US pairings are begun again after extinction (e.g., Napier, Macrae, & Kehoe, 1991; Ricker & Bouton, 1996). Later in this article we describe evidence suggesting that reacquisition may be rapid because the new CS-US pairings return the subject to the context of conditioning (recent CS-US trials were part of the context in which other conditioning trials have occurred). It is therefore another kind of renewal effect. Thus, these four phenomena, and the research literatures that surround them, illustrate not only that extinction is not erasure, but that the responding one observes after extinction depends importantly on the contemporary context.

Renewal, reinstatement, spontaneous recovery, and rapid reacquisition have increasingly been described as “lapse” and “relapse” effects (e.g., Bouton, Woods, Moody, Sunsay, & García-Gutiérrez, 2006; Laborda et al., 2011). This is because, in addition to being a naturally-occurring behavior-change process, extinction is thought to be involved in cognitive behavior therapies that are designed to eliminate learned but unwanted thoughts, behaviors, and emotions such as fear and anxiety disorders (e.g., Craske, Kircanski, Zelikowsky, Mystkowski, Chowdhury, & Baker, 2008). The implication of these effects is that the elimination of classically-conditioned behaviors by extinction is not permanent, and that the eliminated behavior can readily return. Thus, studying renewal, reinstatement, spontaneous recovery, and rapid reacquisition may tell us about some of the mechanisms of clinical relapse (and methods that can be used to prevent it) in addition to the basic extinction process.

Although there is evidence that the relapse effects can also occur after instrumental extinction (e.g., see Bouton, Winterbauer, & Vurbic, 2011, for a review of the drug self-administration literature), research on them using operant and instrumental learning methods has been sparse and less systematic. This is unfortunate, because instrumental learning is crucial to understanding many other examples of disordered behavior such as substance abuse (e.g., Higgins, Heil, & Lussier, 2004) and eating and overeating (e.g., Bouton, 2011). The purpose of the present article is thus to review our laboratory's relatively recent research on relapse phenomena that occur after extinction of instrumental (operant) learning. We will focus on renewal, rapid reacquisition, and *resurgence*, an instrumental extinction effect that has received relatively little attention in the Pavlovian-dominated extinction literature. The results of our experiments confirm that the conceptual tools and principles that have been developed to understand Pavlovian extinction do apply to instrumental extinction. They have also uncovered new insights about relapse.

Renewal after the extinction of instrumental learning

Renewal is a particularly important recovery effect following extinction. Three different forms of renewal have been established in studies of Pavlovian extinction (for an overview

see Bouton, 2004). In the simplest, ABA renewal, the animal receives a conditioning experience in one context (Context A), extinction in a different context (Context B), and then testing in the original Context A. (The contexts are usually provided by different sets of conditioning chambers that differ in their location in the lab and in their olfactory, visual, and tactile respects.) The conditioned response reliably returns upon presentation of the CS in Context A (e.g., Bouton & Bolles, 1979a; Bouton & King, 1983). In ABC renewal, acquisition occurs in Context A, extinction in Context B, and then testing in Context C. Here again, the conditioned response renews even when every phase of the experiment occurs in a new context (e.g., Bouton & Bolles, 1979a). In AAB renewal, acquisition and extinction occur in the same Context A, and the animal is tested in a second context (Context B), which again causes a return to responding to the CS (e.g., Bouton & Ricker, 1994). ABC and AAB renewal both suggest that some sort of inhibition in the extinction context plays a role in producing renewal—mere removal of that inhibition by testing outside the extinction context is sufficient to cause it to happen. A variety of research suggests, though, that under common conditions, the phenomenon does not depend on direct context-US inhibitory associations (or excitatory associations in Context A) (e.g., Bouton & King, 1983; Bouton & Swartzentruber, 1986). We have suggested that renewal is mainly controlled by an occasion setting mechanism in which the extinction context retrieves or activates the CS's current association with no US (e.g., Bouton, 1993). Much like a verbal context that disambiguates the meaning of an ambiguous word, it signals the CS's current meaning, or whether or not it will be paired with a US.

There has now been quite a bit of research investigating the renewal effect in Pavlovian extinction (e.g., Bouton & Woods, 2008). In contrast, as noted earlier, there has been less research on the phenomenon in instrumental learning. In the instrumental case, the reliability of the different forms of renewal has not been clear until recently. ABA renewal of lever pressing has been reported in both the learning literature with food reward (e.g., Nakajima, Tanaka, Urushihara, & Imada, 2000) and in the drug-conditioning literature with a number of drugs as reinforcers (e.g., heroin-cocaine combination, Crombag & Shaham, 2002; heroin, Bossert, Lu, Liu, & Shaham, 2004; cocaine, Hamlin, Clemens, & McNally, 2008, Kearns & Weiss, 2007; alcohol, Hamlin, Newby, & McNally, 2007). However, several of these reports failed to produce evidence of AAB renewal (Bossert et al., 2004; Crombag & Shaham, 2002; Nakajima et al., 2000). Zironi, Burattini, Aicardi, and Janak (2006) found preliminary evidence that lever presses reinforced by sucrose may produce ABC renewal, but that ethanol reinforcers did not (unfortunately, the positive sucrose-pellet experiment did not counterbalance the test contexts). The comparative lack of evidence of ABC and AAB renewal was theoretically important, because these phenomena are essential in forcing the conclusion that extinction is more context-specific than conditioning. If conditioning and extinction were equally context-dependent, they would generalize equally to a new context, and there would be no basis for ABC or AAB renewal.

We therefore conducted several experiments that explored all three forms of renewal in instrumental conditioning with rats (Bouton, Todd, Vurbic, & Winterbauer, 2011). Food pellets were used as the reinforcer. The first experiment examined the relative magnitudes of ABA and AAB renewal. Hungry rats were first conditioned to press a lever for food pellets on a variable interval 30-sec schedule of reinforcement (VI 30) in Context A. (Pellets were made available with a 1/30 probability each second.) Once a high rate of the lever press responding was established, half the animals then received extinction (i.e., were allowed to lever press while pellets were omitted) for several sessions in Context B, while the other half received the same treatment in Context A. In two final sessions, all animals were then, in a counterbalanced order, returned to Context A and Context B and allowed to press the lever (again under extinction). As can be seen in Figure 1, rats in both groups pressed more in the

renewal context than in the extinction context. Both ABA renewal, and for the first time AAB renewal, were clearly observed.

While the ABA effect was significantly stronger than the AAB effect, neither was ambiguous; indeed, 100% of rats in either group pressed more in the renewal context than in the extinction context. Previous failures to obtain the AAB effect (e.g., Bossert et al., 2004; Crombag & Shaham, 2002; Nakajima et al., 2000) used more extensive extinction training. In Pavlovian conditioning, AAB renewal appears to be prevented by extended extinction (Tamai & Nakajima, 2000), so our next experiment asked whether AAB renewal would be weakened by giving the rats three times as much extinction training as they had been given in the first. It was not; AAB remained reliable even with triple the amount of extinction. This finding suggests that, rather than an effect of parametric choices, our ability to detect AAB renewal relied more upon the within-subjects nature of the experimental design. It is worth noting that the context changes that a drug user or overeater experiences in life are invariably also manipulated within-subject.

An additional experiment employed the same within-subjects procedure to show a robust (and reliable) ABC renewal effect. When rats acquired lever pressing in Context A, were extinguished in a second Context B, and were then tested in both Context B and Context C, 15 of 16 rats responded more in the relatively neutral context (Context C) than in the extinction context (Context B). There can thus be little doubt that ABA, AAB, and ABC renewal occurs after instrumental extinction.

These experiments together show that, just as in Pavlovian conditioning, removal from the extinction context after instrumental extinction is sufficient to cause a lapse in behavior. In renewal, context change evokes responding (or removes the inhibitory effects of the extinction context upon responding) without further exposure to any reinforcer. In clinical application, the critical observation is that actions or habits that have been inhibited in some context may return and lapse in a new one. A drug user or an overeater might lose access to the inhibitory “tools” he or she has learned to suppress drug use or overeating, and once again engage in these behaviors when returned to the original or a new context.

While these initial experiments suggested that the theoretical principles developed to understand Pavlovian extinction may apply to the extinction of instrumental behavior, the rats were food-deprived and hungry (as most subjects are in the instrumental learning literature) throughout the experiment. In contrast, problematic overeating, drug abuse, and gambling seem to occur in the absence, at least initially, of a biological deficit for the reinforcer. Such behaviors are acquired in the absence of an actual need. We have therefore begun to study acquisition, extinction, and renewal in rats that have food available on an ad lib basis in the home cage. When they are introduced to the Skinner box, the rats can lever press for either 100% sucrose pellets or high-fat pellets (38% Kcal from fat)—basically, the rat version of junk food. We (Todd, Winterbauer, & Bouton, 2012a) have found that non-deprived rats readily learn to lever press for such pellets, reaching response rates of nearly half the rates reached by deprived rats lever pressing for grain-based pellets reach after the same amount of training. We have then studied extinction of lever pressing and renewal. In the experiment shown in Figure 2, non-deprived rats learned to lever press for sweet or sweet/fatty pellets in Context A and then received extinction of lever pressing in Context B. A final test in both Context B and Context A (counterbalanced order) showed renewed food-seeking in Context A. (To date, there has never been a difference in results with the sweet or sweet/fatty pellets.) A second experiment also demonstrated AAB renewal in this method. It seems clear that even rats without an explicit need for food will learn to work for a tasty food pellet, extinguish normally, and then lapse the way food-deprived rats do.

From either a theoretical or a practical perspective, it is important to understand the variables that increase or decrease the strength of the renewal effect. Since, as we have already noted, ABC renewal in the instrumental situation is not as strong as ABA renewal (although a substantial proportion of the rats respond more in the non-extinction context), we chose to investigate how to strengthen it. Overeaters, drug users, and gamblers typically undergo a very substantial amount of early instrumental learning before inhibition is invoked to control it. In contrast, our early experiments involved a rather minimal amount of training (four or five 30-min sessions only). So an obvious possibility is that ABC renewal might strengthen after more extensive training. Theoretically, if ABC renewal acts by removing an inhibitory influence of the extinction context that has been masking a baseline tendency to respond, the strength of the initial response tendency should manifest itself following that removal.

In an initial experiment (Todd, Winterbauer, & Bouton, 2012b), we allowed one group of hungry rats to acquire lever pressing over four days, while another group of rats was trained for a period of 12 days, all in an initial Context A. All rats were then given four days of extinction in Context B. Finally, rats were tested both in the extinction Context B and a different, renewal Context C. While we replicated the ABC renewal effect, and animals given triple the usual acquisition training lever pressed more rapidly both at the end of acquisition and throughout extinction. However, the more extensive acquisition had no detectable effect upon the amount of renewal. In a subsequent experiment, we found that extensive acquisition *did* increase ABC renewal when we used modified chambers of the same manufacturer's model number and type (which supported more generalization) for Contexts A and C. We also found that more extended training increased the strength of ABA renewal. Thus, increasing the amount of training appears to matter as long as generalization between the context in which the training takes place (A) and the test context (either Context A itself or a similar Context C) is allowed to play a role.

In the natural world, in addition to having long histories of reinforcement, people with substance abuse or overeating problems have often performed their instrumental behaviors (and been reinforced for doing so) in many contexts. This certainly seems true of food consumption in modern America, where people can be seen eating nearly everywhere, including public and private transportation, business or academic meetings, the classroom, movies, sporting events, etc. (see Kessler, 2009). We (Todd et al., 2012b, Experiment 4) therefore asked whether a history of conditioning in more than one context might also strengthen the ABC renewal effect. Rats initially learned to lever press on a VI-30 schedule in either one context (Context A) or two contexts (Contexts A and D), with the total amount of session time controlled. They then received extinction in Context B and then testing in Contexts B and C. As shown in Figure 3, training in multiple contexts enhanced the amount of responding we observed during extinction in Context B as well as the ABC renewal effect. (The effect of training in multiple contexts on ABC renewal had previously been studied in Pavlovian fear conditioning by Gunther, Denniston, and Miller [1998]). We suggested that training in multiple contexts increased the probability that contextual elements associated with conditioning would be encountered in the new context (e.g., Atkinson & Estes, 1963). The results thus suggest that the amount of generalization from training to testing (in addition to the amount of training) can be important in increasing the strength of renewal. As noted above, overeaters and drug takers seem likely to satisfy these conditions, increasing the plausibility that renewal phenomena may contribute to the apparent persistence of these behaviors.

How, then, can lapse in the form of renewal be prevented or attenuated? We already noted that tripling the amount of exposure to the new response – no reinforcer contingency can be surprisingly ineffective (Bouton et al., 2011, Experiment 4). But we reasoned that if direct

associations between the test context and the reinforcer might contribute to the strength of ABA renewal (and perhaps explain its strength relative to AAB and ABC renewal, see Figure 1), then simple extinction exposure to the test context might help reduce the effect. We therefore tested this possibility in an experiment (Bouton et al., 2011, Experiment 4) in which one group of rats received our usual ABA renewal paradigm, where operant training in A was followed by the extinction of lever pressing in B before testing in A and B. A second, experimental group was exposed to the Context A for four 30-min sessions (without the lever present) for every 30-min session they received lever press extinction in Context B. Although the 16 extra exposures to A were expected to extinguish Context A's direct association with food, as shown in Figure 4, they had no impact on either the rate of extinction of lever pressing in B or (more surprisingly) the amount of renewal observed during final testing in Context A. As can be seen in Figure 4, the magnitude of renewal was identical whether or not Context A had undergone the extra extinction treatment. This result supports the idea that excitatory Pavlovian associations between the renewal context and reward do not play a major role in instrumental renewal. It is instead consistent with the idea that Context A may be an occasion setter (or discriminative stimulus) that signals whether or not a response-reinforcer relation will be in force. For example, Rescorla (1986) has shown that a Pavlovian occasion setter is similarly unaffected by simple extinction. This may have important treatment implications. For example, simple extinction exposure to drug-related cues often has little effect at reducing drug intake (Conklin & Tiffany, 2002). Moreover, the results might imply that what is generalizing in the studies described above might be the acquisition context's ability to signal the action-outcome relation, rather than its direct association with the outcome.

A somewhat different way to reduce renewal could be to deepen the learning that occurs during the extinction phase. This has indeed been a general strategy for reducing relapse effects (e.g., see Bouton et al., 2006). For example, in studies of fear extinction, there has been considerable interest in the possibility that the administration of d-cycloserine (DCS), a partial agonist of the NMDA receptor that mediates long-term potentiation (a cellular model of learning), might facilitate the learning of extinction. A number of reports from several laboratories have indicated that DCS can facilitate the rate at which fear extinction is learned (e.g., Ledgerwood, Richardson, & Cranney, 2003; Walker, Ressler, Lu, & Davis, 2002). Such results are consistent with the idea that extinction is new learning, because NMDA receptors are known to influence new learning. However, we have shown that renewal of extinguished fear is still observed after extinction in combination with DCS (Bouton, Vurbic, & Woods, 2008; Woods & Bouton, 2006). Thus, DCS does not qualitatively change the nature of extinction learning—it may be more rapid, but it is still relatively specific to its context. DCS has also been shown to facilitate extinction of a conditioned place preference with drug unconditioned stimuli (e.g., Botreau, Palone, & Stewart, 2006; Groblewski, Lattal, & Cunningham, 2009; Thanos, Bermeo, Wang, & Volkow, 2009), and in some cases, the extinction of an operant response reinforced by drugs of abuse (Nic Dhonnchadha, Szalay, Achat-Mendes, Platt, Otto, Spealman, & Kantak, 2010; Shaw, Norwood, Sharp, Quigley, McGovern, & Leslie, 2009; Vengeliene, Kiefer, & Spanagel, 2008). One complicating issue for the latter experiments, though, is that they all presented an explicit conditioned reinforcer (a cue that had been associated with drug delivery during training) during the extinction phase, thus allowing Pavlovian extinction of the conditioned reinforcer to play a role. Does DCS facilitate the extinction of pure operant learning? Vurbic, Gold, and Bouton (2011) studied effects of DCS on extinction using procedures like those summarized above, where no explicit conditioned reinforcer was present in acquisition or extinction (no tone, light, or lever withdrawal was presented with the reinforcer or at the time a reinforcer would have been scheduled in extinction). In four experiments that involved simple extinction, extinction with additional presentations of noncontingent food reinforcers (designed to reduce the role of simple generalization decrement), and a discriminated operant procedure

in which lever pressing was only reinforced during presentation of a visual discriminative stimulus, we found no effect of DCS on extinction. The results of the discriminated operant experiment are summarized in Figure 5. As can be seen, there was no effect of any of three doses of DCS in extinction, during tests in the extinction context, or back in the original context. (The 15 mg/kg and 30 mg/kg doses have both been effective at facilitating fear extinction in our laboratory [e.g., Bouton et al., 2008].) Notice that the experiment also demonstrates ABA renewal in a discriminated operant procedure (see also Kearns & Weiss, 2007; Nakajima et al., 2000.) One explanation for the failure of DCS to affect operant extinction in our laboratory is that DCS might affect Pavlovian extinction processes more than purely operant processes. Consistent with that hypothesis, a recent pair of experiments with mice suggests that DCS enhances operant extinction when a conditioned reinforcer is present during extinction, but not when it is absent (Thanos et al., 2011).

There are other methods that might help to reduce or defeat the renewal effect, however. Kearns and Weiss (2007) found that pairing a cocaine discriminative stimulus with noncontingent food reinforcers during extinction attenuated (but did not eliminate) the ABA renewal of cocaine-seeking behavior in rats. We have suggested that methods that encourage generalization from the extinction to testing contexts—so called “bridging” treatments—might be especially helpful in reducing the renewal effect (Bouton et al., 2006). For example, presenting cues that help retrieve extinction at the time of testing can attenuate renewal (e.g., Brooks & Bouton, 1994; Collins & Brandon, 2002). Some investigators have also reduced renewal by conducting extinction in more than one context (e.g., Chaudri, Sahuque, & Janak, 2008; Gunther et al., 1998; Thomas, Vurbic, & Novak, 2009; but see Bouton, Garcia, Gutierrez, Zilski, & Moody, 2006; Neumann, Lipp, & Cory, 2007). One explanation of the latter effect is that extinction in multiple contexts might associate extinction with a broader range of contextual elements that are more likely to be present in (and thus create generalization to) a renewal context. Although the retrieval cue and multiple context extinction treatments have been shown to weaken Pavlovian renewal, they have yet to be investigated in the case of instrumental extinction.

Resurgence after the extinction of instrumental learning

Another form of relapse that can occur after instrumental extinction is known as resurgence. In this phenomenon, an operant behavior (e.g., pressing one lever) is first reinforced and then extinguished. While the first behavior is undergoing extinction, a second, alternative behavior (e.g., pressing a second lever) is trained and reinforced. When that alternative behavior is then itself extinguished, the first behavior can return or “resurge” (e.g., Leitenberg, Rawson, & Bath, 1970; Leitenberg Rawson, & Mulick, 1975). The phenomenon again suggests that extinction, even when combined with explicit training of a new behavior, does not cause erasure. It suggests that a person trying to reduce (extinguish) instrumental food- or drug-seeking while learning a new replacement behavior (e.g., jogging, reading, or gardening) might undergo lapse and relapse when the new behavior undergoes extinction. Interestingly, successful “contingency management” treatments for drug taking or overeating (Higgins, Heil, & Lussier, 2004; Volpp, John, Troxel, Norton, Fassbender, & Loewenstein, 2008) work by reinforcing new behaviors to replace target ones. However, they too can be subject to relapse over time (e.g., Volpp et al., 2008).

At least three accounts of resurgence have been proposed. We (Winterbauer & Bouton, 2010; see also Bouton & Swartzentruber, 1991) have suggested that resurgence might be another example of the renewal effect, where the new behavior and its reinforcement might act as a context for extinction of the first response. When this context then changes, as it does when the replacement behavior is no longer reinforced, renewed responding would be consistent with an ABC renewal effect. Alternatively, Shahan and Sweeney (2011; see also

Podlesnik & Shahan, 2009) have interpreted the phenomenon in terms of behavioral momentum theory (e.g., Nevin & Grace, 2000). In brief, when reinforcement of a new behavior is added to extinction, it causes additional disruption of the original behavior while the reinforcement also increases a process that indirectly strengthens the original response. Resurgence of the first behavior occurs when the disruption is removed. Finally, the original experiments on resurgence suggested a third possible explanation. Leitenberg, Rawson, and colleagues (e.g., Leitenberg et al., 1970, 1975; Rawson, Leitenberg, Mulick, & Lefebvre, 1977) developed a “response prevention” hypothesis: They suggested that performing a new response during extinction suppressed the original one and thus prevented the animal from learning the extinction contingency. Hence, when the second response was removed from the animal’s behavior, there would be a relatively unextinguished first response ready to reemerge in behavior.

Winterbauer and Bouton (2010) reported several experiments that explored the resurgence phenomenon in our laboratory. One experiment (Experiment 3) showed that resurgence depends upon the original response’s history of reward, and is not merely an effect of frustration and/or response generalization following extinction of the second response. Only rats that had been reinforced for pressing Lever 1 (instead of receiving simple exposure to it or free food exposure in its presence) showed a substantial increase in responding on the first lever when the second behavior was extinguished. Other experiments addressed the response prevention hypothesis. In Experiment 1, three groups first learned to press Lever 1, which was reinforced on a VI 30 s schedule of reinforcement, over five sessions. Following acquisition, the groups then received extinction of Lever 1 responding during sessions in which a novel second lever was also inserted into the chamber. For the control group, presses on Lever 1 and Lever 2 were never reinforced. For the other groups, presses on the new lever were reinforced on either a VI 10 or VI 30 s schedule. Animals given the richer (VI 10) reinforcement schedule made fewer Lever 1 presses than the extinction control group (and thus experienced “response prevention”). But animals given the VI 30 treatment did not; they pressed the original lever at the same rate as the extinction control group. Nevertheless, both resurgence groups demonstrated strong and apparently equivalent resurgence, suggesting that response prevention is not necessary to produce the effect. A second experiment (Experiment 2) reinforced this conclusion further: After initial Lever 1 training on a VI 10 s schedule, rats received Lever 1 extinction alone or in combination with reinforcement of the new lever on VI 10 or VI 30. Here, the latter group pressed Lever 1 *more* than the extinction group during extinction. However, despite that result, there was clear and apparently equivalent resurgence in the groups that had received VI 10 and VI 30. Response rate on Lever 1 during extinction (compared to extinction controls) thus appears to bear little relation to the strength of resurgence in our methods.

A final experiment (Experiment 4) suggested that the nature of the contingency between Lever 2 responding and reward during extinction is not especially important. Four groups first received Lever 1 training with a VI 30 s schedule. They then received extinction, either without reinforcement of a second response (in the control group) or while pellets were delivered according to one of three schedules. A master group received a pellet for every 10th response on Lever 2 (an FR 10 schedule). A second group received the same pellets at the same times, but not contingent on pressing Lever 2 (each rat in this group was yoked to a rat in the master group). A final group could earn a pellet by pressing Lever 2 if and only if a master rat had earned a pellet; these animals functionally received a VI (rather than an FR) reinforcement schedule (cf. Leitenberg et al., 1975, Experiment 2). The procedure gave the experimental groups the same rate and distribution of reinforcement during the extinction phase. And remarkably, they all showed similar resurgence. Levels of resurgence were indistinguishable among groups that had received ratio, interval, or no contingency between Lever 2 responding and reward in Phase 2.

More recent experiments have investigated methods that might strengthen or weaken the resurgence effect. We discovered that an even greater level of resurgence can be produced with more extensive initial Lever 1 training, and with the use of ratio schedules rather than interval schedules of reinforcement (Winterbauer, Lucke, & Bouton, in press). Figure 6 illustrates the results. Rats were first given instrumental conditioning on Lever 1. Two groups earned pellets on a variable ratio (VR) 16 schedule of reinforcement, in which 16 responses were required (on average) to produce a food pellet. Two other groups were yoked so that they could earn a pellet for the first response after a partnered master rat had earned one (resulting in a VI 23 s schedule of reinforcement). The yoking procedure matched the VR and VI schedules on reinforcement rate and distribution. One group from each condition received only four sessions of training, while the second group from each condition received more extended training (12 sessions). As Figure 6 illustrates, rats given extended training responded faster at the end of training than those given the abbreviated training, and animals on the ratio schedule achieved higher levels of responding than those on the interval schedule (as expected, e.g., Dawson & Dickinson, 1990). All groups then received three sessions of extinction of the initial lever while Lever 2 was rewarded on FR 10. During testing, when responses on both levers were extinguished, each group resurged on Lever 1. The final level of resurgence reflected independent effects of both the amount and nature (VR vs VI) of the Phase 1 training. It is worth emphasizing that the VR and VI groups received the reinforcer at the same rate during Phase 1. Resurgence thus reflected *response rate* at the end of training, possibly because what recovers is the original pattern of responding. The result may be compatible with data reported by Cançado and Lattal (2011), who found resurgence of specific temporal patterns of responding that had been learned during the first phase.

Like other forms of relapse, resurgence can be robust and difficult to eliminate even with extensive Phase 2 training. Winterbauer et al. (in press) found that after 12 sessions of conditioning with Lever 1 on a VI 30 schedule, either 4, 12, or 36 sessions of extinction with Lever 2 reinforced (on FR 10) allowed robust and apparently equivalent levels of resurgence. In contrast, Leitenberg et al. (1975, Experiment) had found that 27 sessions of response elimination weakened resurgence (relative to 0, 3, or 9 sessions), but the rats had received fewer sessions of Phase 1 training (only 5), and neither the session-duration nor the reinforcement schedule used in Phase 2 were described. Given what we know about resurgence, it seems possible that both the amount of initial training (see above) and the reinforcement schedule used in Phase 2 (see below) might influence the effectiveness of increasing the amount of Phase 2 training.

The contextual interpretation of resurgence led us to investigate a different method for eliminating the resurgence effect (Winterbauer & Bouton, in press). If resurgence is a renewal effect caused by changing the pellet or behavior context of extinction, then a manipulation that makes that change more gradual and less detectable should reduce it. In a contingency management setting, it would make sense to slowly “fade” or “thin” the frequency of the reinforcer (e.g., money) used to maintain the replacement behavior. In the experiment summarized in Figure 7, four groups of rats received 12 sessions in which they were reinforced for pressing Lever 1 on a VI 30 s schedule. Then, during the extinction phase shown at left, they received 14 sessions in which responses to Lever 1 were extinguished while responses to Lever 2 were reinforced. Two groups (the solid symbols) received the same reinforcement schedule on Lever 2 throughout the 14 sessions of the phase (either fixed-interval [FI] or random-interval [RI] 20 s). (The 15-min bins shown on the x axis each correspond to half of a 30-min session.) In the final test shown at right, when Lever 2 was extinguished, these groups showed a reliable resurgence of Lever 1 responding despite their extensive extinction training. However, the two remaining groups (open symbols) received a treatment in which the frequency of reinforcement was gradually

thinned during the extinction phase. For these groups, as in the others, reinforcement was delivered on either a RI or FI 20 reinforcement during the first session. But over the next five sessions, the intervals were gradually incremented by a very small amount every second until they reached final RI or FI values of 120 s. The schedules were then held at RI 120 and FI 120 for a final eight sessions. As can be seen at right, this thinning treatment strongly reduced resurgence when Lever 2 was finally put on extinction. Thus, the thinning treatment does reduce resurgence.

However, one very interesting outcome observed in all of our thinning experiments (Winterbauer & Bouton, in press) can be seen in the thinned groups early in the response elimination (extinction) phase. Once the intervals began to increase from their starting values of RI or FI 20, the animals began responding on Lever 1 again—an “early resurgence” occurred as the reinforcement rate was thinned. We performed some fine-grained analyses of responding in real time in order to understand what caused Lever 1 to resurge so early. These revealed that neither chance reinforcement for pressing Lever 1, nor pellet deliveries eliciting or setting the occasion for a habit-like return to the Lever 1, explained the early resurgence of Lever 1 responding. (Very few Phase-2 pellet deliveries were either preceded or followed by a Lever 1 response.) There was also little evidence that Lever 1 responding occurred early in the intervals between successive reinforcers, as one would expect if the Lever 1 responding became a kind of interim or adjunctive behavior (e.g., Staddon, 1977; Staddon & Simmelhag, 1971) that “filled” early portions of the intervals between successive reinforcers. (This account is also challenged by the fact that the early resurgence eventually went away.) Instead, thinning the reinforcement rate on Lever 2 appears to yield early resurgence either by reducing the disruption of Lever 1 responding (Shahan & Sweeney, 2011, see below) or by causing detectable contextual change (see Gallistel, Mark, King, & Latham, 2001). The results suggest that a thinning procedure can indeed ultimately lead to less resurgence, as predicted by the context-change account. But we have yet to identify a thinning method that we would recommend as a clinical treatment—because the early resurgence that fading seems to generate might itself be problematic.

Shahan and Sweeney’s (2011) quantitative model of resurgence deserves more discussion at this point. As noted earlier, according to this model, responding on Lever 1 declines in extinction in part because reinforcement presented during Phase 2 disrupts it. Resurgence then occurs when this source of disruption is removed. Winterbauer and Bouton (in press) reported that simulations of the model indicated that thinned rates of reinforcement on Lever 2 do cause less disruption of Lever 1 responding than an unthinned control rate, and thus result in less final resurgence. The model also correctly predicts that thinning would increase Lever 1 responding during Phase 2, provided reinforcement rate was entered into the model as reinforcers/hr rather than reinforcers/min (the unit was not specified by Shahan & Sweeney, 2011). The model is more challenged by the finding, noted above, that a nine-fold increase in the number of Phase 2 sessions (from 4 to 36) had no impact on the strength of the resurgence effect (resurgence is supposed to decrease with increased Phase 2 training). In its present form, the model can account for some, but not all, of the resurgence findings that have been obtained in this laboratory.

One implication of the results with thinning is that resurgence clearly depends on the schedule of reinforcement used in the response elimination phase. Consistent with this possibility, Leitenberg et al. (1975) found in pigeons that the use of an extremely lean VI 4-min schedule on the alternative response throughout Phase 2 did not produce resurgence when the response was extinguished. For the context-change point of view, this result is not surprising, because it was presumably difficult for the subjects to distinguish a schedule in which the reinforcer was presented only once every 4 min (on average) from one in which it was never presented at all (i.e., during extinction testing). Resurgence depends on a

noticeable transition from Phase 2 to Phase 3; with lean schedules, the animals will generalize better from response elimination to extinction testing. Interestingly, it is worth noting that the context change account of resurgence is entirely compatible with a well-known account of extinction. Specifically, Capaldi (1967, 1994) has argued that responding declines in extinction when the animal fails to generalize between conditioning and extinction. His “sequential theory” used this principle in elegant detail to explain the partial reinforcement extinction effect (PREE), in which intermittently-reinforced behaviors are slower to decline in extinction than those that have always (“continuously”) been reinforced. According to Capaldi, the PREE occurs because the conditions of partial reinforcement generalize better than continuous reinforcement to the conditions of extinction. The account has been very successful as an explanation of the PREE (e.g., see Mackintosh, 1974, for one review). Based on the connection between it and the context-change account of resurgence, one can derive a set of testable predictions of the context-change hypothesis. Specifically, those reinforcement schedules that yield a strong PREE, and thus theoretically permit generalization between conditioning and extinction, will also yield weak resurgence when they are used to reinforce Lever 2 during Phase 2.

Epstein (1983) reported a second form of resurgence that has received less experimental attention than the one introduced by Leitenberg et al. (1970) (but see Lieving & Lattal, 2003, Experiment 1). Pigeons were first reinforced for pecking a key, and then this behavior was extinguished. After extinction, a second behavior (e.g., head turning, although the exact response varied from bird to bird) was briefly reinforced and then extinguished. During extinction of the second behavior, keypecking resurged. This form of resurgence differs from the first form because here the first behavior is extinguished before the replacement behavior is introduced and reinforced. It is more difficult to interpret as a renewal effect, because extinction of the second behavior arguably returns the subject to the context in which keypecking has been extinguished. We therefore investigated the phenomenon in rats (Winterbauer & Bouton, 2011). Responses on Lever 1 were first reinforced and then extinguished for several sessions. A second lever was then inserted and the first 20 presses of it were reinforced. When Lever 2 responses were then extinguished, the rats pressed Lever 1 again. Experimental tests suggested that this example of resurgence occurred because the pellets introduced when Lever 2 was reinforced set the occasion for responding on Lever 1. (Reinforcers are known to “reinstatement” an extinguished behavior through this mechanism, e.g., Reid, 1958.) Consistent with this idea, we found that yoked rats that received the same pattern and distribution of reinforcers as the resurgence group, but not contingent on Lever 2 responding, showed an equivalent recovery of Lever 1 responding. And in another experiment, the delivery of free pellets during extinction, which is known to reduce the reinstating effects of free pellets delivered later (e.g., Rescorla & Skucy, 1969), abolished both the “resurgence” produced by Lever 2-contingent or noncontingent (yoked) pellets. The results strongly suggested that in our conditions, the Epstein form of resurgence is a simple reinstatement effect. Reintroduction of the reinforcer set the occasion for the Lever 1 response. We should note that the results of the original Epstein experiment with pigeons may not be explained as readily by this mechanism, because the birds did not resurge until a median of 32 s had elapsed after presentation of the last reinforcer. As Winterbauer and Bouton (2011) noted, there is a clear need for additional study with the pigeon method.

Resurgence is an important instrumental extinction phenomenon. Like renewal, it provides another illustration of the impermanence of extinction, and it may provide a model for the return of drug taking after an alternative behavior has been reinforced (e.g., Higgins et al., 2004). Resurgence of instrumental alcohol-seeking (Podlesnik, Jimenez-Gomez, and Shahan, 2006) and cocaine-seeking (Quick, Pyszczynski, Colston, & Shahan, 2011) occurs in rats during extinction of a replacement behavior that was reinforced by food. For now, we

suggest that both the Leitenberg- and the Epstein-type of resurgence are consistent with principles of extinction and relapse that have been developed in accounting for Pavlovian extinction. The Leitenberg procedure can be profitably seen as an ABC renewal effect, whereas the Epstein procedure produces reinstatement. By either mechanism, even if a new behavior is trained to replace an extinguishing target behavior, the first behavior can easily return.

Reacquisition after the extinction of instrumental learning

Renewal and resurgence are both phenomena that can lead the overeater or drug user to perform an instrumental behavior again after extinction. We (Bouton, 2000) have suggested that these effects (as well as spontaneous recovery and reinstatement, which space limitations prevent us from reviewing here) can cause a “lapse” in extinguished responding. However, in the natural world of eating and drug-taking, a lapse will usually bring the instrumental response into contact with the reinforcer again. The new pairing(s) of the action and reinforcer might then cause reacquisition of the behavior, a model of the development of full-blown relapse following extinction.

Evidence from our satiated rat preparation (Todd et al., 2012a) suggests that contexts can influence instrumental reacquisition. For example, Figure 8 shows reacquisition in ad lib fed rats that had learned to lever-press for sucrose or our sweet/fatty pellets in Context A, had been extinguished in B, and then had received renewal testing in A and B (these are the same rats as in Figure 2). At the present point in time, half the rats were tested in Context A, the acquisition context, and the other half were tested in Context B, the extinction context. Every fifth lever press now produced the sucrose or sweet/fatty pellet that had been used in training (the figure collapses over pellet type, because the results did not interact with that variable). Both groups reacquired lever pressing, and although there was no control group that had not received acquisition before, reacquisition was presumably more rapid here than we would have observed in naïve controls (see Willcocks & McNally, 2011, for a recent comparison). What is interesting, however, is that rats in the original acquisition context (A) reacquired the food-seeking response more rapidly than those in the extinction context (B) (see Bouton & Swartzentruber, 1989, for a similar effect in fear conditioning). Put another way, the extinction context provided some protection from rapid reacquisition. We have also shown that reacquisition is more rapid in Context B than A when the rats have received both conditioning and extinction in Context A (Todd et al., 2012a, Experiment 2b). In this counterintuitive case, the rats were quicker to reacquire food-seeking in a context they had never been reinforced for lever pressing in before. Thus, there is an important effect of removal from the “inhibitory” extinction context. In another recent study, the rate of reacquisition of an FR-1 beer-seeking response was not as strongly affected by context, although there was evidence that rats in an ABA condition were quicker to begin responding than rats tested in B (Willcocks & McNally, 2011).

It is nevertheless true that reacquisition of extinguished instrumental behavior is more rapid than original acquisition (e.g., Bullock & Smith, 1953; Willcocks & McNally, 2011), just as it often is after Pavlovian extinction (e.g., Ricker & Bouton, 1996). How is this explained? A clue is provided by the fact that reacquisition in Pavlovian conditioning can actually be *slower* than original acquisition when conditioning has involved only a small number of trials and extinction has been comparatively extensive (Bouton, 1986; Bouton & Swartzentruber, 1989; Ricker & Bouton, 1996). As noted at the beginning of this article, we have suggested that the rate of reacquisition depends on which of two available memories (conditioning vs. extinction) is actually retrieved during testing. When reacquisition is fast, the reintroduction of the CS-US or instrumental response-reinforcer pairings may functionally return the subject to the original conditioning context, because CS-US or

response-reinforcer pairings originally occurred in the presence of a memory of recent reinforced trials. In this sense, rapid reacquisition may be another ABA renewal effect (Ricker & Bouton, 1996; Bouton, Woods, & Pineño, 2004; Woods & Bouton, 2007).

There are several testable implications of this idea. For example, in Pavlovian appetitive conditioning, rats are especially likely to respond strongly on a reacquisition trial if the preceding trial was a reinforced rather than a nonreinforced (extinction) trial (Ricker & Bouton, 1996). (Control subjects that had not received previous conditioning and extinction showed no such pattern.) Another implication is that if we can associate the renewing contextual cues—CS-US or response-reinforcer pairings—with extinction, we might be able to weaken or slow the rapid reacquisition effect. We have tested this by introducing occasional CS-reinforcer or response-reinforcer pairings into Pavlovian and instrumental extinction procedures. In Pavlovian experiments (Bouton et al., 2004), rats received trials in which the CS was paired with the pellet US occasionally in the middle of a long string of extinction trials. The idea was to associate CS-pellet pairings with more extinction. The treatment worked: It slowed the reacquisition that occurred when CS and pellet were paired again compared to a group that had received only extinction. In related instrumental learning experiments (Woods & Bouton, 2007), hungry rats initially received training on a VI 30 schedule and then received either extinction or extinction with infrequent response-pellet pairings (we gradually lengthened the reinforcement schedule over sessions until the rats were earning one reinforcer every 32 minutes). The new method reduced, but (somewhat surprisingly) did not quite eliminate lever pressing, so that the rats in this new condition were responding more than a straight extinction group at the end of extinction. But when lever pressing was then frequently reinforced again in a reacquisition phase, the new procedure reduced the boost in responding that was otherwise seen after each new response-reinforcer pairing. The results were consistent with the view that embedding response-reinforcer pairings in extinction associated them with extinction, and thus reduced their ability to signal conditioning (and thus cause rapid reacquisition).

Woods and Bouton (2007) noted that adding reinforced trials to extinction increases generalization from extinction to reacquisition in the same way that adding nonreinforced (extinction) trials to acquisition increases generalization from acquisition to extinction—and causes the partial reinforcement extinction effect (PREE) mentioned above. In fact, our analysis of rapid reacquisition, like that of resurgence, is once again completely compatible with Capaldi's (1967, 1994) well-supported explanation of the PREE.

In summary, the rate of reacquisition (and perhaps relapse) can be modulated by both the background context (Figure 8) and by degrading the ability of response-reinforcer conjunctions to signal more. Relapse may be slower in an extinction context, and occasional experience with action-food or action-drug pairings during extinction may help protect against a lapse turning into a relapse, too.

Conclusion

Our research on renewal, resurgence, and reacquisition after instrumental extinction suggests that the principles that have been developed to understand Pavlovian extinction and relapse transfer easily to the instrumental situation. In either paradigm, extinction is not erasure, and appears to result at least partly from new learning that crucially involves the context. We would note that our conceptualization of "context" includes other stimuli besides the ones provided by the Skinner boxes that have typically been used (e.g., see Bouton, 2002). For example, related research indicates that drug states can provide contexts, so that responding can be renewed after extinction in the context of a drug state when testing then occurs outside the state (e.g., Bouton, Kenney, & Rosengard, 1990; Cunningham, 1979;

Lattal, 2007). Our more recent research on resurgence is consistent with the possibility that a new behavior, and/or the reinforcers that support it, might also provide a context for extinction, so that responding can likewise be renewed when it is removed. The work with reacquisition suggests that recent response-reinforcer pairings (or CS-US pairings) can also provide a context for extinction. And it is worth noting that there is evidence to suggest that the passage of time can also provide a kind of changing context (e.g., Bouton & García-Gutiérrez, 2006; Bouton & Hendrix, 2011), and thus support spontaneous recovery (e.g., see Bouton, 2002). Our results with extinction can be put in the “context” of a great deal of research on context in psychology (e.g., Bouton, 2010); many kinds of contextual cues are available to control extinction and possible lapse and relapse.

We end by noting that although the field’s current interest in recovery effects like renewal, resurgence, and reacquisition may be relatively new, these effects and the contextual analysis of them and of extinction itself are deeply connected with an older perspective on extinction provided by discrimination and generalization decrement theories (e.g., Kimble, 1961; Mackintosh, 1974). As we emphasized above, research on Capaldi’s sequential theory (e.g., 1967, 1994) demonstrated the value of thinking that memories of recent trials can provide stimulus support, or a context, for behavior in extinction. Capaldi’s account of the PREE is a contextual one; nonreinforced trials during conditioning create a context that allows conditioning to generalize more to extinction. A contextual analysis of extinction is thus compatible with a great deal of research on the PREE, in addition to effects like renewal, resurgence, and reacquisition (as well as spontaneous recovery and reinstatement). Viewed this way, a contextual approach to extinction has proven to be successful at understanding a very wide range of complex, and often counterintuitive, extinction phenomena. The field of associative learning is making good progress in understanding extinction, and now, potentially, its concomitant lapse and relapse processes.

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Highlights

- Extinction of instrumental learning does not involve erasure; behavior is subject to relapse
- Extinguished instrumental behaviors are renewed when they are tested in a new context
- Extinguished instrumental behaviors resurge, after replacement by a second reinforced behavior, when the second behavior is extinguished
- Extinguished instrumental behaviors can be reacquired rapidly
- All such effects are consistent with a contextual analysis of extinction that has been developed in studies of Pavlovian extinction

Figure 1.

Renewal after instrumental extinction. Left: Mean responding during each 30-min session of acquisition and extinction. Right: Mean responding during the 10-min test sessions in the extinction context and the nonextinction (renewal) context. AAB, renewal in Context B after extinction in Context A; ABA, renewal in Context A after extinction in Context B. From Bouton et al. (2011).

Figure 2.

Renewal after instrumental extinction with fed (non-deprived) rats lever pressing for sucrose or sweet/fatty pellets. Left: Mean responding during each 30-min session of acquisition and extinction. Right: Mean responding during the 10-min test session in the extinction context (B) and the renewal context (A). From Todd et al. (2012a).

Figure 3.

Mean responding during the 10-min test session in the extinction context (Context B) and the renewal context (Context C) in an experiment investigating the effect of conditioning in multiple contexts. Group A+D+ received acquisition in Context A and D whereas Group Control received the same amount of training in Context A. From Todd et al. (2012b).

Figure 4.

Effect of extinction exposure to Context A before ABA renewal testing. Left: Mean responding during each 30-min session of acquisition and extinction. Right: Mean responding during the 10-min test sessions in the extinction context (Context B) and the nonextinction (renewal) context (Context A). EXP, extra exposures to context A during the extinction phase; NoEXP, no such exposures. From Bouton et al. (2011).

Figure 5.

Effects of d-cycloserine on extinction and ABA renewal in a discriminated operant procedure. Left: Mean elevation scores ($\pm SEM$) during each 16-trial session of discriminated operant training (acquisition). Center: Mean responding ($\pm SEM$) during successive 4-trial blocks of the single extinction session. Right: Mean elevation scores ($\pm SEM$) during the test sessions in the extinction context (B) and the renewal context (A). Note the change in y-axis between panels; 0, 5, 15, and 30 doses (in mg/kg) of DCS. From Vurbic et al. (2011).

Figure 6.

Effects of the amount of training and the schedule used in training on the resurgence effect. Left: Mean responding on Lever 1 during acquisition and extinction. Right: Mean Lever 1 responding during the final extinction session (“pre”) and the test session. R-12 = 12 training sessions with a ratio schedule, I-12 = 12 training sessions with a (yoked) interval schedule, R-4 = four training sessions with a ratio schedule, I-4 = four training sessions with a (yoked) interval schedule. From Winterbauer et al. (in press).

Figure 7.

Effects on resurgence of thinning the reinforcement schedule on Lever 2 during extinction of Lever 1. Upper left: Mean Lever 1 responding of the groups during half-session (15-min) bins of the extinction (response elimination) phase. Upper Right: Mean Lever 1 responding during the last half session of extinction and four 15-min bins of a 60-min resurgence test session. Lower Left: Mean Lever 2 responding of the groups during half-session bins of the extinction (response elimination) phase. Lower Right: Mean Lever 2 responding during the last half-session of extinction and the resurgence test. FI Resurge = Lever 2 reinforced on FI 20 throughout the extinction phase; FI Thinning = Lever 2 first reinforced on FI 20 and then thinned to FI 120 by bin 12 and held there for the remainder of the phase; RI Resurge = Lever 2 reinforced on RI 20 throughout the extinction phase; RI Thinning = Lever 2 first reinforced on RI 20 and then thinned to RI 120 by bin 12 and held there for the remainder of the phase. See text for further explanation. From Winterbauer and Bouton (in revision).

Figure 8. Reacquisition after extinction in satiated (fed) rats. Mean responses per min as a function of 1-minute time bins as shown. Groups are differentiated based on reacquisition context (A vs. B) after receiving conditioning in A and extinction in B. Error bars show 1 *SEM*. The group $\times$ bin interaction was significant; * indicates bins in which the groups were significantly different, $p < .05$. From Todd et al. (2012a).