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CONTEXT CHANGE EXPLAINS RESURGENCE AFTER THE EXTINCTION OF OPERANT BEHAVIOR

EL CAMBIO DE CONTEXTO EXPLICA EL RESURGIMIENTO DESPUÉS DE LA EXTINCIÓN DE LA CONDUCTA OPERANTE

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Abstract

Extinguished operant behavior can return or "resurge" when a response that has replaced it is also extinguished. Typically studied in nonhuman animals, the resurgence effect may provide insight into relapse that is seen when reinforcement is discontinued following human contingency management (CM) and functional communication training (FCT) treatments, which both involve reinforcing alternative behaviors to reduce behavioral excess. Although the variables that affect resurgence have been studied for some time, the mechanisms through which they promote relapse are still debated. We discuss three explanations of resurgence (response prevention, an extension of behavioral momentum theory, and an account emphasizing context change) as well as studies that evaluate them. Several new findings from our laboratory concerning the effects of different temporal distributions of the reinforcer during response elimination and the effects of manipulating qualitative features of the reinforcer pose a particular challenge to the momentum–based model. Overall, the results are consistent with a contextual account of resurgence, which emphasizes that reinforcers presented during response elimination have a discriminative role controlling behavioral inhibition. Changing the "reinforcer context" at the start of testing produces relapse if the

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organism has not learned to suppress its responding under conditions similar to the ones that prevail during testing.

Keywords: resurgence, operant behavior, context change, reinforcer distribution, relapse

Resumen

La conducta operante extinguida puede regresar o "resurgir" cuando una respuesta que la ha reemplazado también se extingue. El efecto de resurgimiento, típicamente estudiado en animales no humanos, puede proveer un entendimiento de la recaída que se observa cuando el reforzamiento es descontinuado después de los tratamientos de gestión de contingencia humana (GC) y el entrenamiento en comunicación funcional (ECF), los cuales involucran reforzar conductas alternas para reducir excesos conductuales. A pesar de que las variables que afectan el resurgimiento se han estudiado por algún tiempo, los mecanismos a través de los cuales promueven la recaída todavía son debatidos. Discutimos tres explicaciones del resurgimiento (prevención de la respuesta, una extensión de la teoría de momento conductual y una explicación enfatizando el cambio de contexto) así como los estudios que las evalúan. Varios hallazgos nuevos de nuestro laboratorio respecto a los efectos de diferentes distribuciones temporales del reforzador durante la eliminación de la respuesta y los efectos de manipular características cualitativas del reforzador representan un reto particular al modelo basado en el momento conductual. En general, los resultados son consistentes con una explicación contextual de resurgimiento, la cual enfatiza que los reforzadores presentados durante la eliminación de la respuesta tienen un papel discriminativo que controla la inhibición conductual. Cambiar el "contexto del reforzador" al inicio de la prueba produce una recaída si el organismo no ha aprendido a suprimir las respuestas bajo condiciones similares a aquellas que prevalecen durante la prueba.

Palabras clave: resurgimiento, conducta operante, cambio de contexto, distribución del reforzador, recaída

Operant behavior has been an important focus of laboratory research for many decades because it provides a model for studying the variables that control voluntary behavior. In a typical study of operant behavior, animals such as rats learn to perform a response (e.g., a lever press or chain pull) to receive an outcome (such as a food reinforcer). Although the animal is free to do whatever it "wants" during a session, it can be shown that the rate of its behavior is lawfully related to its consequences. Indeed, once the response has been acquired, it can be reduced through a process known as *extinction,* in which the reinforcer or outcome is no longer produced by that response. Extinction is a well–known and popular method for reducing behavioral excesses. However, behavior that has been reduced through extinction is prone to recovery and relapse (see Vurbic & Bouton, 2014, for one review). Therefore, the suppression of operant responding that occurs when reinforcers are omitted should not be taken as evidence that the original learning has been erased or unlearned.

One of the best–known phenomena that supports this conclusion is the so–called *renewal effect* (e.g., Bouton & Bolles, 1979). Renewal illustrates that behavioral inhibition is controlled by the context in which it is learned. In typical experiments on renewal, the context is broadly defined as the tactile, visual, and olfactory cues that comprise the operant chamber in which learning takes place. When responding is acquired in one context, Context A, and then extinguished in a second context, Context B, it will recover when that behavior is tested (under extinction conditions) back in Context A. This "ABA renewal" effect has been widely demonstrated when operant behavior has been reinforced with a wide array of drug, alcohol, and food reinforcers (Bossert, Liu, Lu, & Shaham, 2004; Bossert et al., 2011; Bouton, Todd, Vurbic, & Winterbauer, 2011; Crombag & Shaham, 2002; Hamlin, Clemens, Choi, & McNally, 2009; Hamlin, Clemens, & McNally, 2008; Nakajima, Tanaka, Urushihara, & Imada, 2000; Nakajima, Urushihara, & Masaki, 2002). Renewal can also occur when behavior is trained in Context A, extinguished in Context B, and tested in a novel context, Context C (ABC renewal) or when behavior is acquired and extinguished in the same context (Context A), but tested in a novel context, Context B (AAB renewal) (Bouton et al., 2011). While ABA renewal could suggest that behavior returns due to the animal being returned to an excitatory context, ABC and AAB renewal suggest that simple removal from the context of extinction is sufficient to cause responding to recover. Together, the results suggest that extinction results in new learning that is especially dependent upon the context in which it is learned. Further evidence suggests that the new learning involves learning to inhibit a specific response in a specific context (Todd, 2013; Todd, Vurbic, & Bouton, 2014). Moreover, a variety of different kinds of stimuli are known to play the role of context, including both external cues (as described above) and internal cues such as drug state, deprivation level, and mood state (e.g., Bouton, 2002).

Resurgence (Leitenberg, Rawson, & Bath, 1970; see Lattal & St. Peter Pipkin, 2009 for a review) is a relapse phenomenon that may be related to renewal. In a typical resurgence experiment, rats are first taught to perform one response, R1 (e.g., a lever press), in an initial phase (Phase 1) to earn food reinforcement. Once responding is established, the rats are then switched to a second phase, where a newly inserted response, R2 (typically a second lever), now produces food reinforcement while the original R1 response is extinguished (that is, no longer produces reinforcement). During this phase, the R1 response steadily declines while R2 responding increasingly replaces it. During a final testing phase, both the R1 and R2 levers remain available, but reinforcement is not delivered for either response. Typically, while R2 responding decreases, R1 responding returns, or "resurges" when the reinforcement for R2 is removed. Resurgence, like other forms of behavioral relapse such as renewal, again suggests that extinction procedures do not result in an erasure or an unlearning of the original learning. It might also suggest, again, that extinction instead results in new learning that is especially dependent on the context in which it was learned.

Resurgence in the animal laboratory has been suggested to have important implications for human treatment programs for drug addiction. In contingency management (or CM), patients can earn vouchers (redeemable for goods or services) contingent on providing drug–free urine samples. Typically, the amount of the voucher increases with each subsequent clean sample. This value is often "reset" to the original, lower value if a sample tests positive for drug use. Contingency management is an effective tool for promoting cessation of (for example) drug–taking or cigarette smoking (Fisher, Green, Calvert & Glasgow, 2004; see Higgins, Sigmon, & Heil, 2011 for a review). However, the original behavior can potentially resurge when the therapeutic reinforcers are discontinued (Higgins, Silverman, & Heil, 2008). One interesting variation of CM suggested by Silverman and colleagues is called the "therapeutic workplace" (Silverman, Svikis, Robles, Stitzer, & Bigelow, 2001). In this program, participants can earn access to a paid data–entry job in exchange for remaining abstinent from drugs. Each day a participant comes to the therapeutic workplace and tests negative for drug use, they can earn a full day of work. This not only allows the participant to earn rewards in the same way as a typical CM program, but also teaches a new skill that may be transferrable once the treatment ends (Silverman et al., 2001; Silverman, Svikis, Wong, Hampton, Stitzer, & Bigelow, 2002). Moreover, if the job can go on indefinitely, the therapeutic reinforcers would never have to be discontinued (in contrast to a typical CM treatment).

It is worth noting, however, that drug–taking behavior always would be reinforced if the client returned to drug taking during or after CM treatment. This is unlike the extinction conditions that prevail in the typical resurgence experiment. Resurgence may therefore have even more direct implications for understanding relapse for functional communication training (FCT) in children with behavior problems or developmental delays (Carr & Durand, 1985). In FCT, children are placed in an environment with a researcher trained not to reinforce (socially, verbally, or otherwise) behavior that has been defined as problematic for the child (e.g., tantrums, screaming, hand-flapping, etc.). Instead, children must engage in prosocial behavior (such as initiating conversation or soliciting assistance from an adult) to earn reinforcement (such as verbal praise). Once the prosocial behavior has been established, the contingencies that promoted it can theoretically be taught to others (e.g., parents, teachers) to maintain it outside of the clinic, where the unwanted behavior has typically been reinforced. Unlike CM, unwanted behaviors in FCT never produce reinforcement. However, consistent with both resurgence and CM (e.g., Higgins et al., 2008; Roll, Chudzynski, Cameron, Howell, & McPherson, 2013; Stitzer & Petry, 2006), maladaptive behavior that has been reduced this way is prone to relapse once treatment ends and the reinforcers are discontinued (Sprague & Horner, 1992; Volkert, Lehrman, Call, & Trosclair–

Lasserre, 2009). Thus, further understanding of the mechanisms that contribute to the relapse seen in animal resurgence may further our understanding of situations that lead to relapse in CM and FCT.

Basic Features of Resurgence

Although they did not call it resurgence, Leitenberg and colleagues published one of the earliest demonstrations of the phenomenon in 1970 (Leitenberg et al., 1970). They found that extinction of an operant response decreased at a greater rate when an alternative one was introduced and reinforced. However, they also noted that when alternative reinforcement was discontinued, the extinguished behavior returned (i.e., resurged). In contrast, the original behavior did not return when it was simply placed on extinction. In a later extension of these experiments, Leitenberg, Rawson, and Mulick (1975) further demonstrated that resurgence is a robust effect that occurs under a variety of conditions. For example, resurgence was similarly strong when the alternative response was reinforced according to either variable–interval (VI) or fixed–ratio (FR) schedules (using an FR 10 and a yoked VI schedule). Additionally, resurgence was not affected by the topography of the response. That is, whether the original and alternative responses were the same (i.e., both lever presses) or different (i.e., lever pressing vs. licking at a spigot) did not affect the strength of resurgence.

Subsequent research went on to establish some of the basic variables that influence the effect. Overall, the behavior that resurges resembles the response that was originally trained. For example, Winterbauer, Lucke, and Bouton (2013) found that schedules that encouraged more Phase 1 responding resulted in more resurgence at test; the level of responding seen during testing reflected the level achieved during initial training. Further, the actual pattern of responding that resurges resembles the one that was originally learned. Reed and Morgan (2006) found that when three distinct response sequences were trained in succession, the pattern of behavior that resurged when reinforcement was discontinued for the third and final sequence was most consistent with the first learned sequence. Similarly, Cançado and Lattal (2011) found that the typical scalloping pattern of responding that emerged during initial training on a fixed interval (FI) 5–s schedule itself resurged when alternative reinforcement for a second response was discontinued (Experiment 2). The results of Winterbauer et al. (2013), Reed and Morgan (2006), and Cançado and Lattal (2011) all suggest that the behavior that resurges mimics the original response in rate, topography, and temporal characteristics.

Details of training the initial response thus clearly influence the strength and form of the behavior that resurges. The circumstances of training and/or reinforcement during Phase 2 can also influence the effect. For example, resurgence is demonstrably affected by the rate and distribution of alternative reinforcers that are delivered during Phase 2 (see “Theories of Resurgence” section below). However, the amount and type of training during Phase 2 may be less critical than Phase 1 training. For example, in contrast to their results showing that additional Phase 1 training increases resurgence, Winterbauer et al. (2013) found that the levels of resurgence in groups that received 4, 12, or 36 sessions of Phase 2 training with an FR 10 schedule did not differ during final testing. (It is possible that the amount of R1 extinction training plays a greater role with leaner R2 reinforcement schedules during Phase 2; see Leitenberg et al., 1975; Sweeney & Shahan, 2013a). Further, R2–dependent or response–independent reinforcers delivered during R1 extinction can have similar effects (Winterbauer & Bouton, 2010, Experiment 4). In that experiment, high and indistinguishable levels of resurgence were seen when animals received Phase–2 training on an FR 10, a yoked VI, or a yoked variable–time (VT) schedule. Similar results recently have been reported by Trask and Bouton (2016).

Research also has demonstrated the resurgence of drug–seeking behavior reinforced by alcohol (i.e., Podlesnik, Jiminez–Gomez, & Shahan, 2006) or cocaine (i.e., Quick, Pyszczynski, Colston, & Shahan 2011). For example, Quick et al. (2011) trained rats to respond for intravenous cocaine infusions during an initial phase. Then in Phase 2, responses on the cocaine lever were no longer reinforced while a separate nose poke response was reinforced with food pellets. During the resurgence test when food pellet reinforcers were also discontinued, responding on the cocaine lever resurged despite remaining on extinction. By suggesting that resurgence can occur with drug–reinforced behavior, like other operant behavior, the results encourage the view that resurgence should be taken seriously as a possible mechanism of lapse and relapse.

Theories of Resurgence

Although the variables that produce and affect resurgence have been widely studied, the mechanisms through which they affect resurgence are still debated. Several explanations of resurgence have been proposed. The main three will be discussed here.

The Response Prevention Explanation

Leitenberg and colleagues (1970) first proposed that resurgence might occur because reinforcement of R2 behavior might interfere with the ability of the animal to perform R1 and consequently learn that R1 is no longer reinforced. In other words, the animal might not emit enough R1 responses during extinction to truly learn extinction. Perhaps consistent with such a view, Rescorla (1993) has reported evidence suggesting that instrumental extinction learning is better (as measured by transfer to a response with a shared outcome) under conditions that encourage a higher level of responding during extinction. However, it is not uncommon to observe a fairly high amount of responding on R1 (at least initially) at the beginning of Phase 2. As one example, Bouton and Schepers (2014) noted that rats in a group that later showed strong resurgence made an average 597 extinguished R1 responses during the first Phase 2 session alone. Thus, there was ample opportunity to learn R1 extinction. Additionally, parameters that result in higher levels of R1 responding than in control conditions can still produce equivalent resurgence. For example, in an experiment reported by Winterbauer and Bouton (2010, Experiment 2), rats were trained to respond on R2 on a VI 30–s schedule throughout Phase 2. This resulted in a slower loss of R1 behavior compared to rats that were simply extinguished on R1. Despite this slow suppression of R1, animals given VI 30–s still showed robust resurgence, which took the form of more R1 responding after VI 30–s for R2 than after simple extinction. Given such findings, it seems unlikely that response prevention is the primary mechanism through which cessation of alternative reinforcement promotes resurgence, although it is possible that it might play a role in circumstances in which R2 is reinforced at very high rates and can directly interfere with performance of R1.

The Shahan and Sweeney (2011) Behavioral Momentum Model

A second explanation of resurgence, developed by Shahan and Sweeney (2011), is a quantitative model derived from behavioral momentum theory (Nevin & Grace, 2000). Behavioral momentum theory suggests that response rate and resistance to change are two separable aspects of an operant behavior. While response rate is governed by the strength of the response–reinforcer correlation, resistance to change is theoretically determined by the strength of the stimulus–reinforcer correlation (Craig, Nevin, & Odum, 2014). Most research on behavioral momentum has studied responding in multiple schedules in which nonhuman animals are trained within the same session to make two responses (usually with different reinforcement rates) in the presence of two different discriminative stimuli (e.g., colored key lights). Once responding in the two components is established, resistance to change (or *momentum*) is assessed by introducing a disrupter such as pre–session feeding. Using this method it has been demonstrated that a response with the higher reinforcement rate is more resistant to change than a response with a leaner reinforcement rate (see Nevin, 1974). Of theoretical importance is the fact that training with additional free (i.e., response–independent) reinforcers during one component results in more persistence of that behavior in comparison to a behavior in another component that had received the same reinforcement rate (and thus the same response–reinforcer correlation), but no free reinforcers (a weaker stimulus–reinforcer correlation) (Nevin, Tota, Torquato, & Shull, 1990). Similar results have been produced using qualitatively different reinforcers to strengthen stimulus–reinforcer correlations in the stimulus (milk delivered freely during a stimulus that signaled lever pressing for food, Grimes & Shull, 2001; food delivered freely during a context that signaled lever pressing would be reinforced with ethanol, Shahan & Burke, 2004). The results thus suggest that persistence of behavior might be a function of how much overall reinforcement occurs in a certain stimulus or context (Craig, et al., 2014), regardless of the reinforcer type.

Behavioral momentum theory was modified to account for extinction (Nevin, McLean, & Grace, 2001) by assuming that extinction disrupts behavior by changing the response–reinforcer correlation, and introducing generalization decrement. The Shahan and Sweeney (2011) model in turn extends this treatment of extinction to the resurgence design by assuming that adding reinforcement for R2 during Phase 2 actually has two important, though somewhat paradoxical, effects on R1. First, the alternative reinforcement causes further disruption of R1 performance that adds to the disruption created by simple extinction itself. Second, consistent with behavioral momentum theory, the alternative reinforcement also strengthens R1 behavior through contextual conditioning (assuming that, in resurgence, the context is the discriminative stimulus in which learning takes place). Thus, when the alternative reinforcement is discontinued during a resurgence test, the disruptive effects on R1 are removed, but the strengthening effect remains, resulting in a resurgence of R1. Shahan and Sweeney's (2011) momentum–based model thus puts a strong emphasis on rate of reinforcement in Phase 2 as a major variable that affects resurgence: The richer the rate of alternative reinforcement, the more disruption and strengthening of R1 behavior, and thus the greater the resurgence. Conversely, leaner reinforcement rates for R2 should yield weaker resurgence. In addition to the effects of reinforcement rate, the model also assumes that resurgence will be weakened as a function of increased time in extinction (defined as the number of Phase 2 sessions).

The Context Hypothesis

A third explanation of resurgence focuses on the discriminative role of the reinforcers that are delivered during Phase 2. This view suggests that resurgence, like the renewal effect described above (see Bouton et al., 2011), occurs when the contextual or background stimuli are changed between response elimination (i.e., Phase 2) and resurgence testing (e.g., Winterbauer & Bouton, 2010). According to this view, animals learn to inhibit their R1 responding in a context where alternative reinforcement is received. When the alternative reinforcers are discontinued during testing, their removal results in a change of context, and R1 behavior therefore returns. In other words, the resurgence effect is a special case of the renewal effect. While rate of reinforcement is an aspect of this hypothesized "reinforcer context," the approach emphasizes control by the discriminative properties of the reinforcer.

The context hypothesis builds upon the well–documented general role of context in operant and Pavlovian extinction (see Vurbic & Bouton, 2014, for one review).

Moreover, its emphasis on reinforcers as having discriminative properties follows another tradition of research. For example, in a classic paper, Reid (1958) demonstrated that extinguished operant behavior can return when response–independent or free reinforcers (that were originally used to establish that behavior) are presented using rat, pigeon, and human subjects. This phenomenon, now known as *reinstatement*, has been widely replicated (see Baker, Steinwald, & Bouton, 1991; Franks & Lattal, 1976; Rescorla & Skucy, 1969; Winterbauer & Bouton, 2011). Ostlund and Balleine (2007) recently found that reinstatement can depend on the discriminative properties of the reinforcer. They trained animals to respond on one response (R1) for one distinct outcome (O1) immediately after free presentation of a distinctly different outcome (O2), such that O2 could act as a discriminative stimulus to signal the R1–O1 relationship (i.e., O2: R1–O1). The animals also learned that after a free presentation of O1, a second response (R2) would lead to the O2 outcome (O1: R2–O2). Then, after responding was extinguished, animals were tested with free presentations of each outcome. The outcomes each specifically reinstated the response it had preceded in training rather than the one that it followed. That is, O2 presentations caused R1 to increase and O1 presentations caused R2 to increase. This result suggests that the stimulus properties, rather than the reinforcing properties, of an outcome can guide behavior. Moreover, the effect remained intact following reinforcer devaluation, a process that reduces the reinforcing qualities of a reinforcer, but not its discriminative qualities.

The idea that reinforcers have a discriminative function has been extended to suggest that reinforcers can create a distinct context in which learning can occur. For example, Bouton, Rosengard, Achenbach, Peck, and Brooks (1993) conducted an appetitive Pavlovian conditioning experiment in which a tone conditioned stimulus (CS) predicted a food unconditioned stimulus (US). In one group of rats, Group HiLo, unsignaled and response–independent food USs were presented during the intertrial interval (or ITI) throughout conditioning, but not during extinction (when the CS was not followed by the US). In a second group, Group LoHi, similar unsignaled and response–independent food USs occurred during the ITI during extinction, but not conditioning. When tested both with and without reinforcers during the ITI during an extinction test, animals in Group HiLo showed more conditioned responding when the reinforcers were present and animals in Group LoHi showed less responding when the reinforcers were present. Thus, Group HiLo behaved as though the food USs signaled that the CS would be reinforced, whereas Group LoHi behaved as though US presentations signaled that the CS would not be reinforced. Behavioral control by the stimulus effects of reinforcers has long been thought to play a role in extinction (e.g., Sheffield, 1949), and it may play a role in other behavioral paradigms as well (e.g., Lindblom & Jenkins, 1981; Neely & Wagner, 1974).

Evaluating the Theories

We recently have been engaged in a number of experiments that sought to separate the various theories of resurgence. What follows is an overview of resurgence experiments in the literature with a specific focus on our recent work aimed at differentiating the Shahan–Sweeney (2011) momentum–based model and context explanations. (The response prevention hypothesis was addressed above.)

Rich and Lean Rates of Alternative Reinforcement

Consistent with both the momentum–based model and the context hypothesis, resurgence appears to be weakened when alternative reinforcement is available at relatively lean rates over the response elimination phase. For example, Leitenberg et al. (1975, Experiment 3) reported that resurgence was eliminated when alternative reinforcement was delivered according to a VI 240–s schedule (meaning that a reinforcer was available for an R2 response on average every 4 minutes). However, as mentioned by Winterbauer and Bouton (2010), it is possible that such a lean reinforcement rate was not discernibly different from comparison control conditions in which no reinforcement was given at all. Nevertheless, Sweeney and Shahan (2013a) also found no evidence of resurgence following a VI 100–s reinforcement schedule. A recent study in our laboratory (Bouton & Trask, 2016) found significant resurgence following VI 30–s and VI 60–s schedules of reinforcement for R2 during Phase 2, but no resurgence in groups that received relatively lean VI 90–s and VI 120–s rates over the phase. Moreover, the strength of resurgence was shown statistically to be a decreasing linear function of the VI parameter. Such results are consistent with either the momentum–based model or a contextual account of resurgence. However, it should be noted that other results have identified similar resurgence in groups that received different but relatively dense rates during Phase 2 (VI 10–s and VI 30–s, Winterbauer & Bouton, 2010; VI 10–s and VI 17.5–s, Schepers & Bouton, 2015). This type of result is difficult to explain for both accounts of resurgence. Nevertheless, these data suggest that resurgence is generally attenuated when alternative reinforcement is lean while the original response is being extinguished.

Reinforcer Distribution Across Phase 2

Although lean rates of reinforcement for R2 can effectively weaken resurgence, as just described, it may not be necessary for the rate to be lean throughout Phase 2. Winterbauer and Bouton (2012) found that resurgence is also weakened when alternative reinforcement rate is “thinned” over the phase (see also Schepers & Bouton, 2015; Sweeney & Shahan, 2013a). In the Winterbauer and Bouton (2012) report, after R1 was acquired, it was extinguished while the newly–introduced R2 response produced reinforcement on a (relatively rich) VI 20–s schedule. However, the rate of reinforcement was made increasingly lean (or "thinned") over each of the following five sessions by adding 20 s to the schedule, which culminated with the rats earning reinforcers according to a VI 120–s schedule in the final session. The effect of this thinning procedure was to attenuate resurgence compared to a group that remained on the VI 20–s schedule. It similarly weakened resurgence whether thinning was gradual (the rate decreased gradually over each second of the session) or stepped (the rate decrease was introduced in the middle of each session) (see Winterbauer & Bouton, 2012, Experiment 2). Resurgence was also similarly weakened when the thinning interval schedules were fixed or variable (see Experiment 3). The results are predicted by both the Shahan–Sweeney model, which emphasizes R2's reinforcement rate in the last Phase 2 session (immediately before resurgence testing), as well as the context hypothesis, which claims (a) that a thin schedule would make the context change between Phase 2 and testing less detectable and (b) that the animal learns to inhibit its R1 in a context of widely–spaced reinforcers, which is more like the extinction context of resurgence testing. One implication of these results from a purely empirical perspective, of course, is that CM or FCT treatments might be less prone to relapse if the reinforcement rate during treatment is similarly thinned. In fact, Dallery, Raiff, and Grabinski (2013) used an abrupt thinning procedure in which smokers were switched from daily vouchers (contingent upon video submissions demonstrating low breath CO levels) to twice–weekly vouchers halfway through the treatment phase. They found that this procedure was effective at maintaining abstinence during treatment and showed continued abstinence (18% abstinent vs. 7.7% abstinent in a yoked control group) at a three–month follow–up after treatment was discontinued (although group differences were not evident at a six month follow–up).

Another phenomenon that occurs when the reinforcement schedule is thinned over Phase 2 is what has been called "early resurgence" (Winterbauer & Bouton, 2012). When reinforcement rates are rich at the beginning of Phase 2 and then made gradually leaner, R1 responding can increase modestly when the reinforcement rate is decreased despite reinforcement still being delivered (Schepers & Bouton, 2015; Winterbauer & Bouton, 2012). Such a result is consistent with both the momentum–based model and the context hypothesis. For Shahan and Sweeney (2011), decreasing reinforcement decreases the disruption of R1, and for the context hypothesis, thinning might produce detectable context change. Winterbauer and Bouton (2012) considered and tentatively rejected other possibilities (such as adventitious reinforcement of R1).

As just noted, resurgence has often been viewed as a model for relapse after contingency management therapy in humans. However, one important difference is that in a CM treatment an individual must be abstinent (e.g., produce a drug–negative urine sample) to earn reinforcers during treatment. In contrast, a typical resurgence experiment does not have such consequences for making the original response. However, a few exceptions exist in which animals were required to abstain from responding to earn reinforcers during Phase 2. For example, experiments have shown that resurgence can occur when alternative reinforcement is delivered according to a differential–reinforcement–of–other–behavior (DRO) schedule (da Silva, Maxwell, & Lattal, 2008; Doughty, da Silva, & Lattal, 2007; Pacitti & Smith, 1977). According to this schedule, reinforcers during Phase 2 are delivered independent of responding on an explicit R2. Rather, animals could earn a reinforcer every 20 s for simply not responding on R1. Similarly, Bouton and Schepers (2014) designed resurgence experiments that introduced an abstinence contingency associated with earning alternative reinforcement for R2 during Phase 2. In one experiment, for example, after acquiring R1 during the initial phase, R1 was placed on extinction when R2 was introduced and provided alternative reinforcement. However, in one group, R2 was only reinforced (on a VI 10–s schedule) after the animal had abstained from responding on R1 for 45 s. In other words, each R1 response resulted in a 45–s "time–out" in which a reinforcer could not be earned. The result of the abstinence contingency was that in the early sessions, when rats made many R1 responses and thus received many time–outs, they earned relatively few reinforcers. In later sessions, when rats made fewer R1 responses, they earned many more reinforcers; similar to the number in a group earning reinforcers on a constant VI 10–s schedule without the contingency. The resurgence test indicated that the abstinence contingency weakened (but did not eliminate) resurgence compared to the VI 10–s group. However, similarly weakened resurgence was observed in a third "yoked" group that earned reinforcement for R2 whenever a matched animal from the abstinence contingency group had earned one. The yoked group earned the same reinforcers at the same time in each session, but without the abstinence contingency. The fact that the abstinence and yoked groups produced similar resurgence suggests that the distribution of reinforcers provided by the abstinence contingency (and not the abstinence contingency itself) was responsible for weakening resurgence. Upon closer examination, the distribution of reinforcers over the Phase–2 sessions resembled the previously–described thinning schedule in the reverse order (i.e., "reverse thinning"). That is, the abstinence contingency effectively delivered very lean rates in early sessions and richer rates in later sessions of Phase 2.

This result is not consistent with the original version of the Shahan–Sweeney momentum–based model (2011), which specifically predicts that groups who have the same terminal rates of reinforcement (as was the case for all three groups here) should produce equivalent levels of resurgence. To account for the effectiveness of the reverse thinning schedule, it should be noted that Sweeney and Shahan (2013b) suggested that the model could be modified to use the average reinforcement rate when calculating Phase 2 reinforcement under conditions where reinforcement rate varies considerably throughout Phase 2.

In a subsequent experiment, Schepers and Bouton (2015) therefore explicitly compared the effects of thinning to a reverse thinning procedure. Rats in a reverse thinning condition simply received VI schedules in eight Phase–2 sessions that provided reinforcement rates similar to those received by the abstinence contingency group in Bouton and Schepers (2014) just mentioned. (Over sessions, the rats received a lean VI 1200–s schedule for R2 that increased in steps to a rich VI 10–s schedule.) In contrast, Group Thinning received the same reinforcement rates in eight sessions, but the rates were presented in the opposite order (i.e., VI 10–s led to VI 1200–s). In this way, the groups received the same average reinforcement rate over the entire set of Phase 2 sessions. As expected, Groups Thinning and Reverse Thinning each produced less resurgence than a control group that received a VI 10–s schedule throughout the phase. However, the forward thinning schedule was unique in that it completely eliminated resurgence. In fact, these animals showed a decrease in R1 responding between the final extinction session and the test. Together these data suggest that extinguishing R1 in the context of infrequent reinforcers at any time during Phase 2 may allow the inhibition of R1 under lean reinforcement conditions to generalize better to the nonreinforced resurgence test. The fact that the thinning schedule was especially effective at eliminating resurgence suggests that lean rates immediately prior to the test may be additionally effective than those in reverse thinning that are received much earlier. As noted earlier, a lean reinforcer context in the sessions immediately prior to the resurgence test allows a less abrupt shift in context between the end of extinction and the resurgence test. Neither the original terminal–rate version of the Shahan–Sweeney model (which would predict equivalent levels of resurgence in Group Reverse Thinning and Group VI 10–s) nor the average rate version (which would predict equivalent levels of resurgence in Groups Thinning and Reverse Thinning) can accommodate the results. The context hypothesis is uniquely able to predict that both thinning and reverse thinning procedures should weaken resurgence, with reverse thinning being less effective.

In another experiment (shown in Figure 1), Schepers and Bouton (2015, Experiment 3) studied a group of rats (Group Alternating) that received alternating daily Phase–2 sessions in which R2 was either reinforced on a VI 10–s schedule of reinforcement or not reinforced at all (i.e., put on extinction). During a final resurgence test, the behavior of this group was compared to that of a group that always earned the rich rate (i.e., the VI 10–s schedule), as well as a group that earned reinforcement during each session at the same average programmed rate received by Group Alternating over the phase (a constant VI 17.5–s). Animals in Group Alternating showed decreased resurgence in the test (top right panel of Figure 1) relative to both the VI 10–s group and the average reinforcement rate group, which did not differ from each other. Both the VI 10–s rate and the average rate allowed resurgence to occur. However, rats that had alternating experience with extinction showed more generalization to testing conditions, where again no reinforcement was available. This again suggests that neither the terminal–rate (Shahan & Sweeney, 2011) nor the average rate (Sweeney & Shahan, 2013b) versions of the momentum–based model account for the differences observed here. While the terminal rate version predicts that Group VI 10–s and Group Alternating should show equivalent levels of resurgence, the average rate suggests that Group Alternating and Group Average should show equivalent levels of resurgence. In contrast, the context hypothesis explains weakened resurgence in Group Alternating occurs because animals learn to inhibit their behavior under periods of nonreinforcement which better generalize to the test.[1]

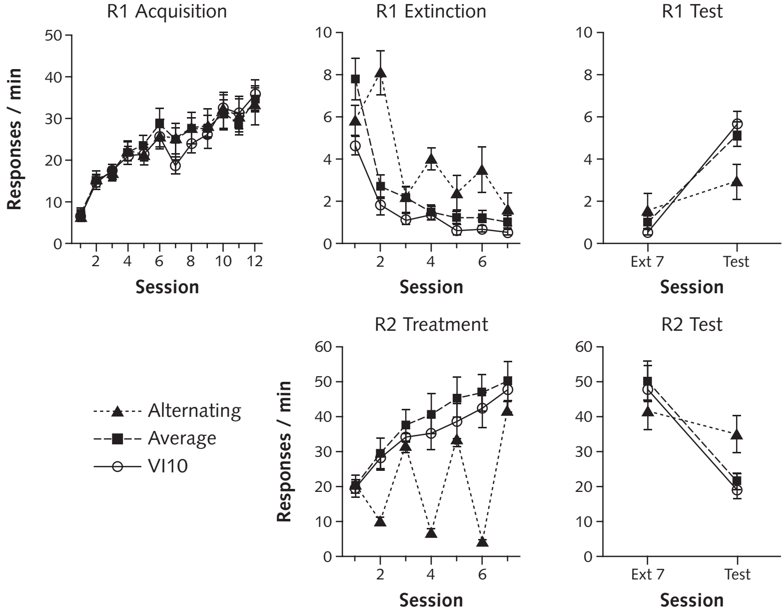

Figure 1. Results of an experiment assessing the effects of different ways of distributing reinforcement across Phase 2 of a resurgence design (Schepers and Bouton, 2015, Experiment 3). During the test, animals in a group that had received alternating sessions of reinforcement on VI 10–s and extinction (Group Alternating) showed no resurgence of R1 responding, whereas groups that received reinforcement throughout (Groups VI 10–s and Average) did. Group Average received the same average programmed reinforcement rate as Group Alternating throughout the phase. See text for further explanation.

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[1] We would note that Sweeney and Shahan (2013b) also found that pigeons given alternating extinction and reinforcement sessions (VI 60–s) did not show a resurgence effect, although the control group, which received the same lean reinforcement rate (a VI 60–s schedule) constantly throughout the phase also failed to show resurgence. Thus, the VI 60–s schedule was presumably lean enough to prevent resurgence on its own in this experiment.

Together, the results summarized in this section suggest that while rate of reinforcement is important in producing resurgence (as is predicted by the Shahan–Sweeney Model), the particular distribution of those reinforcers throughout the phase matters. Several of the results were not anticipated by the momentum–based resurgence model (Shahan & Sweeney, 2011; Sweeney & Shahan, 2013b).

Varying Qualitative Dimensions of Alternative Reinforcement

Another especially important difference between the context hypothesis and the Shahan–Sweeney model (alluded to previously) is that the latter makes no predictions about manipulations of the *qualitative* properties of the reinforcer. The context hypothesis uniquely predicts that manipulating the *types* of Phase–2 reinforcers, rather than merely their rates, might also affect the level of resurgence.

Bouton and Trask (2016) therefore conducted an experiment (the results of which are shown in Figure 2) in which all rats learned to lever press (R1) for one reinforcing outcome (O1, counterbalanced as grain–based or sucrose–based food pellets) during Phase 1. In Phase 2, a new response (R2) was introduced and R1 was placed on extinction. However, instead of leading to the same reinforcer, as is typically the case, R2 now produced the other reinforcer, O2 (sucrose–based or grain–based pellets). For testing, animals were then split into three groups. The first group (Group None) was tested in the typical resurgence design, with a complete removal of reinforcement. A second group (Group O2) was tested with response–independent presentations of the O2 reinforcer delivered at an identical rate to that in Phase 2 (a random time, or RT, 30–s schedule). In Group O2, both the context hypothesis and the momentum based resurgence model predict no resurgence. (In fact, Lieving and Lattal (2003) had shown that response–independent presentation of the reinforcer during testing can eliminate resurgence and that periods of nonreinforcement were necessary to produce resurgence.) The context hypothesis predicts no resurgence because the background reinforcement that provides the context does not change between Phase 2 and test (O2 reinforcement to O2 reinforcement). The momentum–based resurgence model predicts no resurgence because there is no change in rate of reinforcement between Phase 2 and test (VI 30–s to RT 30–s). A third group (Group O1) received *O1* presentations at the same rate as O2 was presented during extinction. Here, while Shahan and Sweeney (2011) predict no resurgence again (because as in Group O2, the reinforcement rate between Phase 2 and test do not change, therefore the disruptive effects of reinforcement should still be in place suppressing behavior), the context hypothesis predicts resurgence, because there is a switch from a context in which O2 was present to a context in which O1 is now present.

The results, shown in the top right panel of Figure 2, were clear: While Group O2 remained suppressed throughout the resurgence test, both Groups None and O1 showed robust resurgence effects. Presentations of O1 had no suppressive effect on

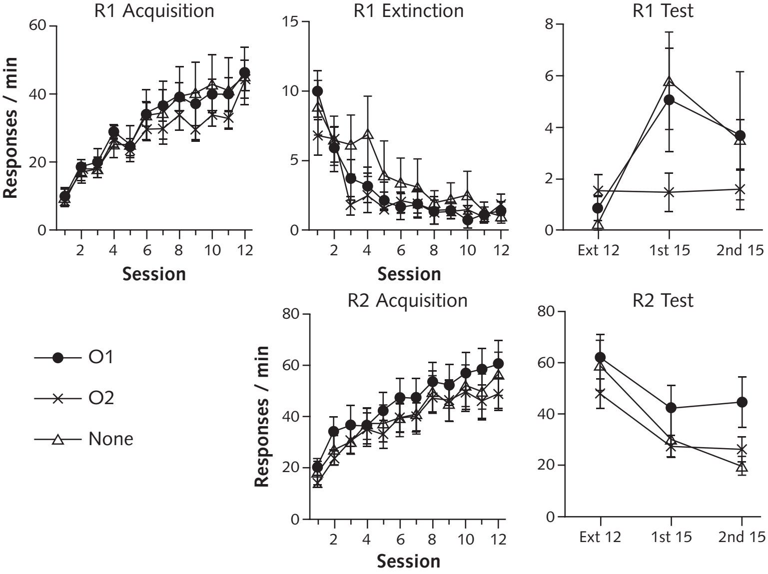

Figure 2. Results of an experiment assessing the effects of presenting response–independent reinforcers of different types during the final resurgence test (Bouton and Trask, 2016, Experiment 2). During testing, animals that received a reinforcer delivered during response elimination (O2) did not show resurgence, whereas animals that received either no reinforcers (None) or a different reinforcer that had been used during acquisition (O1) did. See text for further explanation.

behavior, with Group O1 showing equivalent levels of both resurgence (change from the last day of Phase 2 to the test) and mean responding in the test as Group None. Thus, the results of this experiment support the context hypothesis. The results extend the work of Lieving and Lattal (2003) and suggest that the suppressive effect of reinforcers on resurgence observed in their study was due to the reinforcers' unique association with response inhibition. As indicated by Group O1, reinforcers themselves do not produce generally suppressive effects on behavior and instead require a specific association with response inhibition in order to attenuate the resurgence effect.[2]

Although there is evidence to suggest that rate of reinforcement is important in producing resurgence (Bouton & Schepers, 2014; Leitenberg et al., 1975; Winterbauer & Bouton, 2012), the extent to which resurgence occurs depends on how much gen-

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[2] It should be noted that presenting the reinforcer from Phase–1 (O1) did not reinstate behavior above the level observed in Group None (e.g., cf. Reid, 1958). We would note that previous results indicate that reinforcer presentations during extinction can abolish their subsequent reinstating effect (e.g., Rescorla & Skucy, 1969; Winterbauer & Bouton, 2011). Further experiments suggested that presentations of O2 during response elimination had the same effect here (Bouton & Trask, 2016).

eralization occurs between the contexts of extinction and the resurgence test (Bouton & Trask, 2016). The discriminative properties of the reinforcer—and not its purely reinforcing properties—appear to be paramount.

Reinforcer Context and the Attenuation of Relapse

Other experiments (Trask & Bouton, 2016) have explored additional implications of the idea that the discriminative properties of reinforcers can control the inhibition of operant behavior. In a first experiment, rats learned to lever press in one physical context (Context A) for an O1 reinforcer (counterbalanced again as a grain–based and sucrose–based food pellets). Animals then were switched to Context B, where the response underwent extinction, but a second reinforcer, O2 (counterbalanced as sucrose–based or grain–based), was delivered independently of responding at the same rate O1 was earned in the previous phase. Lever–pressing was then tested under two extinction conditions back in Context A. In one testing condition, animals received no reinforcer presentation. Simple ABA renewal was expected here. In the other condition, O2 was delivered independently of responding at the same rate it was delivered during extinction. (Testing order was counterbalanced so that half of the animals were tested first in the free O2 reinforcer condition, and half of the animals were tested first in the no reinforcer condition). As expected, when tested back in Context A, responding demonstrated a clear and robust renewal effect. However, this effect was attenuated when the rats were tested with O2 presentations in Context A. This finding is consistent with the context hypothesis of resurgence: The "reinforcer context" associated with extinction demonstrably inhibited performance that was otherwise present in the renewal context.

A second experiment then asked whether the reinforcer needed to be specifically associated with extinction in order to attenuate the renewal effect. As before, lever pressing was reinforced with O1 in Context A and then extinguished in Context B with response–independent presentations of O2. Animals were then split into two groups for extinction testing in Context A. One group (Group O2) was tested, as before, with both presentations of O2 and no reinforcer presentations. The second group (Group O1) was tested with presentations of both response–independent O1 reinforcer and no reinforcer presentations. O2 significantly attenuated the renewal effect (Group O2), but O1 presentations did not (Group O1). Thus, in order for reinforcer presentations to attenuate renewal, they had to have been associated with the response inhibition in extinction. Reinforcers do not necessarily have a suppressive (disruptive) effect on behavior, as predicted by Shahan and Sweeney (2011).

A third experiment used identical acquisition in Context A (with lever pressing producing O1 reinforcers) and extinction in Context B (with O2 reinforcers presented independently of responding). In this case, however, different groups were tested in

Context A (Group ABA) or in Context B (Group ABB). In either context, responding was tested with both no reinforcer presentations and response–independent O2 reinforcer presentations (with the testing order once again counterbalanced). The results replicated the finding that O2 reinforcers attenuate the standard ABA renewal effect. In addition, although the overall level of responding was lower in animals tested in Context B (Group ABB) than in Context A (ABA), responding within Group ABB was lower when animals were tested with their O2 reinforcer than without. In other words, removal of the O2 reinforcer was sufficient to cause a resurgence–like return of responding in the extinction context (B). The overall pattern of results further expanded on the idea that the presence of the O2 reinforcers can create a unique "reinforcer context." The effects of reinforcer context and physical context were additive. That is, O2 inhibited responding in both the renewing Context A and the extinction Context B.

The results of these experiments suggest that the "reinforcer context" hypothesized by the contextual view of resurgence can act as a cue that can influence renewal (and could potentially be applied to behavioral relapse as a whole). They are consistent with a recent experiment with pigeons that found that resurgence was increased when animals were also removed from the context of extinction using an ABA renewal design where key color served as the context (Kincaid, Lattal, & Spence, 2015). Further, they extend previous work showing that retrieval cues associated with response inhibition can attenuate both renewal (Brooks & Bouton, 1994) and spontaneous recovery (Brooks & Bouton, 1993) of extinguished responding.

Conclusions

Taken together, the results of the research reviewed here support a role for the discriminative properties of the reinforcer in controlling the resurgence effect. The momentum–based model proposed by Shahan and Sweeney (2011) correctly predicts that increasingly rich rates of reinforcement for R2 during R1 response elimination should result in linear increases in resurgence when they are removed during the test (Bouton & Trask, 2016; Sweeney & Shahan, 2013a). However, results from our laboratory have shown that while reinforcement rate is important, the distribution of the reinforcers delivered during response elimination can play a crucial role (Schepers & Bouton, 2015). Conditions that produce equal reinforcement rates do not necessarily yield equal resurgence. In addition, changing the qualitative properties of a reinforcer between Phase 2 and test (while keeping their rate constant) can also produce resurgence, suggesting that the discriminative function (rather than just the disrupting properties) of the reinforcer can play a crucial role (Bouton & Trask, 2016). Other experiments have demonstrated that a reinforcer specifically associated with the inhibition of an operant behavior can be used to inhibit behavior in renewal tests (Trask & Bouton, 2016).

The results are therefore more consistent with the context hypothesis of resurgence. This hypothesis suggests that lean and thinning rates of resurgence work to decrease resurgence by increasing the amount of generalization between the context of response inhibition and the context of testing. Additionally, experience with either extremely low rates of reinforcement or periods of nonreinforcement during Phase 2 can increase the likelihood that those conditions during test will result in more R1 response inhibition. Conditions that more closely match between the extinction reinforcer context and the test reinforcer context are more likely to reduce resurgence. The context hypothesis emphasizes the contextual—discriminative—properties of the reinforcer. This view is consistent with a long tradition of research (e.g., Franks & Lattal, 1976; Ostlund & Balleine, 2007; Reid, 1958; Rescorla & Skucy, 1969; Sheffield, 1949). Reinforcers do more than merely reinforce.

At a more practical level, regarding the reduction of relapse following treatments like contingency management (CM) and functional communication treatment (FCT), the results suggest that treatments should encourage generalization from the treatment situations to the external world. This might entail using a distribution of reinforcement through treatment that would encourage more generalization to the real world (as in Bouton & Trask, 2016; Schepers & Bouton, 2015; Sweeney & Shahan, 2013a), gradually thinning the rates to encourage generalization (Bouton & Schepers, 2014; Schepers & Bouton, 2015; Winterbauer & Bouton, 2012), or providing distinct cues from treatment once treatment ends (Bouton & Trask, 2016; Trask & Bouton, 2016). In addition, treatments like the therapeutic workplace (Silverman et al., 2001; Silverman et al., 2002) in which treatment conditions with alternative reinforcement continue indefinitely, may provide a promising avenue if treatments aim to promote continued abstinence.

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