# A Quantitative Analysis of Resurgence Following Downshifts in Alternative-Reinforcer Magnitude

by

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# Abstract

Resurgence occurs when a previously reinforced and then extinguished target response increases due to changes in reinforcement conditions for an alternative response, including reductions in the magnitude of reinforcement for the alternative response. Using crowdsourcing, we conducted two experiments to extend prior empirical and theoretical work on alternative-reinforcer magnitude and resurgence. Consistent with predictions of the Resurgence as Choice in Context model (RaC$^2$), resurgence of a target button press occurred with reductions in point gain for an alternative response, with greater reductions producing higher levels of resurgence (Experiment 1). In contrast to model predictions, alternating exposures to high and low point gain for the alternative response did not reduce the overall level of resurgence during testing with low point gain or extinction (Experiment 2). Although RaC$^2$ accurately predicted higher levels of resurgence among groups experiencing greater reductions in alternative-reinforcer magnitude, the model consistently underpredicted and then overpredicted resurgence during tests with low-magnitude reinforcement. Overall, our findings suggest that RaC$^2$ could be a useful framework for understanding resurgence in humans, but additional work will be required to improve how the model accounts for resurgence with downshifts in reinforcer magnitude.

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# List of Abbreviations

| | |
|---|---|
| ASD | Autism Spectrum Disorder |
| CM | Contingency Management |
| DRA | Differential Reinforcement of Alternative Behavior |
| FR | Fixed Ratio |
| HIT | Human Intelligence Task |
| MTurk | Amazon Mechanical Turk |
| RaC | Resurgence as Choice |
| $RaC^2$ | Resurgence as Choice in Context |
| RI | Random Interval |
| SUD | Substance Use Disorder |
| VI | Variable Interval |

# Introduction

## Differential Reinforcement-Based Treatment for Severe Problem Behavior

Individuals with deficits in communication and/or social functioning face a higher risk for the development of severe problem behavior (Koegel et al., 1992). Severe problem behavior could include aggression, property destruction, self-injurious behavior, and elopement from caregivers, among other topographies. Deficits in communication and social functioning are core features of autism spectrum disorder (ASD; American Psychiatric Association, 2013) and children with ASD engage in more problem behavior than their typically developing peers, children with psychopathology, or children with atypical development (Matson, et al., 2009). Among children with ASD, prevalence of some form of problem behavior is estimated to be between 82 and 94% (Jang et al., 2011; Matson et al., 2009; McTiernan et al., 2011; Murphy et al., 2009). In addition to causing harm to the child or others, problem behaviors often limit opportunities for education and social interaction and result in significant financial and emotional costs to families (Buschbacher & Fox, 2003; Podlesnik & Kelley, 2017).

Differential reinforcement of alternative behavior (DRA) is a widely used treatment for severe problem behavior (Kurtz et al., 2011; Petscher et al., 2009). DRA is typically preceded by a functional assessment to identify specific consequences maintaining a target response (e.g., Carr & Durand, 1985). Access to the maintaining consequence is then arranged contingent upon a more appropriate alternative response. For example, if hitting occurs to escape from task demands, breaks could be arranged contingent upon appropriate requests. DRA is highly effective in achieving initial reductions in problem behavior (Kurtz et al., 2011; Petscher et al., 2009) but problem behavior is susceptible to relapse, defined as the return of previously eliminated problematic behavior(s) when a treatment is challenged (Nevin & Wacker, 2013;

Wathen & Podlesnik, 2018). Challenges to treatment may include: (1) treatment-integrity errors such as delivery of reinforcers for problem behavior (e.g., St. Peter Pipkin et al., 2010), (2) reductions in the rate of alternative-reinforcer delivery (e.g., Briggs et al., 2018; Marsteller & St. Peter, 2012; Volkert et al., 2009), or (3) removal of all reinforcers (e.g., Lieving et al., 2004; Sullivan et al., 2019; Volkert et al., 2009; Wacker et al., 2013).

## Differential Reinforcement-Based Treatment for Substance Use

Differential reinforcement-based procedures are also used to treat substance use in individuals with substance use disorders (SUDs). SUDs are highly prevalent in the United States, with 20% of adults reporting prior-month tobacco use, 25% reporting prior-month binge drinking, and 10% reporting prior-month illicit drug use (Substance Abuse and Mental Health Services Administration, 2014). SUDs result in increased morbidity and mortality and significant financial costs, including $700 billion in costs related to crime, lost work productivity, and healthcare (Center for Disease Control, 2014; National Drug Intelligence Center, 2011; U.S. Department of Health and Human Services, 2014). Thus, the development of efficacious treatments for SUDs represents a critical public-health priority.

Voucher-based Contingency Management (CM) is a differential reinforcement-based procedure with empirical support for treatment of SUDs (Higgins et al., 1991; see Higgins, et al., 2002, for a review). During voucher-based CM interventions, individuals earn vouchers exchangeable for a variety of items contingent upon biochemically verified abstinence from targeted drug(s). Given that regular clinic attendance is required for drug screening and voucher collection, CM often increases treatment retention (Higgins et al., 2002). CM is highly effective in reducing drug use during treatment (see Davis et al., 2016; Higgins et al., 2011; Lussier et al., 2006, for reviews) but there is a paucity of data on long-term maintenance of treatment effects.

For example, among 59 studies with significant treatment effects reported by Davis et al., fewer than half included a follow-up assessment. Moreover, fewer than one third of the studies evaluating abstinence following discontinuation of CM reported sustained treatment effects (see also Prendergast et al., 2006; but see Higgins, Wong, et al., 2000; Higgins et al., 1995, for exceptions).

Prior to discontinuation of CM, recurrence of drug use may occur when treatment is challenged. Common challenges to CM include: (1) contact with drug reinforcers (see Higgins, Badger, & Budney, 2000, for a discussion), and (2) reduction in the monetary value of vouchers as treatment is faded (e.g., Roll et al., 2006; cf. Kirby et al., 1998). Thus, like severe problem behavior, drug use is susceptible to relapse following changes in treatment conditions.

## Translational Research on Relapse

Differential reinforcement-based procedures have shown great promise in the treatment of both severe problem behavior (e.g., Kurtz et al., 2011; Petscher et al., 2009) and substance use (e.g., Davis et al., 2016; Higgins et al., 2011; Lussier et al., 2006). However, the many benefits associated with successful treatment, including decreased morbidity and mortality for individuals with SUDs, increased educational opportunities for individuals with severe problem behavior, and reduced treatment costs, are dependent upon maintenance of these treatment effects. Thus, a greater understanding of the variables contributing to relapse is imperative to ensure that differential reinforcement-based treatments promote meaningful, sustained change in the lives of individuals with severe problem behavior, SUDs, and their family members (see Davis et al., 2016; Podlesnik & Kelley, 2017, for discussions). Translational research in behavioral sciences has been defined as the examination of fundamental behavioral processes relevant to everyday problems and outcomes (Mace & Critchfield, 2010). Translational research has led to (1) improved understanding of underlying behavioral processes involved in relapse and (2) technological innovations for relapse mitigation (see Lit & Mace, 2015; Podlesnik & Kelly, 2015, 2017, for discussions). Translational approaches to evaluating and mitigating relapse have frequently incorporated laboratory models of challenges to differential reinforcement-based treatments for drug use (see Marchant et al., 2013; Venniro et al., 2016, for reviews) and severe problem behavior (see Pritchard et al., 2014; Wathen & Podlesnik, 2018, for reviews). The use of laboratory models allows for isolation and systematic evaluation of independent variables to an extent that would be impractical or unethical clinical settings. As a result, laboratory models can be used to develop a greater understanding of the fundamental behavioral processes involved in relapse. A greater understanding of these fundamental behavioral processes can inform clinical practice by suggesting methods for improving treatment implementation and mitigating relapse during common treatment challenges.

### ***Resurgence***

Resurgence is one laboratory model of relapse used to examine how changes in alternative reinforcement conditions influence target responding following successful treatment with differential reinforcement-based procedures. Procedures designed to assess resurgence typically arrange three phases. In Phase 1, a target response (e.g., lever press) is reinforced, providing a model of reinforcement of undesirable behavior under natural and/or baseline conditions. Phase 2 is a model of treatment: the target response is extinguished, and an alternative response (e.g., pressing a second lever) is reinforced. In Phase 3, reinforcement conditions are altered to simulate common challenges to treatment. For example, studies simulating discontinuation of treatment in Phase 3 withhold reinforcement for both responses, and a transient recovery of target responding (resurgence) is typically observed. Resurgence has been observed in several different species, including rats (e.g., Leitenberg et al., 1970; Craig & Shahan, 2016), fish (e.g., da Silva et al., 2014; Kuroda et al., 2017), hens (Cleland et al., 2000), mice (Craig et al., 2020), pigeons (e.g., Liddon et al., 2017; Shvarts et al., 2020), monkeys (Mulick et al., 1976), and humans (e.g., Ritchey et al., 2021; see Kestner & Peterson, 2017, for a review). Resurgence has been demonstrated in clinical populations following discontinuation of treatment for severe problem behavior (e.g., Briggs et al., 2018; Lieving et al., 2004; Muething et al., 2021; Sullivan et al., 2019; Volkert et al., 2009; Wacker et al., 2013) and substance use (e.g., Preston et al., 2002; Silverman, Higgins, et al., 1996; Silverman, Wong, et al., 1996; Silverman et al., 1998).

To further illustrate the relevance of this three-phase model, Figure 1 shows hypothetical data depicting resurgence of severe problem behavior. Phase 1 represents the (pre-treatment) history of reinforcement for problem behavior: hitting peers results in access to toys, and thus a steady rate of hitting is observed. Phase 2 represents treatment with DRA: only a communication response – "toys" – results in access to toys; the result is an increase in the rate of appropriate communication responses as hitting is extinguished. Phase 3 represents a lapse in treatment integrity or discontinuation of treatment. In the former case, if a request for toys is not granted, perhaps due to a distracted teacher or caregiver, we might expect to see a resurgence in hitting. The resurgence effect is shown beginning in Session 21, when hitting increases above levels observed at the end of the preceding treatment phase.

Although resurgence has been described as an extinction-induced phenomenon (e.g., Epstein, 1983; Hoffman & Falcomata, 2014; Lattal & St. Peter Pipkin, 2009), several laboratory experiments have demonstrated that a worsening of reinforcement conditions for an alternative response is sufficient to produce resurgence (see Lattal et al., 2017, for a discussion). Examples of changes in reinforcement conditions that produce resurgence include: (1) delayed alternative-reinforcer delivery (e.g., Jarmolowicz & Lattal, 2014; Nighbor et al., 2017; Venniro et al., 2018), (2) punishment of an alternative response (e.g., Fontes et al., 2018; see Venniro et al., 2018, for related findings), (3) reductions in alternative-reinforcer rate (e.g., Lieving & Lattal, 2003; Schepers & Bouton, 2015; Winterbauer & Bouton, 2012) and (4) reductions in alternative-reinforcer magnitude (Craig et al., 2017; Oliver et al., 2018). For example, Winterbauer and Bouton (2012) examined the effects of downshifts in alternative-reinforcer rate (i.e., reinforcer 'schedule thinning') on resurgence of lever pressing in rats. In one experiment, rats' lever presses produced food on a random-interval (RI) 30-s schedule in Phase 1. When reinforcers are delivered on a RI 30-s schedule, the probability that reinforcement will be arranged during each second is 1 in 30, and the next response after reinforcement is arranged produces the reinforcer. In Phase 2, target responding was extinguished for all rats. For two groups, presses on an alternative lever were reinforced on an RI 20-s schedule. One group experienced a constant rate of alternative reinforcement throughout Phase 2, while a second group experienced systematic decreases in the rate of alternative-reinforcer deliveries during each Phase-2 session (i.e., from an RI 20-s to an RI 160-s schedule). For a third group, neither target nor alternative responses were reinforced in Phase 2. For the group experiencing systematic decreases in alternative-reinforcer rates, target responding increased during Phase 2 and remained at high levels (relative to levels of responding in the other two groups) prior to Phase-3 testing. In other words, schedule thinning produced an early resurgence effect (see Schepers & Bouton, 2015; Sweeney & Shahan, 2013a, for related findings).

Volkert et al. (2009) demonstrated the generality of findings of laboratory evaluations of resurgence to understanding relapse of severe problem behavior in children with disabilities.

Following functional analyses to identify reinforcers maintaining problem behavior (Iwata et al., 1982/1994), problem behavior produced the functional reinforcer on a fixed-ratio (FR) 1 schedule in Phase 1. In other words, reinforcers were delivered following each instance of problem behavior. In Phase 2, problem behavior was extinguished and an alternative communication response (e.g., asking for toys) produced the functional reinforcer on an FR 1 schedule. In Phase 3, the alternative reinforcement schedule was thinned such that the functional reinforcer was delivered following 12 communication responses (an FR 12 schedule of reinforcement). Despite continued availability of alternative reinforcement at a reduced rate, problem behavior resurged in all three participants (see Briggs et al., 2018, for related findings). Resurgence during schedule thinning is significant because the practice of thinning schedules of reinforcement ensures that caregivers can reasonably implement DRA while balancing other responsibilities (e.g., caring for other children). Inadvertent reinforcement of problem behavior during schedule thinning could result in reacquisition of these behavior(s), necessitating further treatment.

**Alternative-Reinforcer Magnitude.** Studies examining resurgence in clinical populations have primarily focused on (1) effects of reductions in alternative-reinforcer rate through schedule thinning (e.g., Volkert et al., 2009; Briggs et al., 2018; Roll et al., 2006) or (2) discontinuation of treatment (e.g., for severe problem behavior: Hoffman & Falcomata, 2014; Lieving et al., 2004; Mace et al., 2010; Sullivan et al., 2019; Volkert et al., 2009; Wacker et al., 2013; for substance use: Higgins et al., 1995; Higgins, Wong, et al., 2000; Preston et al., 2002; Silverman, Higgins, et al., 1996, Silverman, Wong, et al., 1996; Silverman et al., 1998). However, differential reinforcement-based treatments often involve manipulations of reinforcer magnitude for desirable behavior such as communication responses or abstinence. For example, clinical studies examining effects of alternative-reinforcer magnitude on severe problem behavior have manipulated the duration of access to toys (e.g., 10 s versus 60 s: Lerman et al., 1999; see also Roane et al., 2007). Studies examining effects of alternative-reinforcer magnitude on substance use have manipulated the monetary value of vouchers received contingent upon abstinence from the targeted substance (e.g., cigarette smoking: Correia & Benson, 2006; Lamb et al., 2004; Packer et al., 2012; Stitzer & Bigelow, 1983, 1984; cocaine use: Higgins et al., 2007; Petry et al., 2012; Silverman et al., 1999). Results of these studies suggest that higher magnitude reinforcers result in (1) faster elimination of both severe problem behavior and substance use and (2) increased duration of drug abstinence during treatment (but see Carroll et al., 2002; Lerman et al., 2002, for exceptions).

Although many studies have demonstrated the efficacy of high-magnitude alternative reinforcers in reducing undesirable behavior during treatment, current research on effects of alternative-reinforcer magnitude on resurgence of severe problem behavior and substance use is limited in scope and generality. For example, the effect of transitioning from high- to low-magnitude alternative reinforcement on resurgence of undesirable behavior in humans has not been directly examined. Just as schedule thinning is necessary to increase the feasibility of behavioral treatments and to fade interventions, high-magnitude alternative reinforcers must also be replaced with low-magnitude alternative reinforcers (1) to ensure that treatment is practical and/or affordable and (2) to increase long-term maintenance of treatment effects. For example, when long durations of access to toys are used to treat severe problem behavior, these periods may interfere with learning or other activities. Furthermore, the cost of implementing CM is frequently cited as a concern for practitioners treating SUDs (Cunningham et al., 2018), and could explain why CM is not widely adopted (Benishek et al., 2010; McGovern et al., 2004; Willenbring et al., 2004).

Laboratory studies have shown that reductions in alternative-reinforcer magnitude produce resurgence in rats (Craig et al., 2017; Oliver et al., 2018) and pigeons (Oliver et al., 2018), despite continued availability of alternative reinforcement. For example, Craig et al. (2017) reinforced rats' lever pressing with six pellets on a VI 15-s schedule in Phase 1. A VI 15-s schedule arranges reinforcer deliveries for the first response after, on average, a 15-s interval has passed. In Phase 2, target-lever pressing was extinguished and an alternative response (chain pull) produced reinforcers on a VI 15-s schedule. Downshifts in alternative-reinforcer magnitude were assessed across three groups receiving either three pellets (50% reduction), one pellet (83% reduction), or a typical resurgence test with no pellets (100% reduction) in Phase 3. Rats receiving a 50% reduction showed smaller increases in target responding that did not exceed responses on an inactive control lever (a lever that had never produced reinforcement). However, rats receiving an 83% and 100% reduction in alternative-reinforcer magnitude showed robust and similar amounts of resurgence. These results suggest that (1) reductions in alternative-reinforcer magnitude produce resurgence and (2) resurgence is a function of the degree to which alternative-reinforcer magnitude is reduced. The important clinical implication is that, like reductions in alternative-reinforcer rate, reductions in alternative-reinforcer magnitude could increase susceptibility to relapse, despite ongoing treatment.

**Resurgence Mitigation.** Beyond demonstrations of resurgence during simulated treatment challenges, translational research on resurgence has also involved extension of relapse mitigation techniques developed in the laboratory to clinical settings, often with promising results (see Fisher et al., 2020; Fisher et al., 2015; Fisher, Greer, Craig, et al., 2018; Fisher, Greer, Fuhrman et al., 2018; Fuhrman et al., 2016; Marsteller & St. Peter, 2014; Pritchard et al., 2014, for examples; but see also Greer et al., 2020; Lambert et al., 2017). One technique that has attenuated resurgence in the laboratory but has not yet been extended to clinical settings is exposure to alternating Phase-2 conditions in which alternative reinforcement is versus is not available (hereafter referred to as *on/off* alternative reinforcement). This procedure has attenuated resurgence (relative to constant availability of Phase-2 reinforcement) during Phase-3 extinction tests in both rats (Schepers & Bouton, 2015; Trask et al., 2018) and humans (Thrailkill et al., 2019).

In Phase 1 of their experiment, Thrailkill et al. (2019) reinforced university students' key presses on a computer keyboard with a tangible food reinforcer on a VI 12-s schedule. In Phase 2, presses on a second key produced virtual USD $0.10 coins while presses on the first key were extinguished. For one group, alternative-key presses produced reinforcers during odd 1-min blocks on a VI 3-s schedule but were extinguished during even blocks. For a second group, alternative-key presses produced reinforcers on a VI 6-s schedule across all Phase-2 blocks. Reinforcement schedules were adjusted to equate the overall amount of reinforcement across groups. Results showed attenuated resurgence of target-key pressing during Phase-3 extinction tests for the group receiving alternative reinforcers only during odd 1-min blocks. The clinical implication is that periodic exposure to unavailability of alternative reinforcement during treatment could mitigate resurgence during a subsequent treatment challenge. Similarly, it is possible that periodic exposure to low-magnitude alternative reinforcement during treatment (e.g., 5 min with an iPad as opposed to 10 min) could mitigate resurgence during subsequent deliveries of low-magnitude alternative reinforcement. However, the extent to which this modified technique would effectively mitigate resurgence remains an empirical question.

## Resurgence as Choice in Context (RaC$^2$)

In addressing empirical questions about resurgence, the use of a quantitative theoretical framework allows for precise descriptions of complex functional relations between changes in environmental conditions (e.g., reductions in alternative-reinforcer magnitude) and recurrence of target responding. Precise formalization of underlying behavioral processes is important to ensure that predictions about variables contributing to resurgence can be evaluated for accuracy and utility. A greater understanding of variables contributing to resurgence can then be used to inform the development of relapse-mitigation techniques; such techniques can be incorporated into behavioral treatments to improve outcomes during common challenges to treatment.

Resurgence as Choice in Context (RaC$^2$; Shahan et al., 2020a) is an example of a quantitative model that can be used to make specific predictions about how changes in parameters of reinforcement affect the rate at which a target response occurs. Thus, this quantitative model is particularly useful for addressing questions about effects of reinforcer magnitude on resurgence. RaC$^2$ suggests that resurgence is a shift in response allocation which occurs due to changes in values of outcomes produced by each of the available response options over time (Shahan & Craig, 2017). The value of target and alternative response options are calculated separately using Equation 1:

$$V = \sum w_x(R_x M_x), \tag{1}$$

where value is the sum of weighted ($w_x$), multiplicative effects of the parameters of reinforcement, including reinforcer rate ($R_x$) and magnitude ($M_x$). Reinforcer rate is the number of reinforcers obtained per unit of time (e.g., per hr), and reinforcer magnitude is amount of reinforcement obtained each time a schedule requirement is met.

Weightings ($\boxed{w_x}$) applied to each session are calculated using a modified version of a temporal weighting rule (see Shahan & Craig, 2017, for a detailed discussion; see Devenport & Devenport, 1994; Mazur, 1996, for reviews). The general idea behind the temporal weighting rule used in RaC$^2$ is that the weight of a past outcome is a function of the relative recency of that outcome, with more recent outcomes receiving greater weighting. Figure 2 provides an example of how weightings (middle panel) are applied to obtained target reinforcement rates (top panel) to determine the value of a target response (bottom panel). The top panel shows target reinforcement rates across three phases. Each phase comprises five sessions. Target responding produces six reinforcers on a VI 15-s schedule in Phase 1 and is subsequently extinguished in Phase 2. Extinction remains in place during Phase 3. For clarity, weightings in the middle panel are shown only for even sessions, 2-14. As shown in the middle panel, the function of the decrease in $\boxed{w_x}$ from present to the past sessions is hyperbolic: the weight of recent outcomes decreases quickly at first, but the function decelerates as those experiences recede further into the past. For instance, the influence of Session 14 is large and approaches 1 during that session but the weight of Session 1 is ~0.02 and influences responding during Session 14 much less. Thus, recent reinforcement conditions can have large impact on value, but effects of outcomes obtained in early sessions will linger for a long time. For example, the bottom panel shows a steep decrease in value from Session 5 to Session 6 when reinforcement is presented and subsequently removed between these two sessions. However, after ten sessions of extinction (by Session 15), the value of the target response remains above zero. This non-zero value reflects the lingering effects of reinforcement obtained in early sessions.

In the RaC$^2$ model, value of the target and alternative response options are used to estimate the conditional probability of each response. For example, the conditional probability of a target response ($pT$) is calculated using Equation 2:

$$\boxed{pT = \frac{V_T}{V_T + V_{Alt}}} \qquad \boxed{(2)}$$

Equation 2 suggests that $pT$ is a function of the value of outcomes historically produced by the target response ($V_T$) relative to the value of outcomes historically produced by the alternative ($V_{Alt}$). The original model (RaC; Shahan & Craig, 2017) proposed conversion of $pT$ to a target response rate (target responses/min; $\boxed{B_T}$) using Equation 3:

$$\boxed{B_T = \frac{kV_T}{V_T + V_{Alt} + \frac{1}{A}}} \qquad \boxed{(3)}$$

In Equation 3, the parameter $k$ represents asymptotic baseline response rates (Herrnstein, 1970), and $A$ reflects the invigorating effects of reinforcement (i.e., arousal; Killeen, 1994). $A$ is a linear function of the total value of the target and alternative response options. More specifically, $A = a(V_T + V_{Alt})$, where $a$ is a parameter scaling $V_T$ and $V_{Alt}$ into *arousal*. As $A$ increases, target response rates increase. That is, with greater arousal, target response rates approach an asymptote more quickly as the value of the target option increases (see Shahan & Craig, 2017, for a detailed discussion).

Figure 3 demonstrates the use of Equations 2 and 3 to calculate $pT$ and $\boxed{B_T}$, respectively, in two simulated experiments. Parameters for these and all subsequent simulations were based on fits of RaC$^2$ to other data sets from our lab. The data in Figure 3 clarify the relation between changes in value of each response option (top panels) and resurgence. In Simulation 1 (left panels), each phase comprises five sessions. Target responding produces six reinforcers on a VI 15-s schedule in Phase 1 and is subsequently extinguished in Phase 2. Alternative responding produces six reinforcers on a VI 15-s schedule in Phase 2. Phase 3 is an extinction test in which neither response produces reinforcers. The top-left panel shows that the value of the target in Phase 1 ($V_T$) is initially equivalent to the product of reinforcer rate and magnitude (Equation 1; 240 reinforcers per hr * 6 = 1,440 reinforcers per hr). During Phases 2 and 3, $V_T$ decreases with continued exposure to extinction. Recall that weightings are applied to each session to account for the effects of a history of reinforcement (Equation 1). This results in a hyperbolic decrease in $V_T$ across extinction sessions.

The middle-left panel of Figure 3 shows the conditional probability of target responding ($pT$) in Simulation 1 (Equation 2). The bottom left panel shows the conversion of $pT$ into target responses per min, $\boxed{B_T}$ (Equation 3). An increase in $pT$ is observed in the first session of the Phase-3 extinction test (Session 11). This increase in $pT$ is produced by the steep decrease in the value of the alternative response ($V_{Alt}$; top left panel), resulting from the removal of alternative reinforcement. In other words, because $V_{Alt}$ is in the denominator of Equation 2, a reduction in $V_{Alt}$ increases $pT$. RaC$^2$ therefore predicts that removal of reinforcement for an alternative response will increase the conditional probability of a target response (and absolute target response rate), despite continued extinction for that response. This prediction is consistent with results of empirical studies of resurgence (see Wathen & Podlesnik, 2018, for a review).

The right panels of Figure 3 show the results of Simulation 2. Each phase again comprises five sessions, and all aspects of Phases 1 and 2 are consistent with Simulation 1. In Phase 3, the magnitude of alternative reinforcement is reduced by 83%. Thus, alternative responding continues to produce reinforcers on a VI 15-s schedule, but one reinforcer is delivered instead of six each time a schedule requirement is met. As shown in the right panels, RaC$^2$ predicts an increase in the conditional probability of target responding (and absolute target response rate) in Phase 3, despite continued availability of alternative reinforcement. This is consistent with empirical work on resurgence following reductions in alternative-reinforcer magnitude in nonhumans (Craig et al., 2017; Oliver et al., 2018). RaC$^2$ therefore suggests that the same process that governs responding during discontinuation of treatment also governs responding during a reduction in alternative-reinforcer magnitude: response allocation in both cases is determined by changes in the relative values of the response options.

### *Effects of On/Off Alternative Reinforcement on Resurgence*

Beyond accounting for empirical data demonstrating resurgence under changing reinforcement conditions, RaC$^2$ also accounts for empirical data demonstrating the attenuating effects of on/off alternative reinforcement on resurgence (see Shahan et al., 2020a, for a review). Shahan et al. (2020b) modified Equation 3 to calculate biasing effects of exposure to sessions in which alternative reinforcement is available (i.e., typical Phase-2 sessions) versus unavailable (i.e., typical Phase-3 sessions) on target response rates:

$$\boxed{B_T = \frac{\frac{kV_T}{d_0}}{\frac{V_T}{d_0} + \frac{d_1(V_{Alt})}{d_0} + \frac{1}{A}}} \qquad \boxed{(4)}$$

Equation 4 incorporates variables representing discriminative effects of the presence ($d_1$) or absence ($d_0$) of reinforcer deliveries on response allocation. Equations for $d_1$ and $d_0$ are based on a simplified version of the Weibull learning curve (see Gallistel et al., 2004):

$$\boxed{d_1 = d_m(1 - e^{-x_{on}})} \qquad \boxed{(5)}$$

$$\boxed{d_0 = d_m(1 - e^{-x_{off}})} \qquad \boxed{(6)}$$

The parameter $d_m$ represents an asymptotic value of $d_1$ and $d_0$; $x_{on}$ and $x_{off}$ represent the number of sessions in which alternative reinforcement is available versus unavailable, respectively. A detailed discussion of calculations of these discriminative effects are described in detail by Shahan et al. (2020a). Briefly, RaC$^2$ suggests that an organism learns to discriminate between the availability and unavailability of alternative reinforcement with repeated exposure to each of these reinforcement conditions. As such, $d_1$ increases across sessions in which alternative reinforcement is available (i.e., a typical Phase-2 session), and $d_0$ increases during extinction of both target and alternative responses (i.e., a typical Phase-3 session). Both $d_1$ and $d_0$ are unitless ratios, indicating bias. Increasing values of $d_1$ indicate increasing bias toward the alternative response. For example, if $d_1 = 2$, this represents a 2/1 bias toward the alternative response, given otherwise equal conditions. As $d_1$ increases, target response rates decrease. In contrast, values of $d_0$ greater than 1 indicate a bias away from both response options, resulting in decreased target and alternative responding.

In addition to accounting for changes in responding during, slight modifications to Equations 5 and 6 can be used to predict changes in bias toward the alternative ($d_{1s}$) or changes in bias away from both response options ($d_{0s}$) during downshifts in alternative-reinforcer rate or magnitude,

$$d_{1s} = pd_1 \tag{7}$$

$$d_{0s} = (1-p)d_1. \tag{8}$$

In Equations 7-8, $p$ is the post-shift alternative reinforcement rate or magnitude (RAlt2) as a proportion of the pre-shift alternative reinforcement rate or magnitude (RAlt1),

$$p = \left(\frac{R_{Alt2}}{R_{Alt1}}\right)^{s} \tag{9}$$

and $s$ is a parameter representing sensitivity to the change in reinforcement conditions (Shahan et al., 2020b).

Equations 4-6 can be used to generate predictions of $\text{RaC}^2$ for simulated experiments in which on/off alternative reinforcement procedures are used in Phase 2. The top panel of Figure 4 shows results of Simulation 3. In this simulation, two groups experience different Phase-2 procedures. Consistent with Simulations 1 and 2, target responding produces six reinforcers across five successive sessions on a VI 15-s schedule in Phase 1 (not shown) and is subsequently extinguished in Phase 2 while alternative responding is reinforced. Alternative responding produces six reinforcers on a VI 25-s schedule across all Phase-2 sessions for one group (Group Constant). For a second group (Group On/Off), alternative responding produces six reinforcers on a VI 15-s schedule in sessions 6, 8, and 10 only. For Group On/Off, all reinforcers are removed in sessions 7 and 9. Reinforcement schedules were adjusted to equate the overall amount of reinforcement across groups (Thrailkill et al., 2019; cf. Schepers & Bouton, 2015). $RaC^2$ predicts that exposure to the on/off procedure will attenuate resurgence when all reinforcers are removed in Phase 3 by increasing generalization of reinforcement conditions from the preceding phase (Figure 4, top panel, Sessions 11-15). This prediction is consistent with results of empirical studies examining effects of on/off alternative reinforcement on resurgence (Schepers & Bouton, 2015; Shahan et al., 2020; Thrailkill et al., 2019; Trask et al., 2018).

$RaC^2$ also predicts that alternating exposures to high- and low-magnitude alternative reinforcement will attenuate resurgence produced by subsequent exposures to low-magnitude alternative reinforcement. To date, no studies have tested this prediction, despite its empirical and clinical importance. The results of Simulation 4 (Figure 4, bottom panel) were calculated using Equations 4 and 7-9. For both groups in this simulation, target responding produces six reinforcers on a VI 15-s schedule in Phase 1 (not shown). Target responding for both groups is subsequently extinguished in Phase 2 while alternative responding is reinforced. For one group (Group Constant), alternative responding produces six reinforcers on a VI 21-s schedule across all Phase-2 sessions. Alternative responding produces six reinforcers on a VI 15-s schedule in sessions 6, 8, and 10 only for a second group (Group High/Low). For Group High/Low, alternative responding produces one reinforcer on a VI 15-s schedule in sessions 7 and 9. As in

Simulation 3, reinforcement schedules were adjusted to equate the overall amount of reinforcement in each group. In Phase 3 (beginning in Session 11), alternative responding produces one reinforcer on a VI 15-s schedule across all sessions in both groups. This represents an 83% reduction in alternative-reinforcer magnitude relative to some Phase-2 sessions (Group High/Low) or all Phase-2 sessions (Group Constant). As shown in the figure, RaC$^2$ predicts that the high/low procedure will attenuate resurgence when only low-magnitude alternative reinforcement is available in Phase 3. Further evaluation of RaC$^2$ could facilitate a greater understanding of underlying behavioral processes that govern resurgence following the introduction and subsequent fading of high-magnitude reinforcement. This is important because a greater understanding of these underlying processes could suggest methods for (1) improving implementation of differential reinforcement-based treatments and (2) promoting long-term maintenance of treatment effects.

## The Present Study

The present study included two crowdsourcing experiments with human participants (e.g., Ritchey et al., 2021; Robinson & Kelley, 2020). Experiment 1 evaluated the relation between reductions in alternative-reinforcer magnitude and resurgence. Experiment 2 evaluated effects of Phase-2 high/low magnitudes of alternative reinforcement on resurgence following a transition to low-magnitude reinforcement or extinction in Phase 3. In each case, we fit predictions of RaC$^2$ to the data. The following hypotheses were based on RaC$^2$ simulations (Figures 5-6):

- **Hypothesis 1 (Experiment 1):** 0%, 50%, and 83% reductions in alternative-reinforcer magnitude from Phase 2 to Phase 3 will produce resurgence, with greater reductions resulting in increased resurgence (Figure 5).
- **Hypothesis 2 (Experiment 2):** Repeated exposures to an 83% reduction in alternative-

reinforcer magnitude in Phase 2 will mitigate resurgence (relative to constant exposure to high-magnitude reinforcement) during subsequent exposures to an 83% reduction or extinction in Phase 3 (Figure 6).

## General Methods

### Participants

A power analysis with data from a prior study of resurgence using the crowdsourcing website Amazon Mechanical Turk (MTurk; Robinson & Kelley, 2020), indicated that a sample size of at least five participants per group would ensure ample power (>.80) to detect resurgence with an effect size of 2.59. However, previous research has demonstrated differences in responding among MTurk participants experiencing identical experimental contingencies (Ritchey et al., 2021). For example, Ritchey et al. (2021) observed statistically significant differences in Phase-1 response rates between groups despite arranging identical VI schedules which successfully equated reinforcement rates. One way to minimize such differences might be to increase overall sample size. Thus, we increased our sample size from 20 per group in previous research (e.g., Podlesnik et al., 2020; Ritchey et al., 2021) to 50 per group in the present study. We recruited a total of 443 participants from the MTurk website ranging in age from 19 to 77 (*M* = 36.7, *SD* = 11.7). Table 1 shows participant demographic information.

### Apparatus

The experiment was constructed using MTurk, WordPress (ver. 5.0.2), and Xserver, the details of which have been described in detail elsewhere (Kuroda et al., under review; Ritchey et al., 2021). Participants could only access the Human Intelligence Task (HIT) on MTurk using Windows or Mac (either desktop or laptop) computers and one of the following browsers: Google Chrome, Mozilla Firefox, or Microsoft Edge. We recruited participants with an MTurk approval rate at or above 95%; that is, 95% of tasks had resulted in payment from MTurk employers (Chandler & Shapiro, 2016). Individuals were not eligible to participate if they had completed any of our previously published HITs.

### *Attrition*

Our program contained an index and list of random numbers for random assignment to control and experimental groups (see Kuroda et al., under review, for details). Within each experiment, the index value was incremented each time group assignment occurred. We used this feature to track attrition in all experiments – see Table 1. To calculate the attrition rate, we first identified the number of dropouts by subtracting the number of saved files from the index value. We then divided the number of dropouts by the index value and multiplied this number by 100.

## Procedure

The experimental task was presented in several parts. First, participants read a general description of the HIT on the MTurk website. Clicking a link on the MTurk website presented an informed consent form followed by instructions for the experimental task. Next, participants completed the experimental task and a post-experiment survey. Upon completion of the post-experiment survey, a unique payment code was provided along with instructions to return to the MTurk website to submit the payment code. Appendix A lists all instructions and post-experiment survey questions.

Appendix A also shows objects presented on the browser during the task – hereafter this will be referred to as the *interface*. A beach scene was presented in the background and two buttons (the “target” and “alternative” buttons) were presented in the foreground with either a red heart or black club symbol. Buttons randomly moved 20 px (a fifth of button size) in one of four directions (up, down, left, and right) at 0.2-s intervals within a rectangular workspace. Button symbol and location (left or right side of the interface) were completely counterbalanced across participants.

During some parts of each experiment, clicking a button (1) intermittently produced a yellow star above the button, (2) switched the color of the point bar from gray to green for 0.4 s, (3) increased the point counter by 100 points, and (4) added USD $0.000005 per point to the total earnings within the session – these events comprised reinforcement. In both experiments, each click on either button also produced a response cost (e.g., Shanks & Dickinson, 1991; Chen & Reed, 2020), indicated by (1) a 0.4-s presentation of red text – "-1" – below the button, (2) a switch in the point-bar color from gray to red for 0.4 s, and (3) a deduction of $0.000005 per point lost from total. Clicks on other parts of the interface were recorded but resulted in no programmed consequences. These included clicks (1) within a workspace but not on a button, (2) on the background outside a workspace, (3) on any text indicating number of points earned, total points earned, total monetary earnings, (4) on the point bar or point-bar label, or (5) on the yellow star. Table 2 provides a summary of experimental procedures.

The interface disappeared when participants completed the experimental task, and onscreen text indicated that the game portion ended. Participants were then instructed to respond to 19 survey questions which included questions about the experimental task and demographic information (see Appendix A). After answering all survey questions, a unique payment code was provided using *xorshift Random Number Generator* (*RNG*; Marsaglia, 2003). To receive payment, participants were instructed to submit their payment code on the MTurk website within 45 min of initiating the HIT.

## Data Screening

We eliminated data sets meeting any of four exclusion criteria, similar to criteria described in our previous research (Ritchey et al., 2021). First, to eliminate data likely produced by "bots," we excluded data sets with more than 20 responses per second. To ensure at least minimal contact with the experimental contingencies, we eliminated data sets with no responses across a two-min period in Phase 1 or Phase 2, or no alternative responses throughout Phase 2. We also eliminated data sets if participants did not complete the experiment, including the post-experiment survey. Table 3 provides a summary of excluded data sets.

## Data Analysis

### *Statistical Analysis*

We used a mixed-effects modeling approach to evaluate effects of experimental contingencies on the rate of responding on target and alternative buttons. We performed multilevel modeling with the R Statistical Program (R Core Team, 2013), using the lme method contained in the *lme4* package (Bates et al., 2015). Target and alternative responses were analyzed in separate models.

For all analyses, we first evaluated the random-effects structure using the second-order Akaike Information Criterion (AICc) with up to two simultaneous random slope effects. Specifically, we evaluated random-slope effects of (1) Time and (2) Phase which allowed for participant-level differences in changes in responding across 1-min bins and phases, respectively. We performed model comparisons using AICc via the *MuMIn* R package (Barton, 2009) and subsequently evaluated fixed effects using likelihood-ratio tests. We then used the *emmeans* package (Lenth, 2016) to conduct post hoc comparisons of responding in the last bins of Phases 1 and 2 and the first bin of Phase 3. To account for multiple comparisons, adjusted *p* values are reported and were calculated using the Holm-Bonferroni method (Holm, 1979).

## Experiment 1

Experiment 1 examined the relation between reductions in reinforcer magnitude and resurgence in human participants recruited via MTurk. The purpose of this first experiment was to evaluate (1) the generality of empirical work on reductions in reinforcer magnitude with nonhumans (e.g., Craig et al., 2017; Oliver et al., 2018) and (2) whether RaC$^2$ could account for resurgence with decreases in reinforcer magnitude.

### Participants

226 individuals participated in Experiment 1. Participants ranged in age from 19 to 77 (*M* = 36.7, *SD* = 11.5). One hundred fifty-six participants identified as male (69.3%), 67 identified as female (29.8%), and three participants did not provide demographic information. Participants were randomly assigned to one of four groups in which they experienced either no reduction in alternative-reinforcer magnitude from Phase 2 to Phase 3 (i.e., no reduction in stars/points exchangeable for money; Group 6 to 6, *n* = 50), a 50% reduction (Group 6 to 3, *n* = 52), an 83% reduction (Group 6 to 1, *n* = 50) or a 100% reduction (Group 6 to 0, *n* = 50). Group names indicate the number of stars produced by alternative-button clicks meeting a schedule requirement in Phases 2 and 3. For example, Group 6 to 3 earned six stars per eligible alternative-button click in Phase 2 and three stars per eligible alternative-button click in Phase 3. Each star was worth 100 points and exchangeable for \$0.0005 (100*\$0.000005).

We excluded twenty-four additional participants: 17 due to no responding for at least two min in Phase 1 or Phase 2, three due to inexplicably high response rates (i.e., > 20 responses per second), one due to no alternative responses in Phase 2, and three due to no post-experiment survey. See Table 3 for details.

### Procedure

Table 2 provides a summary of experimental procedures. Experiment 1 consisted of three phases, each lasting five min. All groups experienced identical contingencies in Phases 1 and 2. In Phase 1, clicks on the target button produced six stars on a variable-interval (VI) 2-s schedule. The VI 2-s schedule was selected based on the results of unpublished and published research from out lab (Podlesnik et al., 2020; Ritchey et al., 2021; see also Bernal-Gamboa et al., 2020; Smith et al., 2017). Briefly, this schedule has been more effective than leaner schedules (e.g., VI 5-s schedule) in maximizing the number of participants demonstrating target- and alternative-response acquisition during brief experimental procedures. In Phase 2, clicks on the alternative button produced six stars on a VI 2-s schedule, while clicks on the target button were not reinforced. For all groups in Phase 3, clicks on the target button resulted in no programmed consequences, consistent with the previous phase. The availability and magnitude of alternative reinforcement differed across groups. For Group 6 to 6, Phase-2 contingencies remained in place; that is, clicks on the alternative button produced six stars on a VI 2-s schedule. For Group 6 to 3, clicks on the alternative button produced three stars on a VI 2-s schedule. For Group 6 to 1, clicks on the alternative button produced one star on a VI 2-s schedule. For Group 6 to 0, no stars resulted from clicks on either button. There was a response cost (-1 point) for all button clicks in all phases and across all groups. We included the response cost to facilitate performance regulation (see Ritchey et al., 2021).

## Results

**Reinforcer Rates.** Table 4 shows obtained reinforcer rates (star deliveries per min) in each phase across both experiments. Separate one-way ANOVAs confirmed that reinforcer rates were not significantly different across groups in Phase 1 [*F*(3.00, 199.00) = 1.07, *p* = .365] or in Phase 2 [*F*(3.00, 199.00) = 0.92, *p* = .431]. In Phase 3, reinforcer rates were not significantly different among Groups 6 to 1, 6 to 3, and 6 to 6 [*F*(2.00, 150.00) = 1.94, *p* = .148]. Thus, VI schedules were successful in controlling reinforcer rates.

**Target Responding.** The top panel of Figure 7 shows mean target response rates across all three phases in each group. The figure shows that target response rates increased across Phase-1 bins before decreasing to near-zero rates in all four groups in Phase 2. At the onset of Phase 3, target responding increased from Phase-2 levels in each group except for Group 6 to 6. Ordinal correspondence between magnitude reduction and the level of target responding is evident in the first min of Phase 3 – that is, we observed higher response rates with greater reductions.

Table 5 shows the results of the statistical analysis of target responding, with Phase (2) and Group (6 to 6) factors as the individual contrasts. Results indicated a significant effect of Time ($\beta = -10.69$, $p < .001$), whereby response rates in Group 6 to 6 decreased over time in Phase 2, and a significant effect of Phase (1; $\beta = 130.24$, $p < .001$), with higher response rates in Group 6 to 6 in Phase 1 compared to Phase 2. Significant interactions between Time and Phase ($\beta$s $\geq 11.01$, *p*s < .001) indicated differences in changes in response rates over time in Group 6 to 6 in Phases 1 and 3 compared to Phase 2.

Despite arranging identical reinforcement conditions among groups in Phase 1, the interaction between Phase (1) and Group (6 to 3) was significant ($\beta = 42.71$, $p = .004$), indicating a different effect of Phase (1 versus 2) in Group 6 to 3 compared to Group 6 to 6 (see Ritchey et al., 2021, for similar findings). Moreover, three-way interactions between Time, Phase (1) and Group (6 to 1, 6 to 3) were significant ($\beta$s $\geq 6.86$, *p*s $\leq .010$), indicating differences in the interaction effect between Time and Phase (1 versus 2) in Groups 6 to 1 and 6 to 3 compared to Group 6 to 6.

Interactions between Phase (3) and each experimental group ($\beta$s $\geq$ 15.72, *p*s < .028) were significant, indicating different effects of Phase (3 versus 2) in each of these groups compared to Group 6 to 6. A significant three-way interaction between Time, Phase (3), and Group (6 to 1; $\beta$ = -5.32, *p* = .047) indicated differences in the interaction effect between Time and Phase (3 versus 2) in Group 6 to 1 compared to Group 6 to 6.

To further evaluate the significant interactions among Time, Phase, and Group, we conducted post-hoc tests of within- and between-group differences in target responding in the last min of Phases 1 and 2 and the first min of Phase 3 – see Appendix B for detailed results. Briefly, all groups except for 6 to 6 demonstrated higher response rates on the target button in the first min of Phase 3 compared to the last min of Phase 2. Thus, both reductions in reinforcer magnitude (6 to 1, 6 to 3) and removal of alternative reinforcement (6 to 0) produced resurgence. We also observed ordinal correspondence between the reduction amount and level of resurgence: in the first min of Phase 3, Group 6 to 0 responded at higher rates on the target button compared to the other three groups, and Groups 6 to 1 and 6 to 3 responded at higher rates compared to Group 6 to 6. However, target responding increased to similar levels in Groups 6 to 1 and 6 to 3. Overall, the results of the statistical analysis suggest that the involvement of Group in the three-way interaction among Bin, Phase, and Group reflects differences in Phases 3 resulting from the presence or absence of reductions in alternative-reinforcer magnitude.

**Alternative Responding.** The bottom panel of Figure 7 shows mean alternative response rates across all three phases in each group. The figure shows that alternative response rates remained low in Phase 1 and increased in all four groups in Phase 2. Levels of alternative responding remained relatively steady in Phase 3 compared to the end of the preceding phase in Groups 6 to 3 and 6 to 6 but rates decreased relative to Phase 2 in Groups 6 to 1 and 6 to 0.

Appendix C presents results of the statistical analysis of alternative responding (Table C1). Briefly, the statistical analysis supported the conclusions that (1) significant reductions in alternative response rates from Phase 2 to Phase 3 occurred only with reductions from six stars to one star or zero stars (Groups 6 to 1, 6 to 0) and (2) removing alternative reinforcement (6 to 0) decreased alternative responding in Phase 3 to a greater extent than reductions in reinforcer magnitude (6 to 1).

**RaC$^2$ Fits.** Figure 8 shows RaC$^2$ fits to target (top panel) and alternative response rates in each group (bottom panel). Obtained data and RaC$^2$ predictions are shown as solid and dashed lines, respectively. In line with previous research, we simultaneously fit the model to log-transformed target and alternative response rates (e.g., Shahan et al., 2020a, b). Overall, RaC$^2$ provided a good fit to Experiment-1 data, accounting for 89% of the observed variance. However, the top panel shows that while RaC$^2$ accurately predicted differences in the overall level of resurgence at the beginning of the test, resurgence was initially underpredicted in each experimental group (Minute 6) and overpredicted as Phase 3 progressed. Regarding responses on the alternative button, the bottom panel shows that the model underpredicted responding across Phase-3 bins in Group 6 to 3 and overpredicted responding in Group 6 to 0.

## Discussion

Experiment 1 extended prior research in two ways. First, we assessed the generality of empirical work on resurgence produced by reductions in alternative-reinforcer magnitude. In line with nonhuman studies (Craig et al., 2017; Oliver et al., 2018), our findings indicate that reductions in reinforcer magnitude produce resurgence in humans under controlled conditions. This is important because fading high-magnitude reinforcement is necessary to ensure the feasibility and maintenance of behavioral treatments (e.g., Hagopian et al., 2011). One implication of our findings is that such fading procedures could produce resurgence of previously eliminated problematic behavior. However, additional research is required to evaluate generality of this finding to less controlled conditions (e.g., clinical settings).

Second, Experiment 1 evaluated the generality of $RaC^2$ by fitting the model to human data for the first time. Overall, $RaC^2$ accounted for 89% of the variance in our Experiment-1 data. This is in line with prior studies fitting $RaC^2$ to rats' responding following downshifts in reinforcer rate (Shahan et al., 2020b). In the present study, the ordinal predictions of the model were accurate in that greater reductions in the magnitude of alternative reinforcement produced higher rates of target responding during the test. However, the model underpredicted resurgence at the onset of testing and subsequently overpredicted resurgence later in this phase. Shahan et al. (2020b) observed the same pattern of under and then overpredictions for rats experiencing downshifts in alternative-reinforcer rate. The early underpredictions were particularly evident for groups experiencing an ~88% reduction in reinforcement rate (VI 10 s to VI 80 s), while the later overpredictions were particularly evident for one group experiencing a 50% reduction in reinforcement rate (VI 10 s to VI 20 s). Given the similar pattern of errors in predictions in our study and Shahan et al., one area with potential room for improvement for $RaC^2$ would include simultaneously accounting for effects of extinction versus downshifts in reinforcer rate or magnitude on target responding during testing. In line with this idea, further examination of our Experiment-1 fits revealed that the values of free parameters resulting in the best fit to group-level data were inconsistent across groups experiencing a low-magnitude test and extinction test.

## Experiment 2

Research with nonhumans (Schepers & Bouton, 2015; Trask et al., 2018) and humans (Thrailkill et al., 2019) has shown that exposure to alternating Phase-2 conditions in which alternative reinforcement is versus is not available (on/off) attenuates resurgence during extinction tests relative to constant availability of Phase-2 reinforcement. Similarly, RaC$^2$ predicts that exposure to alternating high- and low-magnitude reinforcement during Phase 2 (hereafter *high/low reinforcement*) will mitigate resurgence produced by subsequent deliveries of low-magnitude alternative reinforcement when compared with constant availability of high-magnitude reinforcement in Phase 2 – hereafter, *high reinforcement*. The purpose of Experiment 2 was to examine effects of Phase-2 high/low reinforcement on resurgence with MTurk participants during subsequent exposure to (1) low-magnitude reinforcement or (2) extinction in Phase 3.

**Participants**

217 individuals participated in Experiment 2. Participants ranged in age from 19 to 74 (*M* = 36.7, *SD* = 11.8). One hundred sixteen participants identified as male (53.5%), 98 identified as female (45.2%), one identified as other (0.5%), and two participants did not provide demographic information. Participants were randomly assigned to one of four groups in which they experienced either high/low or high reinforcement for alternative responding in Phase 2 and either low-magnitude alternative reinforcement or extinction in Phase 3. As in Experiment 1, group names indicate the number of stars produced by alternative-button clicks meeting a schedule requirement in Phases 2 and 3. Thus, Groups 6/1 to 1 (*n* = 50) and 6/1 to 0 (*n* = 50) alternated between six- and one-star reinforcement in Phase 2 and experienced one-star reinforcement or extinction in Phase 3, respectively. Groups 6 to 1 (*n* = 51) and 6 to 0 (*n* = 50) experienced constant six-star reinforcement in Phase 2 and one-star reinforcement or extinction in Phase 3, respectively. We excluded sixteen additional participants: 14 due to no responding for at least two min in Phase 1 or Phase 2 and two due to no post-experiment survey. See Table 3

for details.

## Procedure

Table 2 provides a summary of experimental procedures. Experiment 2 consisted of three phases, lasting five, nine, and five min, respectively. In line with previous research examining effects of on/off alternative reinforcement on resurgence, a brief, 1-s blackout occurred every minute for the duration of the experiment (e.g., Thrailkill et al., 2019). Transitions between phases were not signaled. In Phase 1, clicks on the target button produced six stars on a VI 2-s schedule across all groups. As in Experiment 1, each star was worth 100 points, exchangeable for $0.0005 per star. Alternative-reinforcer magnitude differed across groups in Phase 2 and clicks on the target button were not reinforced. For Groups 6/1 to 1 and 6/1 to 0, clicking the alternative button in Phase 2 produced six stars on a VI 2-s schedule; however, this occurred only during even-numbered 1-min bins. During odd-numbered 1-min bins, alternative responding in these groups produced one star on a VI 2-s schedule. For Groups 6 to 1 and 6 to 0, clicks on the alternative button produced six stars on a VI 3.175-s schedule across all Phase-2 bins. The reinforcement schedule was adjusted to equate overall earnings across groups in Phase 2 (e.g., Thrailkill et al., 2019). In Phase 3, extinction remained in place for clicks on the target button across all groups, while the availability and magnitude of alternative reinforcement differed across groups. For Groups 6/1 to 1 and 6 to 1, clicks on the alternative button produced one star on a VI 2-s schedule across all Phase-3 bins (hereafter *low-magnitude test*). For Groups 6/1 to 0 and 6 to 0, clicks on the alternative button resulted in no programmed consequences (hereafter *extinction test*). As in Experiment 1, there was a 1-point response cost for each button click in all phases and across all groups.

## Results

**Reinforcer Rates.** Table 4 shows obtained reinforcer rates (star deliveries per min) in each phase. Separate one-way ANOVAs confirmed that reinforcer rates were not significantly different across groups in Phase 1 [$F(3.00, 197.00) = 1.41$, $p = .242$]. As expected, reinforcer rates differed among groups in Phase 2 [$F(3.00, 197.00) = 22.51$, $p < .001$]. Post-hoc tests confirmed higher rates in the high/low reinforcement groups experiencing the VI 2-s schedule (i.e., 6/1 to 1 and 6/1 to 0) compared to the high reinforcement groups experiencing the VI 3.175-s schedule (i.e., 6 to 1 and 6 to 0), $t$s $\geq 4.84$, $p$s $< .001$. Differences in Phase-2 reinforcer rates between the high/low reinforcement groups (i.e., 6/1 to 1 versus 6/1 to 0) and between the high reinforcement groups (i.e., 6 to 1 versus 6 to 0) were not significant, *ps* = .632. Finally, a *t*-test indicated that Phase-3 reinforcer rates were not significantly different between the 6/1 to 1 and 6 to 1 groups [$t(99.00) = -1.63$, $p = .106$]. Overall, these findings confirm that VI schedules were successful in controlling reinforcer rates.

Figure 9 shows the mean number of stars presented for each group across 1-min bins of Phase 2 (top panels) and cumulative number of star presentations (bottom panel). Despite adjusting VI schedules to equate total earnings among groups in Phase 2, a one-way ANOVA indicated significant differences in total points earned among the four groups [$F(3.00, 197.00) = 4.59$, $p = .004$]. Post-hoc tests revealed higher earnings in Group 6 to 1 ($M = 717.65$ points, $SD = 149.00$) compared to Group 6/1 to 1 ($M = 590.40$ points, $SD = 197.71$), $t(99.00) = 3.48$, $p = .004$. Differences in Phase-2 earnings all remaining groups were not significant, $p$s $> .085$.

**Target Responding.** The top panel of Figure 10 shows mean target response rates across all three phases in each group. The figure shows that target response rates increased across Phase-1 bins before decreasing to near-zero rates in all four groups in Phase 2. For the groups experiencing high/low reinforcement in Phase 2, target response rates were slightly higher with availability of low-magnitude reinforcement (odd 1-min bins) versus high-magnitude reinforcement (even 1-min bins). In the first min of Phase 3, target responding increased from Phase-2 levels in each group, although those increases were smaller in the groups experiencing the low-magnitude test (6 to 1 and 6/1 to 1) versus the extinction test (6 to 0 and 6/1 to 0). Overall levels of target responding were similar within each type of test regardless of prior exposure to high/low or high reinforcement.

Table 6 shows the results of the statistical analysis of target responding, with Phase (2) and Group (6 to 0) factors as the individual contrasts. Results indicated a significant effect of Time ($\beta = -3.32$, $p < .001$), whereby response rates in Group 6 to 0 decreased over time in Phase 2, and a significant effect of Phase (1: $\beta = 106.43$, $p < .001$; 3: $\beta = 27.63$, $p < .001$), with higher response rates in Group 6 to 0 in Phases 1 and 3 compared to Phase 2. The significant interaction between Time and Phase (1; $\beta = 10.29$, $p < .001$) indicated differences in changes in Phase-1 response rates over time in Group 6 to 0 as compared to Phase 2. Finally, significant interactions between Phase (3) and Group (6 to 1: $\beta = -15.48$, $p = .012$; 6/1 to 1: $\beta = -20.47$, $p < .001$) indicated different effects of Phase (3 versus 2) in each of these groups compared to Group 6 to 0.

As in Experiment 1, we conducted post-hoc tests of within- and between-group differences in target responding in the last min of Phases 1 and 2 and the first min of Phase 3 – Appendix B provides detailed results. All groups except 6/1 to 1 responded on the target button at higher rates in Phase 3 compared to Phase 2. Thus, Phase-2 high/low reinforcement mitigated resurgence following a transition to a low-magnitude test (6/1 to 1) but not to an extinction test (6/1 to 0). In the first min of Phase 3, Groups 6 to 0 and 6/1 to 0 responded at higher rates than Groups 6 to 1 and 6/1 to 1, indicating that extinction produced higher levels of target responding than a reduction from six stars to one star, consistent with Experiment 1. Finally, differences in the overall level of target responding between each group transitioning to the (1) low-magnitude test and (2) extinction test were not significant in the first min of Phase 3. This suggests that Phase-2 high/low reinforcement did not reduce the overall level of resurgence in Phase 3.

**Alternative Responding.** The bottom panel of Figure 10 shows mean alternative response rates across all three phases in each group. The figure shows that alternative response rates remained low in Phase 1 and increased in all four groups in Phase 2. Levels of alternative responding remained relatively steady in Phase 3 compared to the end of the preceding phase in Groups 6/1 to 1 but decreased relative to Phase 2 in the remaining groups, with larger decreases in the groups experiencing the extinction test (6 to 0, 6/1 to 0) compared to Group 6 to 1. Appendix C shows the results of the statistical analysis of alternative responding (Table C2). Briefly, the statistical analysis indicated that significant reductions in alternative response rates from Phase 2 to Phase 3 occurred only during the extinction test (6 to 0, 6/1 to 0). However, post-hoc tests indicated that reductions from the last Phase-2 to first Phase-3 bin were marginally not significant for Group 6 to 1 [$t(217.00) = 1.96$, $p = .051$].

**RaC$^2$ Fits.** Figure 11 shows RaC$^2$ fits to target (top panel) and alternative response rates in each group (bottom panel). As in Experiment 1, we simultaneously fit the model to log-transformed target and alternative response rates. RaC$^2$ accounted for 84% of the variance in the Experiment-2 data. The top panel shows that RaC$^2$ underpredicted responding across Phase-3 bins in each group experiencing the extinction test. For Groups 6 to 1 and 6/1 to 1, RaC$^2$ underpredicted responding initially in Phase 3 (Minute 10) and later overpredicted responding (Minutes 13-14). The bottom panel shows that the model overpredicted alternative responding across Phase-3 bins.

### Discussion

Experiment 2 used RaC$^2$ to make novel predictions about the potential attenuating effects of alternating between high- and low-magnitude reinforcement in Phase 2 on resurgence in Phase 3. More specifically, RaC$^2$ predicts that high/low reinforcement will attenuate resurgence compared to constant availability of high-magnitude reinforcement, with greater attenuation during subsequent exposures to low-magnitude reinforcement versus extinction. Previous research has demonstrated that increasing the similarity of reinforcement conditions during (1) elimination of an operant response and (2) subsequent testing can attenuate resurgence (e.g., Schepers & Bouton, 2015; Thrailkill et al., 2019; Trask et al., 2018; cf. Sweeney & Shahan, 2013b). That we observed no difference in the resurgence effect with or without the high/low procedure among participants experiencing an extinction test in Phase 3 might suggest that alternating exposures to high- and low-magnitude reinforcement do not facilitate generalization to testing conditions in which reinforcement is removed altogether.

Compared to Phase-2 high reinforcement (6 to 1), Phase-2 high/low reinforcement effectively attenuated target-response increases from Phase 2 to Phase 3 during the low-magnitude test (6/1 to 1). This suggests that presenting the establishing operation for the target response alone (i.e., removal of high-magnitude reinforcement) was not responsible for target-response increases in the 6 to 1 group in Phase 3 (see Derosa et al., 2015). However, Phase-2 high/low reinforcement did not reduce the overall level of resurgence during the low-magnitude test. In other words, we observed similar levels of target responding in the first min of Phase 3 in Groups 6 to 1 and 6/1 to 1. One reason for this null effect might be that despite experiencing a decrease in reinforcer magnitude across the last two phases, Group 6 to 1 also experienced a slightly denser schedule of reinforcement in Phase 3 (VI 2-s schedule) compared to Phase 2 (VI

3.175-s schedule). That rationale is consistent with research demonstrating that humans and nonhumans are more sensitive to rate manipulations compared to magnitude manipulations (e.g., Catania, 1968; Kuroda et al., in press; Wurster & Griffiths, 1979). For example, Wurster and Griffiths arranged for the delivery of points exchangeable for money for adult participants' button presses. They arranged concurrent VI VI schedules with points delivered to separate counters. When five points were delivered according to VI 30-s versus VI 15-s or VI 30-s versus VI 150-s schedules, relative rate of responding increased in the component with the denser schedule. When a VI 30-s VI 30-s schedule was arranged and point values associated with each counter were 7 and 3, or 9 and 1, however, the relative rate of responding did not differ across components. Thus, relative rate of responding was sensitive to changes in relative reinforcer rate but insensitive to changes in relative reinforcer magnitude (but see Chen & Reed, 2020, for an example of humans' sensitivity of reinforcer magnitude).

To further evaluate effects of the increase in reinforcer rate from Phase 2 to Phase 3 in the 6 to 1 group, we conducted a follow-up experiment (hereafter *Version 2*) with a slight variation in which reinforcer rates were held constant in Groups 6 to 1 and 6/1 to 1 across the last two phases. This contrasts with the present experiment (hereafter *Version 1*), which arranged (1) increases in reinforcer rates for Group 6 to 1 from Phase 2 (VI 3.175-s schedule) to Phase 3 (VI 2-s schedule) and (2) no increases in reinforcer rates for Group 6/1 to 1 (VI 2-s schedule in Phases 2 and 3). The procedures in Version 1 were designed to (1) equate overall earnings in Phase 2 and (2) control for reinforcer rates in Phase 3. Version 2 instead controlled for overall earnings in Phase 2 and changes in reinforcer rates across Phases 2 and 3. In Version 2, the 6 to 1 group experienced a VI 3.175-s schedule of reinforcement across Phases 2 and 3, while the 6/1 to 1 group experienced a VI 2-s schedule in each of these phases. All other aspects of the experimental procedures in Versions 1 and 2 were identical.

Figure 12 shows reinforcer data for these two groups in Version 1 (top panels) and Version 2 (bottom panels). The figure shows mean reinforcer rates (i.e., star deliveries per min, left panels) and mean earnings in USD (center panels) across Phases 1-3. The right panels show mean target response rates in the last min of Phase 2 and first min of Phase 3. When holding reinforcer rates constant for Group 6 to 1 across the last two phases in Version 2 (bottom-left panel), we observed a robust resurgence effect in that group but not in the group experiencing Phase-2 high/low reinforcement (Group 6/1 to 1, bottom-right panel). In contrast to Version 1, Group 6/1 to 1 also demonstrated lower overall levels of resurgence in Phase 3 compared to Group 6 to 1. These findings suggest the increase in reinforcer rate from Phase 2 to Phase 3 attenuated the resurgence effect in Group 6 to 1 in Version 1. However, that conclusion remains tentative given that this manipulation occurred across experiments.

## General Discussion

The present study arranged two human operant experiments using crowdsourcing. Consistent with predictions of RaC$^2$, we found that reductions in points exchangeable for money in Experiment 1 produced resurgence of a previously reinforced response, with ordinal correspondence between the reduction amount and degree of response recurrence (see Craig et al., 2017; Oliver et al., 2018, for similar findings with nonhumans). In contrast to model predictions, alternating exposures to high and low point gain for an alternative response in Experiment 2 did not reduce the overall level of resurgence during subsequent tests with low point gain (6/1 to 1) or extinction (6/1 to 0). Overall, RaC$^2$ provided a reasonably good fit to target and alternative response rates across manipulations within each experiment, but there were systematic patterns of errors in predictions which were consistent across experiments. Our findings therefore demonstrate the viability of $RaC^2$ for making predictions about relapse in humans while also highlighting limitations of the model to be addressed in subsequent work.

In the present study, the systematic errors in $RaC^2$ predictions were consistent with previous evaluations of this model (Shahan et al., 2020a, b). For example, during low-magnitude tests in each experiment, $RaC^2$ initially underpredicted and then overpredicted target responding as Phase 3 progressed. Moreover, when transitioning from high-magnitude reinforcement to extinction across Phases 2 and 3, $RaC^2$ underpredicted resurgence across Phase-3 bins (see Shahan et al., 2020a, b, for similar findings). Regarding alternative responding, $RaC^2$ tended to overpredict response rates in groups experiencing low-magnitude tests (6 to 1) and extinction tests. In contrast, Shahan et al. (2020b) reported that $RaC^2$ consistently underpredicted rats' alternative responding during extinction testing. Shahan et al. suggested that one likely source of those alternative-response prediction errors was the model's use of a simplified version of the Weibull learning curve (Gallistel et al., 2004) to quantify increasing bias away from both responses during extinction. With the simplified learning curve, both (1) the asymptote of the biasing effects of local reinforcement conditions and (2) the speed of discriminating the transition to extinction are held constant across groups. It is possible that allowing these parameters to vary across groups could improve fits to the present data, albeit at the expense of added model complexity (see Shahan et al., 2020b, for a discussion). Nevertheless, $RaC^2$ provided a good fit to response rates in each experiment, accounting for 89% (Experiment 1) and 84% of the observed variance (Experiment 2).

$RaC^2$ is a recently developed quantitative theoretical framework but builds upon decades of behavioral choice research (see Baum & Rachlin, 1969). The model accounts well for nonhuman data by accurately predicting that cycling between availability and unavailability of alternative reinforcement in Phase 2 will attenuate resurgence during extinction testing in Phase 3 (Shahan et al., 2020a). RaC$^2$ also addresses the shortcomings of narrative theories of resurgence (e.g., Context Theory; Bouton et al., 2013; Trask et al., 2015) by formalizing the behavioral processes contributing to resurgence. Briefly, Context Theory suggests that resurgence occurs because behavior fails to generalize across contexts. In studies of resurgence, changes in reinforcement conditions can be conceptualized as changes in context (e.g., Bouton et al., 2012; Trask et al., 2015). Regarding target responding, Context Theory asserts that the inhibitory learning that occurs in Phase 2 is highly context specific, resulting in increases in that response when reinforcement conditions change in Phase 3 (Bouton, 2004). Context Theory accounts well for responding during resurgence tests but, as a conceptual model, also has been criticized for being unfalsifiable. This is because the context changes hypothesized to produce relapse must be inferred from behavior (see Craig and Shahan, 2017; Greer & Shahan, 2019, for detailed discussions). RaC$^2$ addresses this shortcoming of Context Theory by quantifying discriminability of reinforcement contexts and their biasing effects of responding (Craig & Shahan, 2020a).

Theoretical perspectives from the incentive relativity literature could also provide important insights into the underlying behavioral processes contributing to resurgence. One phenomenon which is particularly relevant to behavior change following reductions in reinforcer magnitude is Successive Negative Contrast (SNC). SNC procedures involve exposing some subjects to a worsening of conditions – e.g., a sudden downshift in the quality and/or quantity of food. Those subjects often demonstrate lower anticipatory and/or consummatory responses relative to control subjects always experiencing no shift and only the less favorable condition (Flaherty, 1996). This phenomenon has been demonstrated in rats (e.g., Pecoraro et al., 1999), mice (e.g., Mustaca et al., 2000), dogs (e.g., Dzik et al., 2019; Riemer et al., 2018), and humans (e.g., Morillo-Rivero et al., 2020), among other species (e.g., Freidin et al., 2009; Papini et al., 1988; Waldron et al., 2005). From the perspective of the functional-search hypothesis (Pecoraro et al., 1999), the lower levels of consummatory responses observed following the sudden downshift in SNC procedures result from a shift in motivation for exploration over consumption (see also Bernstein et al., 1988). Relatedly, Freidin et al. (2009) found that birds experiencing a shift from availability of mealworms (a preferred food) to turkey crumbs (a less preferred food) demonstrated not only (1) suppression of consummatory responses but also (2) increased activity such as walking and flying, and (3) increased exploratory behavior (i.e., switching between feeders) relative to the control group. While foraging for food, allocating responding to exploring as opposed to exploiting an impoverished food source could result in greater net gains despite the exploitation cost (see Freidin et al., 2009, for a discussion). With regard to resurgence, a sudden worsening in reinforcement conditions (e.g., downshift in alternative-reinforcer magnitude) could also produce a shift in motivation for exploration over exploitation of alternative reinforcement, thereby resulting in the recurrence of a previously reinforced response and/or increases in other responses which have never resulted in reinforcement (e.g., Bolívar et al., 2017; Cox et al.., 2019). To further characterize exploration versus exploitation during resurgence tests, future studies could include one or more control responses with no reinforcement history across all phases of the experiment (but see Lattal and Oliver, 2020).

Finally, the present experiments had several limitations. First, with crowdsourcing research, it is difficult to ensure that participants engage with experimental task versus other activities. That is, unlike laboratory studies, control of the participants' environment is limited. To discourage off-task behavior, we instructed participants that navigating away from the browser where they were completing the task would mean forgoing payment (e.g., Ritchey et al., 2021;

Robinson & Kelley, 2020). A second limitation of the present study (and of online research more generally) is attrition. We experienced an attrition rate of 32.7% in Experiment 1 and 44.8% in Experiment 2. Chandler and Shapiro (2016) reported similar attrition rates among longitudinal MTurk studies (30-55%), but attrition among short-term studies is rarely reported (see Crump et al., 2013, for a discussion). In the present study, attrition appeared to be related to exogenous factors as opposed to the arranged experimental manipulations (see Arechar et al., 2018, for similar findings). For example, attrition in Experiment 1 was similar in groups experiencing continued availability of reinforcement (6 to 6, 36%) versus extinction in Phase 3 (6 to 0, 30%). In Experiment 2, attrition did not vary across groups experiencing the low-magnitude (6 to 1 and 6/1 to 1, 45%) or extinction tests in Phase 3 (6 to 0 and 6/1 to 0, 45%). Nevertheless, researchers in this area might consider increasing pay (e.g., Crump et al., 2013; Auer et al., 2021) or incorporating additional instructions to reduce attrition (see Zhou & Fishbach, 2016).

## Conclusion

We extended prior empirical and theoretical work on resurgence produced by downshifts in reinforcer magnitude using crowdsourcing. Consistent with predictions of $\text{RaC}^2$, resurgence of a target button press occurred with reductions in point gain for an alternative response, with greater reductions producing higher levels of resurgence. While alternating exposures to high and low point gain for the alternative response attenuated target-response increases from Phase 2 to Phase 3, those exposures did not reduce the overall level of resurgence during testing with low point gain or extinction, in contrast to model predictions. Fits of $\text{RaC}^2$ to data from each experiment demonstrated that $\text{RaC}^2$ could be a useful framework for understanding variables that contribute to resurgence in humans. However, additional refinements to the model will be necessary to address errors in predictions during downshifts in reinforcer magnitude and extinction tests. Future work using quantitative theoretical frameworks to formalize underlying behavioral processes involved in resurgence following downshifts in reinforcer magnitude could help to improve common behavioral treatments that initially arrange and subsequently fade high-magnitude differential reinforcement.

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**Table 1**

*Participant Demographics* (*N=443)*

| Measure | *M* (*SD)* | *n* | Percent of Sample |
|---|---|---|---|
| Age | 36.7 (11.7) | | |
| Sex | | | |
| Male | | 272 | 61.4 |
| Female | | 165 | 37.2 |
| Other | | 1 | 0.2 |
| Not reported | | 5 | 1.1 |
| Nationality | | | |
| American | | 275 | 62.1 |
| Brazilian | | 31 | 7.0 |
| British | | 30 | 6.8 |
| Canadian | | 7 | 1.6 |
| Indian | | 58 | 13.1 |
| Italian | | 9 | 2.0 |
| Other | | 28 | 6.3 |
| Not reported | | 5 | 1.1 |
| Place of Residence | | | |
| United States | | 283 | 63.9 |
| Brazil | | 30 | 6.8 |
| United Kingdom | | 31 | 7.0 |
| Canada | | 7 | 1.6 |
| India | | 55 | 12.4 |
| Italy | | 8 | 1.8 |
| Other | | 23 | 5.2 |
| Not reported | | 5 | 1.1 |
| Color Blindness | | 26 | 5.9 |
| Red-green | | 17 | 3.8 |
| Blue-yellow | | 5 | 1.1 |
| Total | | 1 | 0.2 |
| Other | | 3 | 0.7 |
| Not reported | | 5 | 1.1 |
| Attrition Rate | | 298/758 | 39.3 |
| Experiment 1 | | 112/343 | 32.7 |
| Experiment 2 | | 186/415 | 44.8 |

*Note. M*=Mean; *SD*=Standard deviation. We did not exclude participants with color blindness due to redundant cues during reinforcer deliveries (see Fig. 1).

**Table 2**

*Summary of Experimental Procedures*

| Experiment/Group | Phase 1 | Phase 2 | Phase 3 |
|---|---|---|---|
| 1 | | | |
| 6 to 6 | R1+ (6 stars) | R1- | R1- |
| | R2- | R2+ (6 stars) | R2+ (6 stars) |
| 6 to 3 | R1+ (6 stars) | R1- | R1- |
| | R2- | R2+ (6 stars) | R2+ (3 stars) |
| 6 to 1 | R1+ (6 stars) | R1- | R1- |
| | R2- | R2+ (6 stars) | R2+ (1 star) |
| 6 to 0 | R1+ (6 stars) | R1- | R1- |
| | R2- | R2+ (6 stars) | R2- |
| 2 | | | |
| 6 to 1 | R1+ (6 stars) | R1- | R1- |
| | R2- | R2+ (6 stars)* | R2+ (1 star) |
| 6/1 to 1 | R1+ (6 stars) | R1- | R1- |
| | R2- | R2+ (6 stars/1 star) | R2+ (1 star) |
| 6 to 0 | R1+ (6 stars) | R1- | R1- |
| | R2- | R2+ (6 stars)* | R2- |
| 6/1 to 0 | R1+ (6 stars) | R1- | R1- |
| | R2- | R2+ (6 stars/1 star) | R2- |

*Note.* In Phase 2 of Experiment 2, Groups 6/1 to 1 and 6/1 to 0 earned six stars each time a schedule requirement was met during even 1-min bins and one star each time a schedule requirement was met during odd 1-min bins. All groups earned reinforcement according to a VI 2-s schedule except where noted with *; *=VI 3.175-s schedule of reinforcement.

**Table 3**

*Summary of Excluded Data Sets*

| Experiment/Group | Stopped Responding | High Responding | No Alternative | No Survey |
|---|---|---|---|---|
| 1 | | | | |
| 6 to 6 | 2/55 (3.6) | -- | 1/55 (1.8) | 2/55 (3.6) |
| 6 to 3 | 5/58 (8.6) | 1/58 (1.7) | -- | -- |
| 6 to 1 | 5/58 (8.6) | 2/58 (3.4) | -- | 1/58 (1.7) |
| 6 to 0 | 5/55 (9.1) | -- | -- | -- |
| Total: | 17/226 (7.5) | 3/226 (1.3) | 1/226 (0.4) | 3/226 (1.3) |
| 2 | | | | |
| 6 to 1 | 2/53 (3.8) | -- | -- | -- |
| 6/1 to 1 | 4/55 (7.3) | -- | -- | 1/55 (1.8) |
| 6 to 0 | 5/56 (8.9) | -- | -- | 1/56 (1.8) |
| 6/1 to 0 | 3/53 (5.7) | -- | -- | -- |
| Total: | 14/217 (6.5) | -- | -- | 2/217 (0.9) |
| **Grand Total:** | **31/443 (7.0)** | **6/443 (1.4)** | **2/443 (0.5)** | **4/443 (0.9)** |

*Note.* This table shows the number of participants meeting one of four exclusion criteria. Percentage of participants meeting each exclusion criterion are shown in parentheses. Stopped responding=no responses for any two-min period in Phase 1 or Phase 2; High responding=more than 20 responses per second; No alternative responses=no alternative responses in Phase 2; No survey=did not complete post-experiment survey.

**Table 4**

*Reinforcer Rates: Means and Standard Deviations*

| Experiment/Group | Phase 1 | Phase 2 | Phase 3 |
|---|---|---|---|
| 1 | | | |
| 6 to 0 | 22.21 (4.47) | 19.63 (5.78) | -- |
| 6 to 1 | 20.41 (5.59) | 19.85 (6.39) | 20.79 (5.95) |
| 6 to 3 | 22.00 (4.26) | 20.92 (4.57) | 22.81 (4.21) |
| 6 to 6 | 20.78 (4.54) | 19.17 (5.24) | 21.56 (5.52) |
| 2 | | | |
| 6 to 1 | 19.38 (4.82) | 13.52 (2.86) | 20.35 (5.58) |
| 6/1 to 1 | 17.61 (4.71) | 17.93 (5.67) | 18.47 (5.95) |
| 6 to 0 | 19.03 (5.53) | 12.76 (3.54) | -- |
| 6/1 to 0 | 19.34 (4.80) | 18.86 (5.63) | -- |

*Note.* Values represent mean star deliveries per min, and do not account for magnitude.

**Table 5**

*Experiment 1*: *Results of Linear Mixed-Effects Regression for Target Responding*

| **Factor** | **$\beta$ (SE)** | ***df*** | ***t*** | ***p*** |
|---|---|---|---|---|
| Intercept | -3.11 (3.91) | 415.15 | -0.79 | .428 |
| **Time** | **-10.69 (1.40)** | **1075.71** | **-7.62*** ** | **<.001** |
| **Phase (1)** | **130.24 (10.40)** | **264.46** | **12.52*** ** | **<.001** |
| Phase (3) | 6.60 (5.07) | 300.03 | 1.30 | .193 |
| Group (6 to 0) | 0.77 (5.54) | 415.15 | 0.14 | .890 |
| Group (6 to 1) | 2.59 (5.51) | 415.15 | 0.47 | .638 |
| Group (6 to 3) | -2.88 (5.48) | 415.15 | -0.53 | .600 |
| **Time*Phase (1)** | **15.55 (1.90)** | **2224.99** | **8.18*** ** | **<.001** |
| **Time*Phase (3)** | **11.01 (1.90)** | **2225.00** | **5.79*** ** | **<.001** |
| Time*Group (6 to 0) | -0.50 (1.99) | 1075.70 | -0.25 | .800 |
| Time*Group (6 to 1) | 0.18 (1.98) | 1075.70 | 0.09 | .927 |
| Time*Group (6 to 3) | -3.02 (1.97) | 1075.70 | -1.54 | .125 |
| Phase (1)*Group (6 to 0) | 9.58 (14.71) | 264.46 | 0.65 | .516 |
| Phase (1)*Group (6 to 1) | 15.36 (14.64) | 264.46 | 1.05 | .295 |
| **Phase (1)*Group (6 to 3)** | **42.71 (14.57)** | **364.46** | **2.93** ** | **.004** |
| Time*Phase (1)*Group (6 to 0) | 1.29 (2.69) | 2225.00 | 0.48 | .631 |
| **Time*Phase (1)*Group (6 to 1)** | **6.86 (2.67)** | **2225.00** | **2.57* ** | **.010** |
| **Time*Phase (1)*Group (6 to 3)** | **11.10 (2.66)** | **2225.00** | **4.17*** ** | **<.001** |
| **Phase (3)*Group (6 to 0)** | **39.45 (7.17)** | **300.03** | **5.51*** ** | **<.001** |
| **Phase (3)*Group (6 to 1)** | **16.44 (7.13)** | **300.03** | **2.31* ** | **.022** |
| **Phase (3)*Group (6 to 3)** | **15.72 (7.10)** | **300.03** | **2.22* ** | **.028** |
| Time*Phase (3)*Group (6 to 0) | -4.24 (2.69) | 2225.00 | -1.58 | .115 |
| **Time*Phase (3)*Group (6 to 1)** | **-5.32 (2.67)** | **2225.00** | **-1.99* ** | **.047** |
| Time*Phase (3)*Group (6 to 3) | -0.32 (2.66) | 2225.00 | -0.12 | .904 |

*Note.* $*p < .05$ $**p < .01$ $***p < .001$. Statistically significant results are shown in bold. SE = standard error. The Phase (2) and Group (6 to 6) factors served as the individual contrasts.

**Table 6**

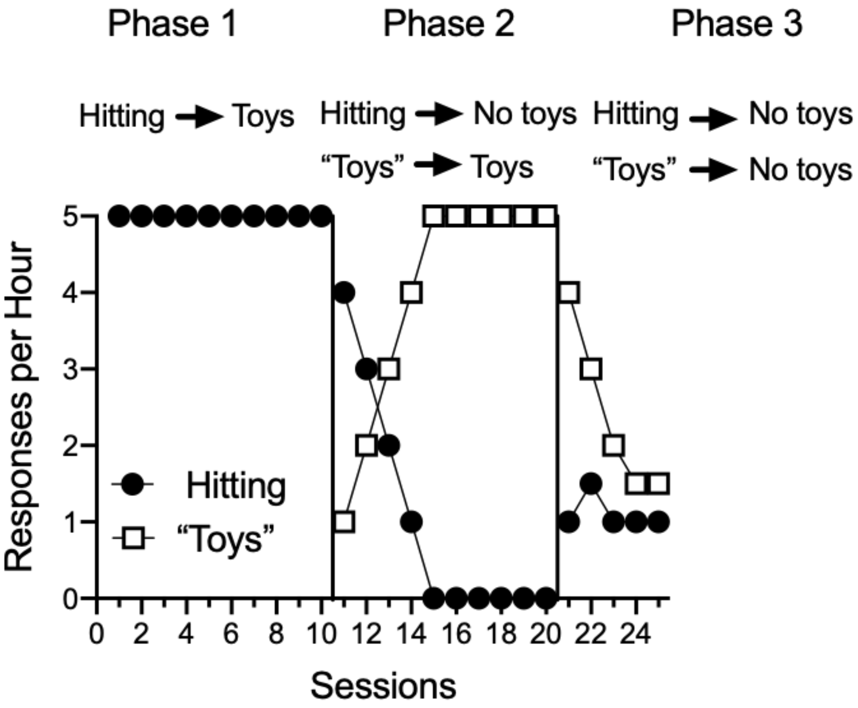
*Experiment 2*: *Results of Linear Mixed-Effects Regression for Target Responding*

| **Factor** | ***β* (SE)** | ***df*** | ***t*** | ***p*** |
|---|---|---|---|---|
| Intercept | 5.07 (2.94) | 329.19 | 1.72 | .086 |
| **Time** | **-3.32 (0.61)** | **330.80** | **-5.43*****| **<.001** |
| **Phase (1)** | **106.43 (9.72)** | **243.19** | **10.95***** | **<.001** |
| **Phase (3)** | **27.63 (4.35)** | **549.82** | **6.36***** | **<.001** |
| Group (6 to 1) | -1.31 (4.14) | 329.19 | -0.32 | .751 |
| Group (6/1 to 1) | 0.84 (4.16) | 329.19 | 0.20 | .840 |
| Group (6 to 0) | -5.86 (4.16) | 329.19 | -1.41 | .160 |
| **Time*Phase (1)** | **10.29 (1.34)** | **3204.02** | **7.69***** | **<.001** |
| Time*Phase (3) | 0.24 (1.34) | 3204.02 | 0.18 | .859 |
| Time*Group (6 to 1) | -0.38 (0.86) | 330.80 | -0.45 | .655 |
| Time*Group (6/1 to 1) | 0.55 (0.86) | 330.80 | 0.64 | .524 |
| Time*Group (6/1 to 0) | -1.49 (0.86) | 330.80 | -1.73 | .085 |
| Phase (1)*Group (6 to 1) | 9.05 (13.67) | 243.19 | 0.66 | .509 |
| Phase (1)*Group (6/1 to 1) | -18.54 (13.74) | 243.19 | -1.35 | .179 |
| Phase (1)*Group (6/1 to 0) | 18.60 (13.74) | 243.19 | 1.35 | .177 |
| Time*Phase (1)*Group (6 to 1) | 1.92 (1.88) | 3204.02 | 1.02 | .308 |
| Time*Phase (1)*Group (6/1 to 1) | 0.53 (1.89) | 3204.02 | 0.28 | .781 |
| Time*Phase (1)*Group (6/1 to 0) | 1.60 (1.89) | 3204.02 | 0.85 | .398 |
| **Phase (3)*Group (6 to 1)** | **-15.48 (6.12)** | **549.82** | **-2.53*** | **.012** |
| **Phase (3)*Group (6/1 to 1)** | **-20.47 (6.15)** | **549.82** | **-3.33***** | **<.001** |
| Phase (3)*Group (6/1 to 0) | 9.93 (6.15) | 549.82 | 1.62 | .107 |
| Time*Phase (3)*Group (6 to 1) | 0.80 (1.88) | 3204.02 | 0.42 | .672 |
| Time*Phase (3)*Group (6/1 to 1) | 0.67 (1.89) | 3204.02 | 0.35 | .724 |
| Time*Phase (3)*Group (6/1 to 0) | 1.00 (1.89) | 3204.02 | 0.53 | .597 |

*Note***.** *$p < .05$ **$p < .01$ ***$p < .001$. Statistically significant results are shown in bold. SE = standard error. The Phase (2) and Group (6 to 0) factors served as the individual contrasts.

**Figure 1**

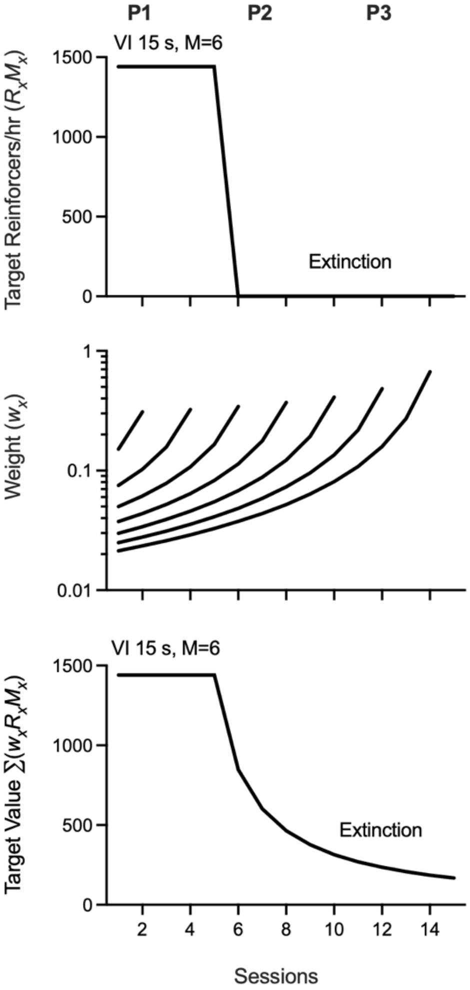
*Hypothetical Data Depicting Resurgence of Problem Behavior*



*Note.* Phase 1 represents the (pre-treatment) history of reinforcement for problem behavior. Phase 2 represents treatment with DRA. Phase 3 represents a lapse in treatment integrity or discontinuation of treatment.

**Figure 2**

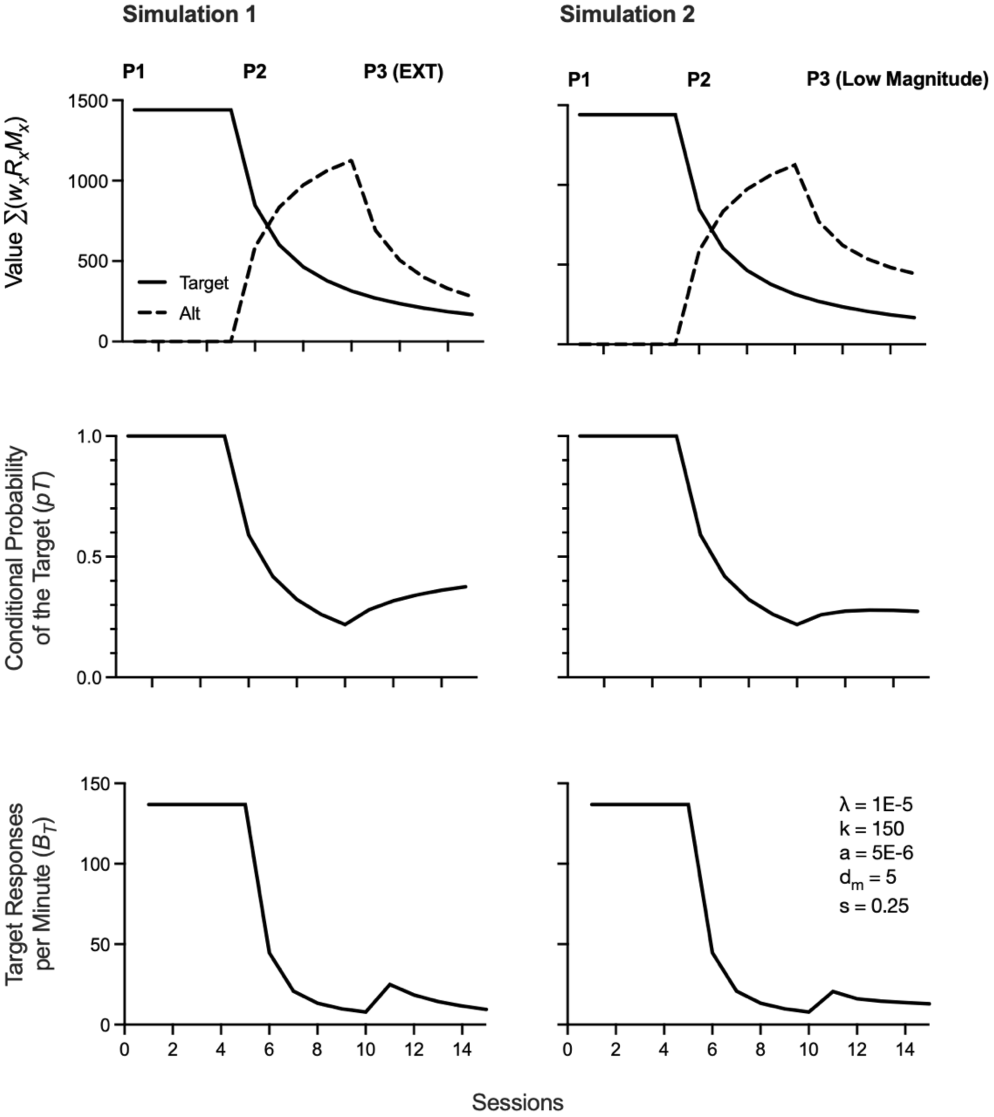
*Calculating the Value of a Target Response from Obtained Reinforcement Rates*



*Note.* Top panel: obtained reinforcement rates during a three-phase resurgence procedure. Obtained reinforcement rates are the product of reinforcer rate ($R_x$) and magnitude ($M_x$). In Phase 1, six reinforcers (M=6) are delivered on a VI 15-s schedule. In Phases 2 and 3, target responding is extinguished. Middle panel: weighting functions generated by a temporal weighting rule (Shahan & Craig, 2017) for even-numbered sessions 2-14; note the logarithmic y-axis. Lambda = .00001. Bottom panel: value of the target response obtained by applying weighting functions ($w_x$) to reinforcement rates across sessions in the top panel. P1=Phase 1; P2=Phase 2; P3=Phase 3.

**Figure 3**

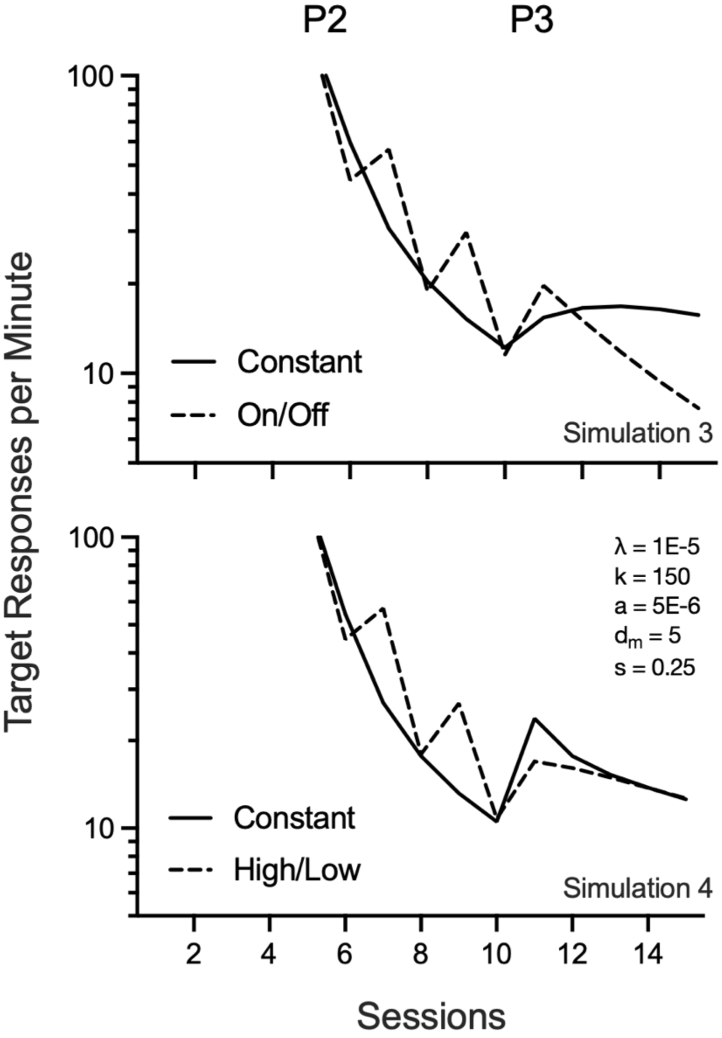
*Results of RaC² Simulations 1 and 2*



*Note.* Value functions for target and alternative responses (top panels), conditional probability of a target response (*pT*; middle panels), and target response rates ($B_T$; bottom panels) across sessions in two simulated experiments. Phase 3 comprises an extinction test (left panels) or an 83% reduction in alternative-reinforcer magnitude (right panels). Value functions and conditional probabilities were calculated using Equations 1 and 2, respectively. Response rates were calculated using Equation 3. P1=Phase 1; P2=Phase 2; P3=Phase 3.

**Figure 4**

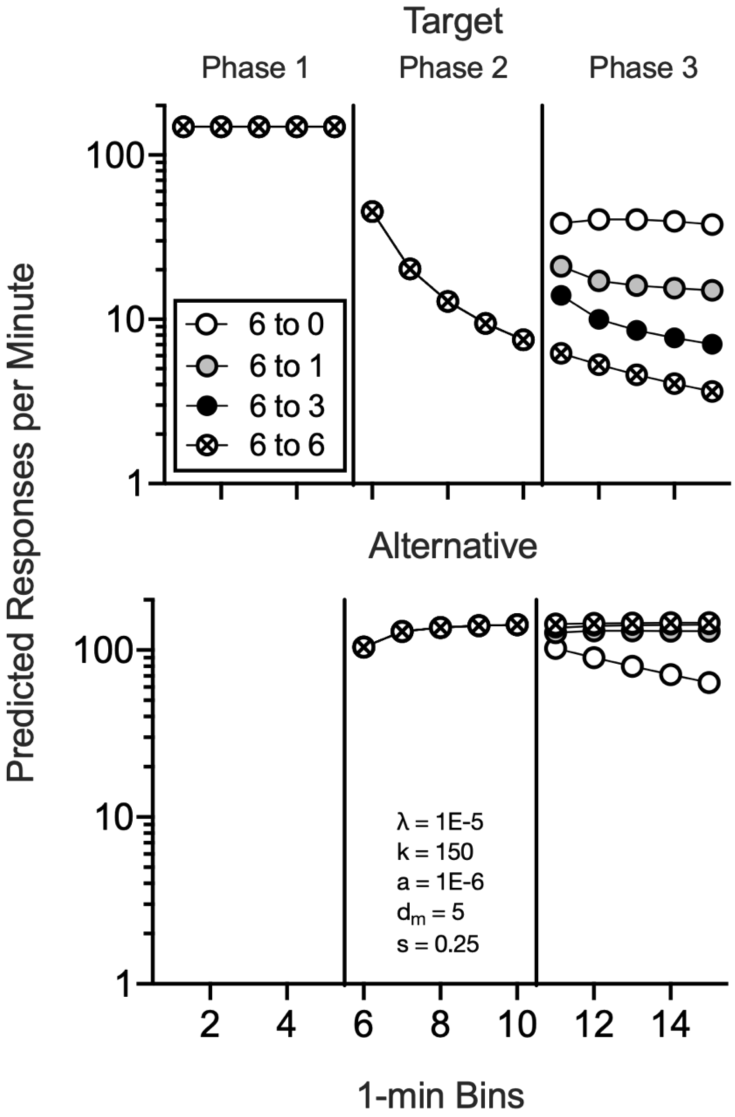
*Results of RaC$^2$ Simulations 3 and 4*



*Note.* Y-axes are logarithmic. This figure shows target responses per min across sessions in two simulated resurgence experiments. Phase-1 data is not shown. Phase 2 comprises constant exposure to alternative reinforcement (solid line), on/off alternative reinforcement across sessions (dashed line, top panel), or high/low alternative reinforcement across sessions (dashed line, bottom panel). Phase 3 comprises an extinction test (top panel) or 83% reduction in alternative-reinforcer magnitude (bottom panel). Responses per min were calculated using Equations 4-6 (top panel) and Equations 4 and 7-9 (bottom panel). P2= Phase 2; P3=Phase 3.

**Figure 5**

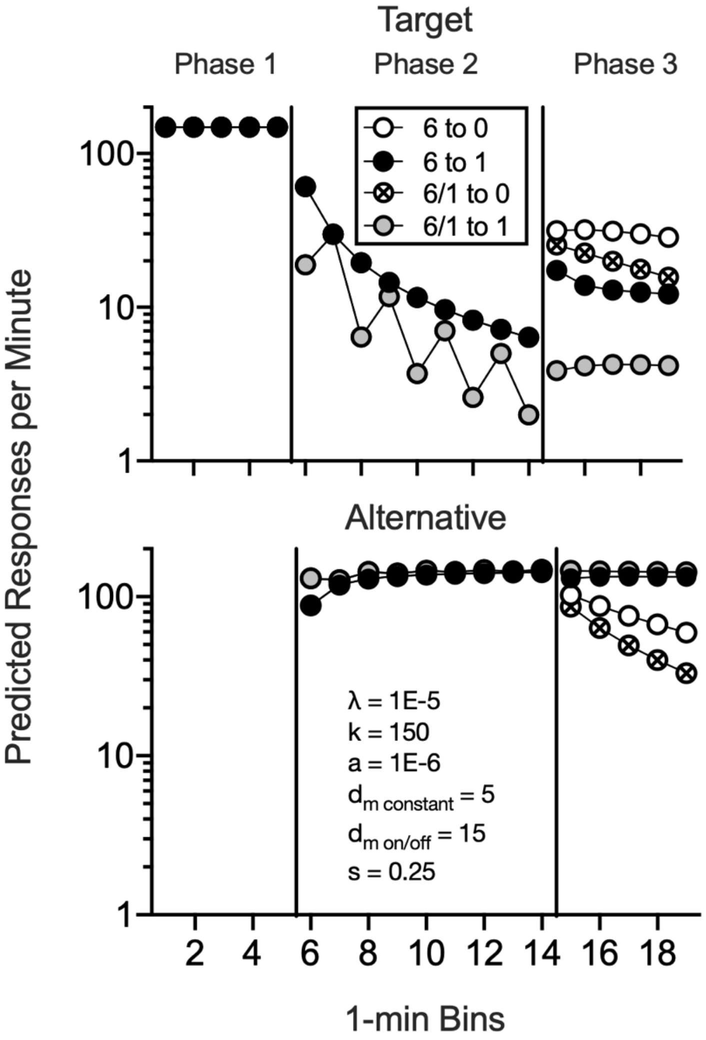
*RaC$^2$ Simulation of Experiment 1*



*Note*. Y-axes are logarithmic. The figure simulates responding on a target (top panel) and alternative button (bottom panel) following a 100% (6 to 0), 83% (6 to 1), 50% (6 to 3), or no reduction in alternative-reinforcer magnitude from Phase 2 to Phase 3 (6 to 6). Group names indicate the number of alternative-response reinforcers produced each time a schedule requirement is met across the last two phases. Target responding is reinforced in Phase 1 and extinguished in Phases 2 and 3.

**Figure 6**

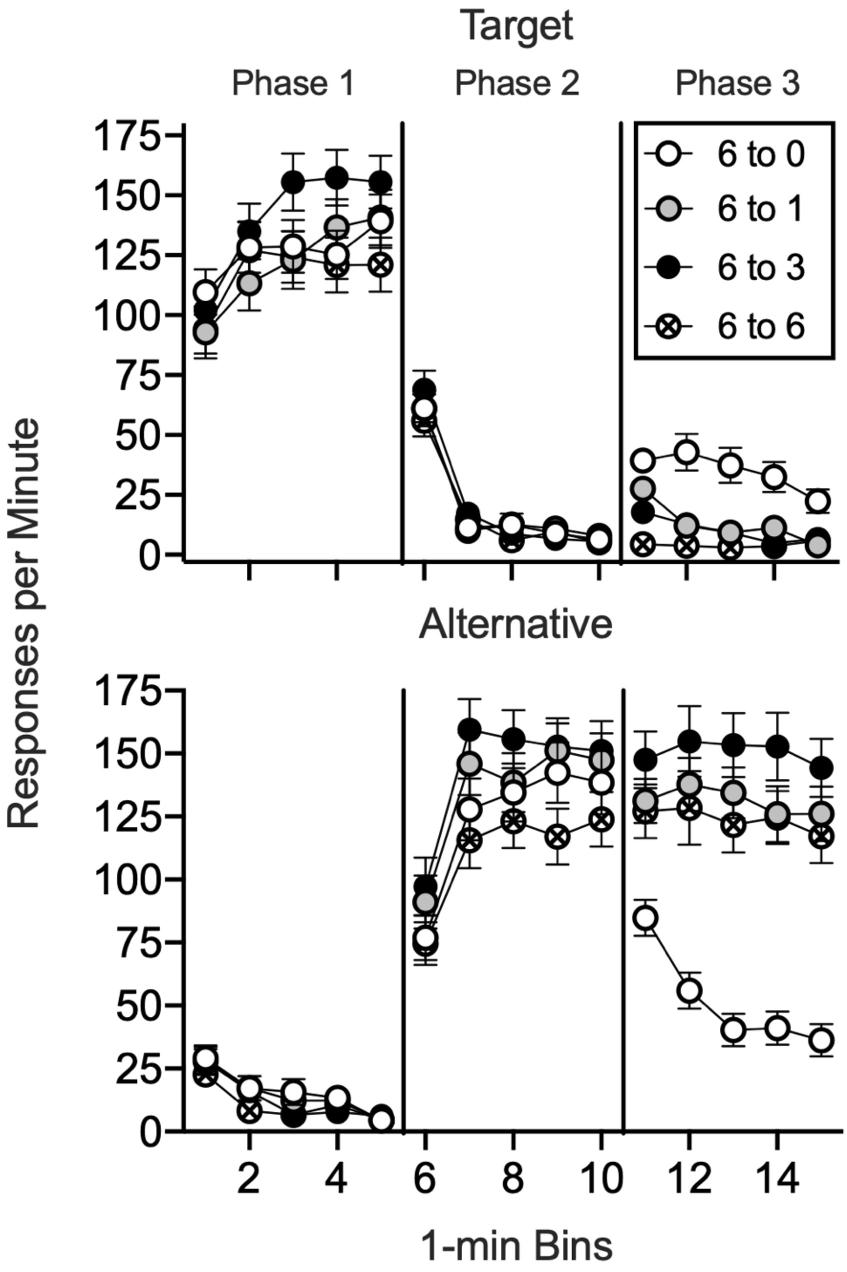
*RaC$^2$ Simulation of Experiment 2*



*Note*. Y-axes are logarithmic. The figure simulates responding on a target (top panel) and alternative button (bottom panel) following exposure to high/low alternative reinforcement (6/1 to 1, 6/1 to 0) or constant high-magnitude alternative reinforcement in Phase 2 (6 to 1, 6 to 0). For Groups 6/1 to 1 and 6/1 to 0, high-magnitude reinforcement is delivered during even 1-min bins in Phase 2. Phase 3 simulates responding during extinction (6 to 0, 6/1 to 0) or a low-magnitude test (6 to 1, 6/1 to 1). Group names indicate the number of alternative-response reinforcers produced each time a schedule requirement is met in Phases 2 and 3.

**Figure 7**

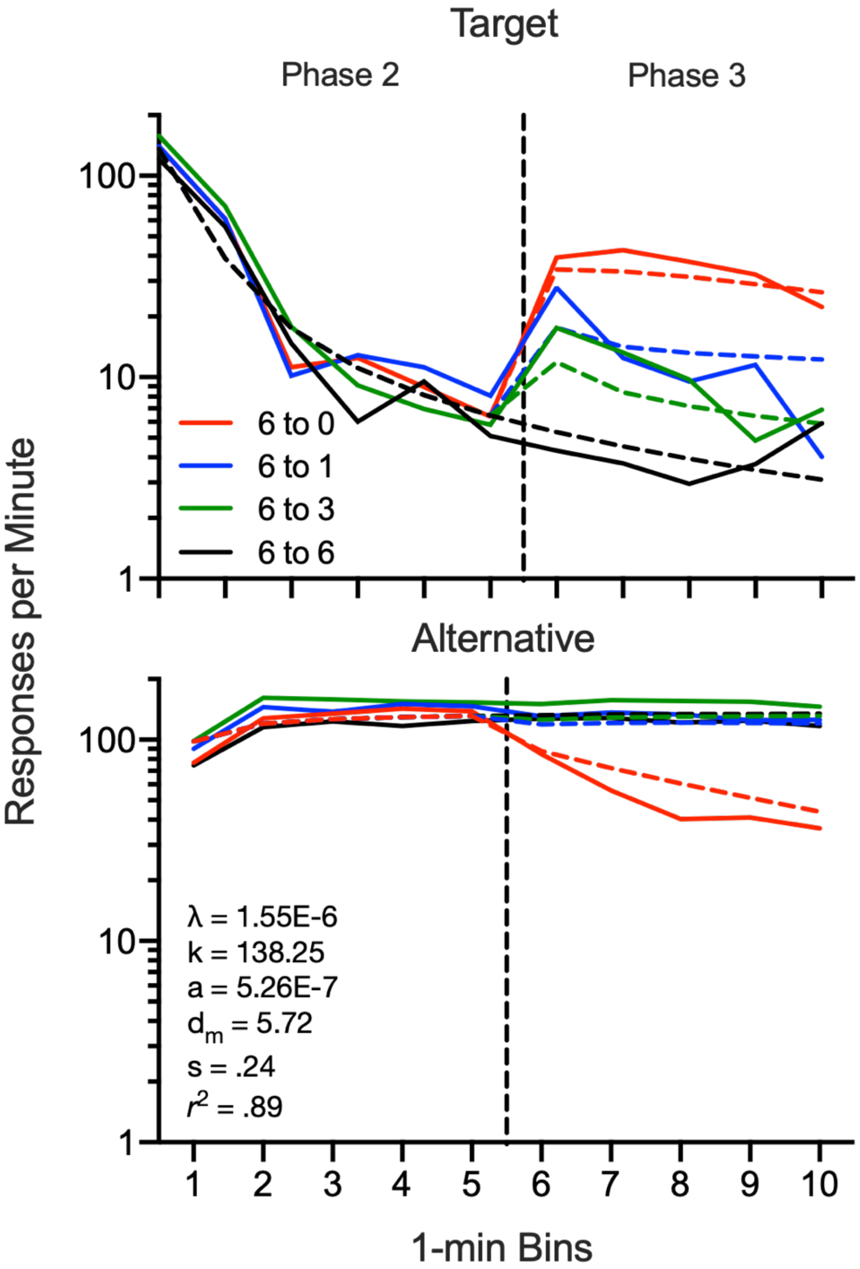
*Response Rates on Each Button in Experiment 1*



*Note.* Mean target (top panel) and alternative (bottom panel) responses per min across all groups. Error bars represent standard errors of the mean.

**Figure 8**

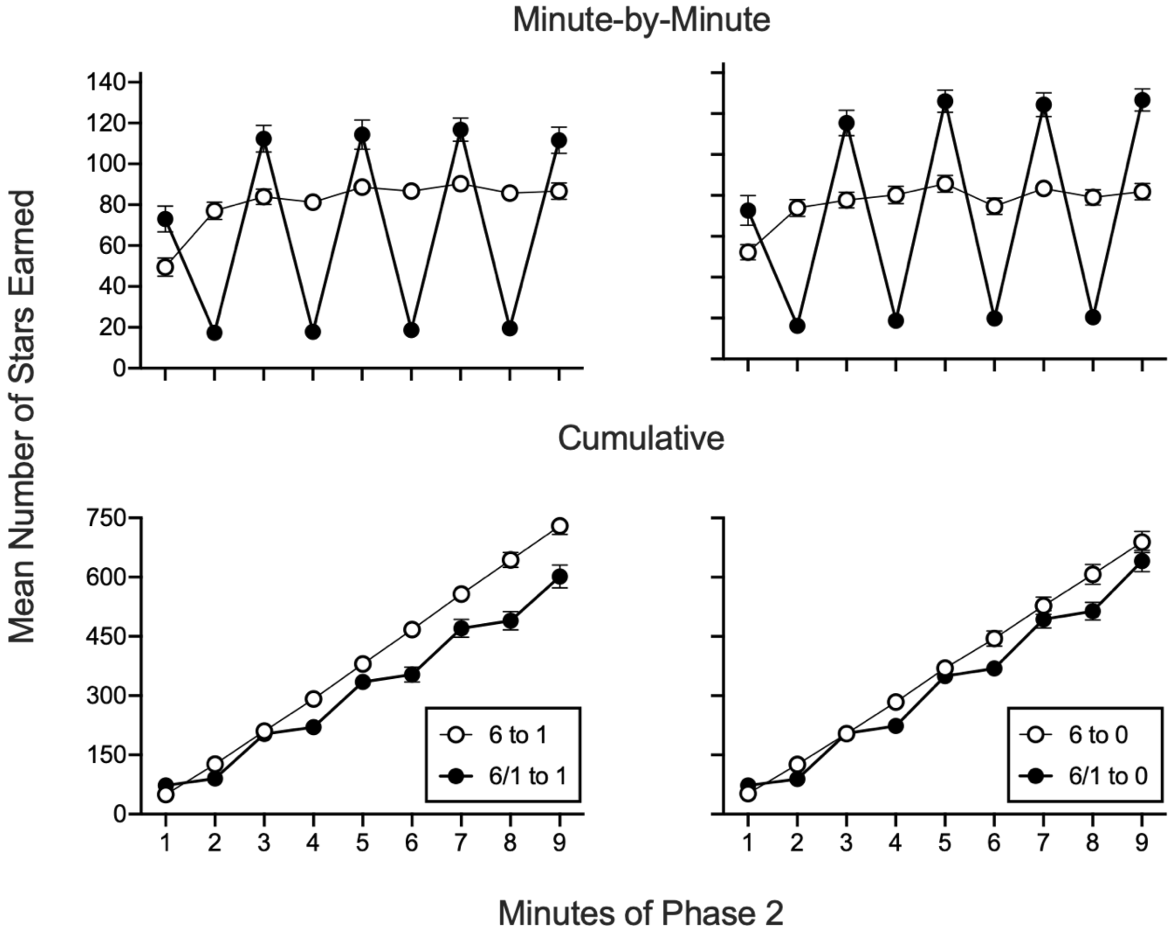
*Experiment 1 Fits*



*Note.* Y-axes are logarithmic. Data for the last Phase-1 session is shown above 0 on the x-axis. Obtained data and $RaC^2$ predictions are shown as solid and dashed lines, respectively.

**Figure 9**

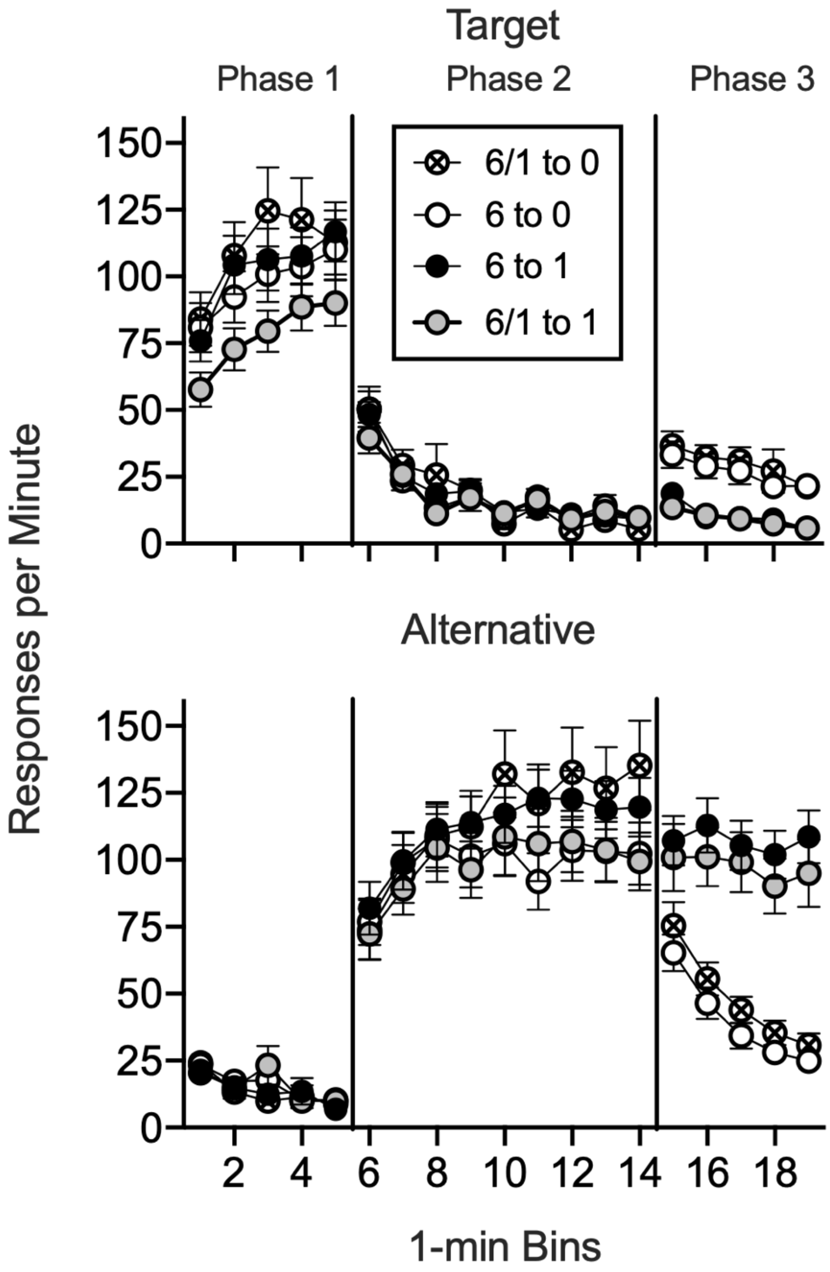
*Experiment 2: Reinforcer Deliveries in Phase 2*



*Note.* Mean number of star deliveries for Groups 6 to 1 and 6/1 to 1 (left panels) and Groups 6 to 0 and 6/1 to 0 (right panels). The top panels show data for each minute of Phase 2. The bottom panels show cumulative records. Each star was worth 100 points, exchangeable for $0.0005. Error bars represent standard errors of the mean.

**Figure 10**

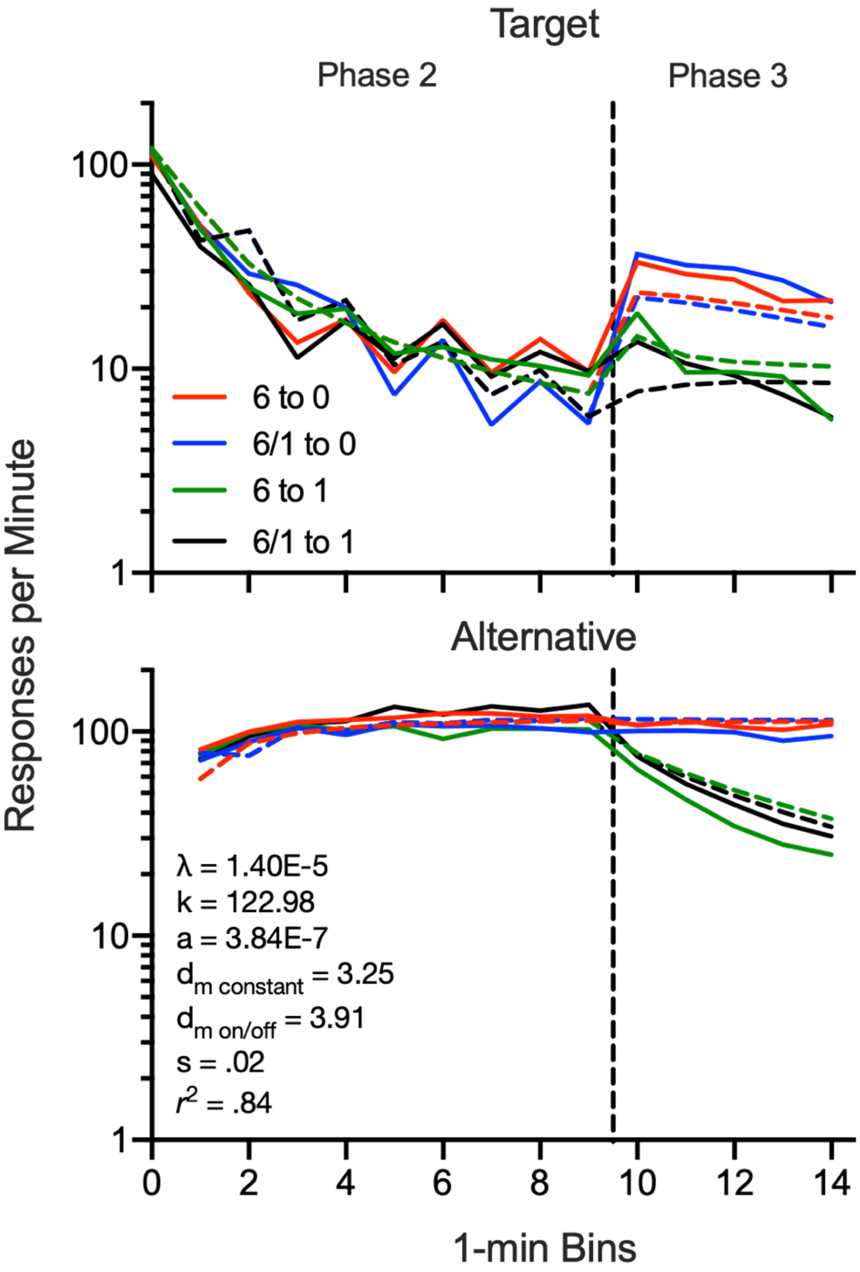
*Response Rates on Each Button in Experiment 2*



*Note.* Mean target (top panel) and alternative (bottom panel) responses per min across all groups. Error bars represent standard errors of the mean.

**Figure 11**

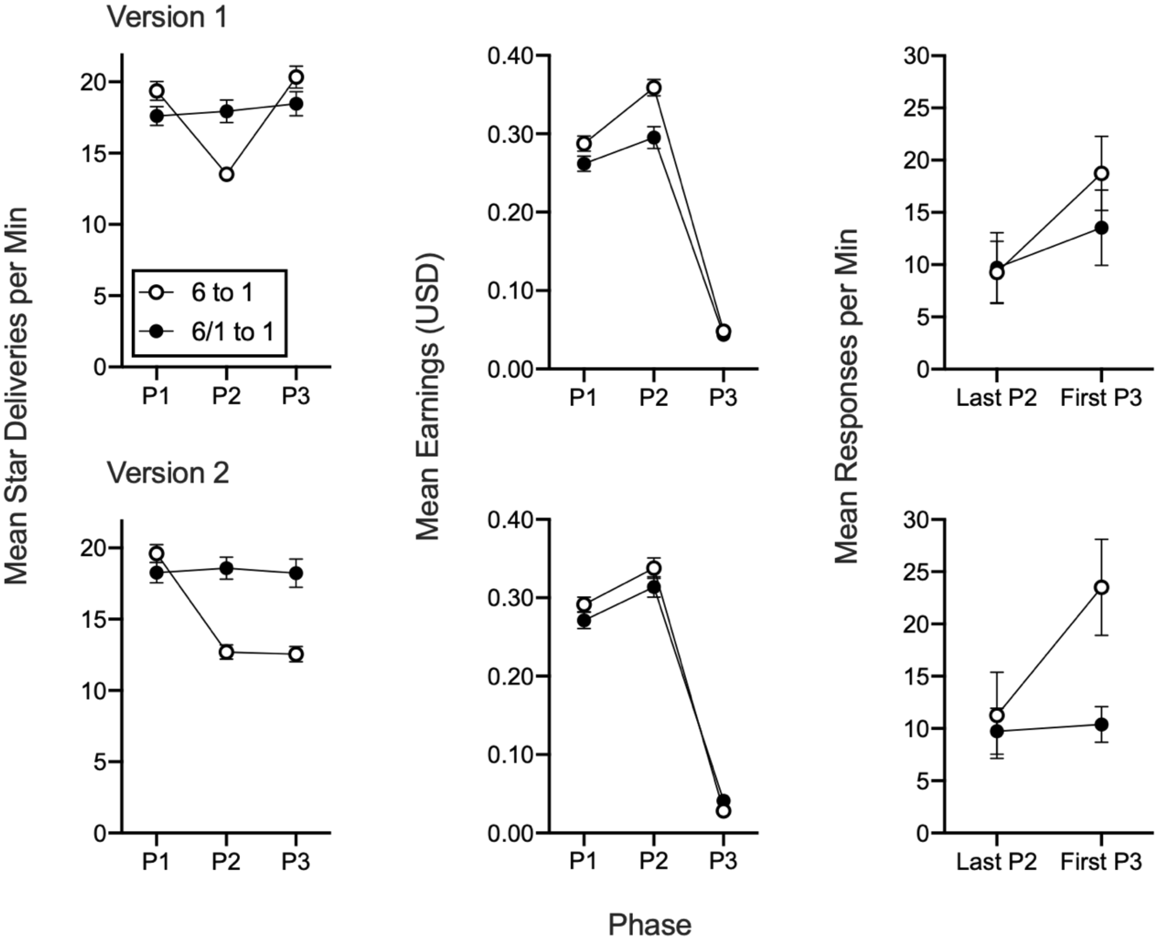
*Experiment 2 Fits*



*Note.* Y-axes are logarithmic. Data for the last Phase-1 session is shown above 0 on the x-axis. Obtained data and RaC$^2$ predictions are shown as solid and dashed lines, respectively.

**Figure 12**

*Comparison of Two Versions of Experiment 2*



*Note.* Data for the version of Experiment 2 presented in this manuscript (i.e., Version 1) are shown in the top panels, and data for a follow-up experiment (Version 2) are shown in the bottom panels. These experiments were identical with the exception that Group 6 to 1 earned stars according to a VI 3.175-s schedule in Phase 2 and a VI 2-s schedule in Phase 3 (Version 1) or a VI 3.175-s schedule across Phases 2 and 3 (Version 2). Group 6/1 to 1 earned stars according to a VI 2-s schedule in Phases 2 and 3 in each version.

# Appendix A

## HIT Page Instructions

Play an easy button-pressing game for academic research. You will earn base pay = $0.50. Bonus pay from in-game points could earn you even more for more optimal performances. A simple survey follows about your participation. Click the link below to begin. At the end of the game, you will receive a payment code. Paste the code into the box below to receive payment.

This HIT must be completed on a **WINDOWS** or **MAC COMPUTER** with one of the following browsers: **GOOGLE CHROME**, **MOZILLA FIREFOX**, or **MICROSOFT EDGE**.

**Make sure to leave this window open as you play the game.** When you complete the HIT, return to this page to paste the **PAYMENT CODE** **(NOT YOUR WORKER ID)** into the box.

## Task Instructions

Page 1: Hello and thank you for choosing this HIT! IMPORTANT: Please read the following instructions before beginning!

1. Payment for participating requires you stay on this tab of your web browser for the entire duration of the HIT. Please close any other tabs that you have open that could distract you. We use server-side coding so we will know if and how long you leave the HIT page. You WILL NOT BE PAID for participation if you violate this rule – no exceptions.
2. Do not press the “back page” button or "refresh" button at any time during the HIT. Doing so will end the HIT and your opportunity for payment.
3. Only do this HIT on a laptop or desktop computer – do NOT USE a phone or tablet.
4. Use one of the following web browsers: Google Chrome, Mozilla Firefox, or Microsoft Edge.
5. When the HIT is over, the HIT code will be displayed onscreen for you to enter for payment.

Press this button when ready to continue:

Page 2: After pressing the PROCEED button below, you will play a game to earn as many points as you can. A new page will appear and you will see one or more buttons. Pressing buttons could sometimes increase or decrease your points. Points will be tracked by a bar on the screen.

The game will take approximately 15-20 minutes to complete. If you complete the game, you will be paid for completing the HIT and every point earned will be worth US$0.000005.

Failing to begin engaging with the game within 30 seconds after proceeding will terminate the opportunity to participate in this HIT and the opportunity for payment. Therefore, do not proceed unless you are ready to begin and complete the game.

Press the PROCEED button when ready to continue and please begin the game as soon as the interface appears.

## Survey Questions

1) On a scale of 1 (definitely no) to 100 (definitely yes), how sure are you there was a button with a RED HEART at some point during the HIT?

2) On a scale of 1 (definitely no) to 100 (definitely yes), how sure are you there was a button with a BLACK SPADE at some point during the HIT?

3) On a scale of 1 (definitely no) to 100 (definitely yes), how sure are you there was a button with a RED DIAMOND at some point during the HIT?

4) On a scale of 1 (definitely no) to 100 (definitely yes), how sure are you there was a button with a BLACK CLUB at some point during the HIT?

5) On a scale of 1 (not effective) to 100 (very effective), how sure are you the button with a RED HEART was effective for earning points at some point during the HIT?

6) On a scale of 1 (not effective) to 100 (very effective), how sure are you the button with a BLACK SPADE was effective for earning points at some point during the HIT?

7) On a scale of 1 (not effective) to 100 (very effective), how sure are you the button with a RED DIAMOND was effective for earning points at some point during the HIT?

8) On a scale of 1 (not effective) to 100 (very effective), how sure are you the button with a BLACK CLUB was effective for earning points at some point during the HIT?

9) What do you think was the overall purpose of the study you just completed? If you do not know, please feel free to respond, “I don’t know.” Leave the question blank if you prefer not to answer.

10) Did you have an overall strategy that you used throughout the study?

- Yes

- No
- I prefer not to answer.

11) Please describe your overall strategy that you used throughout the study. If you did not have a strategy, please feel free to respond, “I did not have a strategy.” Leave the question blank if you prefer not to answer.

- I did not have a strategy.
- I prefer not to answer.
- My strategy did not change.
- My strategy did change (If so, please describe below how your strategy changed).

12) Did your strategy change as you moved forward in the study?

13) If there is any other information you wish to explain about your experience during the study, please describe here:

14) What is your age?

15) What gender/sex do you identify with?

16) What is your nationality?

17) In what country do you live?

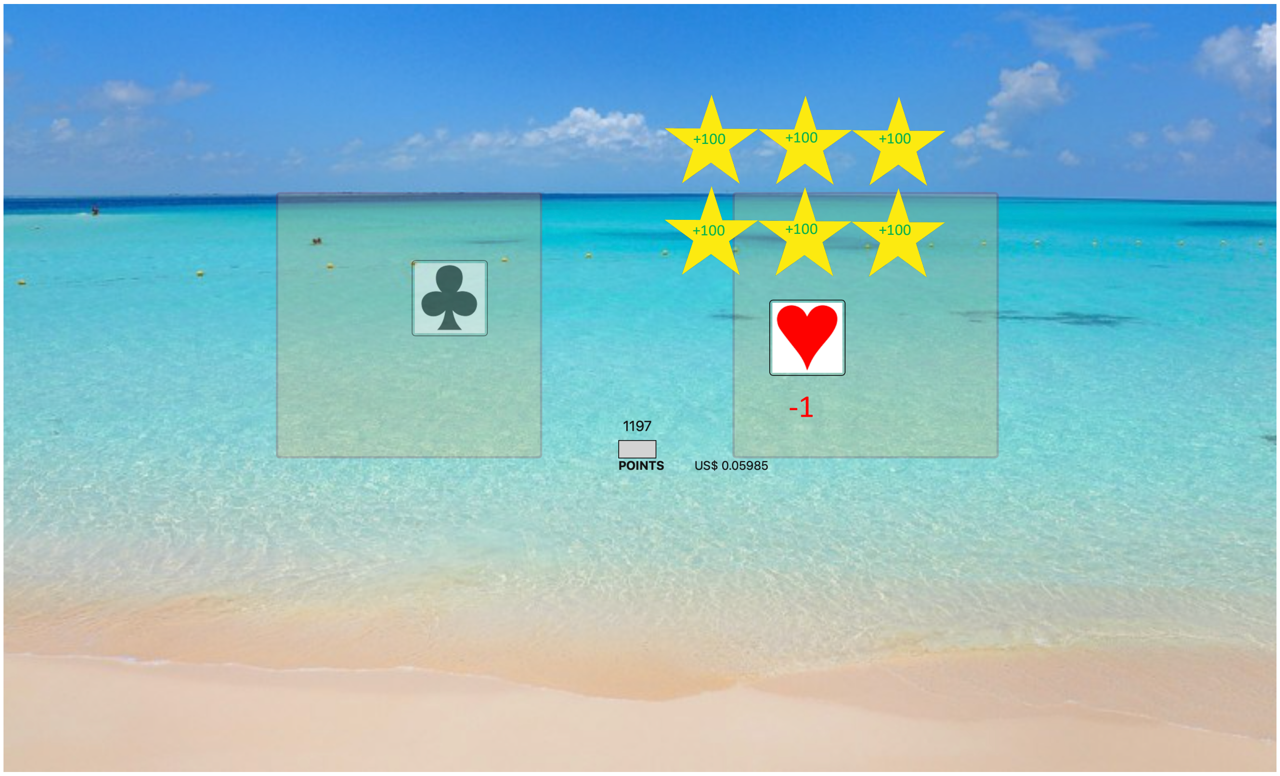
18) How much distress did you feel resulting from this task from 1 (no stress) to 100 (very stressful)?

19) Do you have any problems with color vision?

- No.
- Yes, red-green color blindness.
- Yes, blue-yellow color blindness.
- Yes, total color blindness.

- Yes, other.

## Task Interface



An example of objects shown on the browser during the experimental task. Each workspace shown above is 350-px by 350-px. Two buttons (each consisting of a 100 by 100-px square with a superimposed symbol) are also shown. Yellow stars with green text ("+100") are shown above one of the buttons, indicating reinforcement. Red text is shown below the button indicating a response cost (-1 point). A point counter is shown between the two workspaces and total earnings are shown to the right of the point counter.

# Appendix B

## Results of Post Hoc Tests of Target Responding

### *Experiment 1*

Group 6 to 3 responded at higher rates on the target button than Group 6 to 6 at the end of Phase 1 [$t(219.00) = 2.81$, $p = .033$], but differences among the remaining groups were not significant, $p$s $\geq .195$. By the end of Phase 2, response rates were comparable among groups, $p$s $= 1.00$.

In the first min of Phase 3, Group 6 to 0 responded at higher rates on the target button than each of the other groups ($t$s $\geq 3.81$, $p$s $\leq .003$). Groups 6 to 1 and 6 to 3 responded at higher rates on the target button than Group 6 to 6 ($t$s $\geq 2.32$, $p$s $\leq .042$). Differences in target responding between Groups 6 to 1 and 6 to 3 were not significant, $p = .261$.

All groups except for Group 6 to 6 responded at higher rates on the target button in Phase 3 compared to Phase 2 ($t$s $\geq 4.49$, $p$s $< .001$). For Group 6 to 6, differences in responding between these two timepoints were not significant, $p = .193$.

### *Experiment 2*

Between-group differences at the end of Phases 1 and 2 were not significant, $p$s $\geq .151$. Thus, response rates were comparable among groups by the end of each phase. All groups except 6/1 to 1 responded on the target button at higher rates in Phase 3 compared to Phase 2 ($t$s $\geq 2.82$, $p$s $\leq .005$). For Group 6/1 to 1, differences in responding between these two timepoints were not significant, $p = .101$. These findings suggest that Phase-2 high/low reinforcement mitigated resurgence following a transition to a low-magnitude test (6/1 to 1) but not to an extinction test (6/1 to 0).

In the first min of Phase 3, Groups 6 to 0 and 6/1 to 0 responded at higher rates than Groups 6 to 1 and 6/1 to 1 (*t*s $\geq$ 2.72, *p*s $\leq$ .021). That is, extinction produced higher levels of target responding than a reduction from six stars to one star, as in Experiment 1. Differences in responding (1) between each group transitioning to the low-magnitude test (6 to 1 and 6/1 to 1) and (2) between each group transitioning to the extinction test (6 to 0 and 6/1 to 0) were not significant, *p*s = 1.00. This suggests that Phase-2 high/low reinforcement did not reduce the overall level of resurgence in Phase 3 compared to constant high reinforcement in Phase 2.

# Appendix C

## Table C1

*Experiment 1*: *Results of Linear Mixed-Effects Regression for Alternative Responding*

| Factor | *β* (SE) | *df* | *t* | *p* |
|---|---|---|---|---|
| **Intercept** | **130.83 (10.79)** | **219.17** | **12.13***** | **<.001** |
| **Time** | **10.00 (1.58)** | **974.15** | **6.35***** | **<.001** |
| **Phase (1)** | **-127.05 (10.73)** | **270.04** | **-11.84***** | **<.001** |
| Phase (3) | -2.36 (7.03) | 268.46 | -0.34 | .737 |
| Group (6 to 0) | 20.76 (15.26) | 219.17 | 1.36 | .175 |
| Group (6 to 1) | 27.51 (15.18) | 219.17 | 1.81 | .071 |
| **Group (6 to 3)** | **32.59 (15.11)** | **219.17** | **2.16*** | **.032** |
| **Time*Phase (1)** | **-13.39 (2.02)** | **2424.00** | **-6.61***** | **<.001** |
| **Time*Phase (3)** | **-12.34 (2.02)** | **2424.00** | **-6.09***** | **<.001** |
| Group (6 to 0)*Time | 3.77 (2.23) | 974.15 | 1.69 | .091 |
| Group (6 to 1)*Time | 1.77 (2.22) | 974.15 | 0.80 | .424 |
| Group (6 to 3)*Time | 0.08 (2.21) | 974.15 | 0.04 | .970 |
| Group (6 to 0)*Phase (1) | -19.28 (15.17) | 270.04 | -1.27 | .205 |
| Group (6 to 1)*Phase (1) | -26.70 (15.10) | 270.04 | -1.77 | .078 |
| Group (6 to 3)*Phase (1) | -33.84 (15.03) | 270.04 | -2.25 | .025 |
| **Group (6 to 0)* Time*Phase (1)** | **-5.73 (2.86)** | **2424.00** | **-2.00*** | **.046** |
| Group (6 to 1)* Time*Phase (1) | -3.53 (2.85) | 2424.00 | -1.24 | .216 |
| Group (6 to 3)*Time*Phase (1) | -1.89 (2.84) | 2424.00 | -0.67 | .505 |
| **Group (6 to 0)*Phase (3)** | **-75.17 (9.94)** | **268.46** | **-7.56***** | **<.001** |
| **Group (6 to 1)*Phase (3)** | **-20.51 (9.89)** | **268.46** | **-2.07*** | **.039** |
| Group (6 to 3)* Phase (3) | -8.79 (9.85) | 268.46 | -0.89 | .373 |
| **Group (6 to 0)*Time*Phase (3)** | **-12.62 (2.86)** | **2424.00** | **-4.41***** | **<.001** |
| Group (6 to 1)*Time*Phase (3) | -1.64 (2.85) | 2424.00 | -0.58 | .564 |
| Group (6 to 3)*Time*Phase (3) | 1.41 (2.84) | 2424.00 | 0.50 | .620 |

*Note***.** *$p < .05$ **$p < .01$ ***$p < .001$. Statistically significant factors and interactions shown in bold. SE = standard error. The Phase (2) and Group (6 to 6) factors served as the individual contrasts.

## Table C2

*Experiment 2: Results of Linear Mixed-Effects Regression for Alternative Responding*

| Factor | $\beta$ (SE) | *df* | *t* | *p* |
|---|---|---|---|---|
| **Intercept** | **105.53 (12.38)** | **200.62** | **8.52***** | **<.001** |
| Time | 1.60 (1.05) | 231.99 | 1.53 | .128 |
| **Phase (1)** | **-96.39 (11.23)** | **243.95** | **-8.58***** | **<.001** |
| **Phase (3)** | **-45.91(9.88)** | **216.52** | **-4.65***** | **<.001** |
| Group (6 to 1) | 22.50 (17.42) | 200.62 | 1.29 | .198 |
| Group (6/1 to 1) | 4.13 (17.51) | 200.62 | 0.24 | .814 |
| **Group (6/1 to 0)** | **36.28 (17.51)** | **200.62** | **2.07*** | **.040** |
| **Time*Phase (1)** | **-4.91 (1.56)** | **3006.99** | **-3.15**** | **.002** |
| **Time*Phase (3)** | **-11.51 (1.56)** | **3006.99** | **-7.39***** | **<.001** |
| Group (6 to 1)*Time | 2.40 (1.48) | 231.99 | 1.63 | .105 |
| Group (6/1 to 1)*Time | 1.18 (1.48) | 231.99 | 0.79 | .428 |
| **Group (6/1 to 0)*Time** | **5.02 (1.48)** | **231.99** | **3.39***** | **<.001** |
| Group (6 to 1)*Phase (1) | -23.90 (15.80) | 243.95 | -1.51 | .132 |
| Group (6/1 to 1)*Phase (1) | -2.79 (15.88) | 243.95 | -0.18 | .861 |
| **Group (6/1 to 0)*Phase (1)** | **-38.34 (15.88)** | **243.95** | **-2.41*** | **.017** |
| Group (6 to 1)*Time*Phase (1) | -2.13 (2.19) | 3006.99 | -0.97 | .332 |
| Group (6/1 to 1)*Time*Phase (1) | -0.46 (2.20) | 3006.99 | -0.21 | .836 |
| **Group (6/1 to 0)*Time*Phase (1)** | **-4.94 (2.20)** | **3006.99** | **-2.24*** | **.025** |
| Group (6 to 1)*Phase (3) | 26.70 (13.90) | 216.52 | 1.92 | .056 |
| **Group (6/1 to 1)*Phase (3)** | **38.03 (13.97)** | **216.52** | **2.72**** | **.007** |
| Group (6/1 to 0)*Phase (3) | -25.78 (13.97) | 216.52 | -1.85 | .066 |
| **Group (6 to 1)*Time*Phase (3)** | **6.70 (2.19)** | **3006.99** | **3.05**** | **.002** |
| **Group (6/1 to 1)*Time*Phase (3)** | **6.47 (2.20)** | **3006.99** | **2.94**** | **.003** |
| **Group (6/1 to 0)*Time*Phase (3)** | **-6.08 (2.20)** | **3006.99** | **-2.76**** | **.006** |

*Note***.** $*p < .05$ $**p < .01$ $***p < .001$. Statistically significant factors and interactions shown in bold. SE = standard error. The Phase (2) and Group (6 to 0) factors served as the individual contrasts.