A Comparison of Resurgence During Three and Four-Phase Procedures

By

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Submitted to the graduate degree program in the Department of Applied Behavioral Science and the Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of Master of Arts.

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Date Defended: 12 October 2021

The thesis committee for Robert S. LeComte certifies that this is the approved version of the following thesis:

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Abstract

Resurgence, or the reemergence of previously extinguished responding when current behavior is challenged, is typically studied using either a three or four-phase procedure. In three-phase procedures, a target response is reinforced (1); that response is extinguished while an alternative response is concurrently reinforced (2); and the alternative response is then placed on extinction (3). In four-phase procedures, a target response is reinforced (1); that response is extinguished absent of alternative reinforcement (2); the target response remains on extinction while an alternative response is reinforced (3); and the alternative response is then placed on extinction (4).

Although both procedures have generated a wealth of data, some debate remains as to whether extinguishing the target response before reinforcing an alternative significantly impacts resurgence. To evaluate resurgence in three and four-phase procedures, the current study used a within-subjects approach with 12 rats. All animals completed training under both three and four-phase resurgence arrangements. Results showed markedly greater resurgence when animals completed a three-phase resurgence procedure compared to when a four-phase procedure was in effect. These findings potentially carry a range of implications both for the selection of procedures and for current theoretical models attempting to account for the mechanisms underlying resurgence behavior.

Acknowledgements

Thank you to the National Institutes of Health, who provided support for the current research under COBRE grant 1P20GM113109-01A1, the University of Kansas Animal Care Unit, and the many undergraduate research assistants who made this work possible.

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Introduction

Resurgence refers to the reemergence of a previously reinforced, but not currently occurring behavior in response to worsening conditions of reinforcement for an established alternative response (Lattal et al., 2017). Having been studied in a variety of experimental contexts, both basic and applied, the reemergence of past behavior has far-reaching implications for areas such as substance abuse and addiction (Podlesnik et al., 2006), problem behavior in children (St. Peter, 2015), and our understanding of more complex behavioral repertoires like those included in problem solving (Epstein, 1985). Interestingly, despite robust behavioral accounts of resurgence in today's literature, early research on resurgence was not always grounded in behavioral analytic theory.

Some of the earliest known publications documenting resurgence in behavioral terms appear, in some ways, to have borrowed from psychoanalytic interpretations of *regression* (Epstein, 2015). Described by psychoanalyst, Sigmund Freud, *regression* refers to a defense mechanism wherein the ego reverts to a previous, more child-like, stage of development in response to trauma or stressors encountered in adulthood (Lokko & Stern, 2015). One such study documenting behavioral regression comes from Hull (1934). In Experiment 1, rats were trained to run down a 40-foot runway toward a food receptacle. During training, Hull noted the appearance of a gradient such that animals' speed initially increased down the runway and slowed in the remaining 20 feet as they approached the food receptacle. Over repeated sessions, this gradient tended to disappear. Upon the removal of the food receptacle, however, initially observed changes in speed reappeared as animals approached the end of the runway.

Another example of early behavioral work with regression comes from Mowrer (1940), examining the regression of certain "habits". In this study, naïve rats were placed into a chamber with an electrified floor grate and a pedal that, when pressed, terminated electric shock. Initially, the pedal was covered by a metal grate and could not be manipulated. As the magnitude of shock increased during each session, Mowrer noted that several rats took to sitting back on their hind legs, which mitigated some of the electrical stimulation. This response of sitting on their back legs was classified as “Habit A”. Next, animals were placed into the same chamber, but with the pedal available. Over repeated training sessions, animals came to reliably press the pedal, referred to as “Habit B”, which terminated the shock. Lastly, during “frustration” (Mowrer, 1940, p. 68), rats entered the same chamber containing an available pedal, but with its surface electrified. Given punished attempts at engaging in “Habit B”, Mowrer noted a regression of animals’ behavior toward engaging in “Habit A”.

One of the first systematic investigations of behavioral resurgence appears to have been conducted by Carey (1951), using rats. In this study, single or double lever presses were initially reinforced. In the next phase, rats trained on the opposite lever response (i.e., single responses if double responses were initially trained and vice versa) before moving into a test phase wherein reinforcement no longer occurred. During the test phase, Carey noted a decline in the emission of the most recently trained response and an increase in the initially reinforced response pattern. Similar results would be demonstrated again by Carey (1953) as part of an unpublished dissertation [1].

Later resurgence work by Enkema et al. (1972) involved pigeons wherein key pecks were initially reinforced with access to a grain hopper. Subjects were then divided into two groups. For the experimental group, responding was placed on extinction by removing the grain hopper and providing response independent (i.e., free) access to grain at the back of each chamber.

[1] A full copy of Carey’s (1953) dissertation was unable to be found by the Columbia University Library (Cançado & Lattal, 2011).

Subjects in the control group experienced extinction for key pecking without access to response independent grain. Although a reduction in key pecking was observed in both groups during extinction, faster suppression of key pecking was observed in the experimental group. Further, upon the removal of free access to grain, responding among subjects in the experimental group returned to a higher level than control subjects experiencing extinction alone. In a similar study by Epstein and Skinner (1980), pigeons were trained to peck at a dot moving from left to right in their chamber. As the dot reached its endpoint, it was paired with the presentation of a food hopper. In the next phase, access to grain was provided independently of any responding to the moving dot, which led to a substantial reduction in rates of key pecking. Upon the removal of the grain hopper, however, a marked increase in key pecking occurred. Broadly, these studies demonstrated that despite a decrement in responding during free access to reinforcement, responding still reliably occurred under later conditions of extinction.

In addition to basic research, the reemergence of past behavior is also relevant within applied work. While evaluating behavioral interventions, for example, problem behavior is often reinforced during the baseline phase (cf. Phase 1). When implementing treatment, problem behavior contacts extinction while reinforcement is delivered for a more appropriate response (cf. Phase 2). Although effective for reducing frequencies of problem behavior, rates of reinforcement for appropriate responding often cannot be maintained in the post-treatment environment (Ringdahl & St. Peter, 2017). As such, treatment is often modified (e.g. schedule thinning; Hagopian et al. (2005)) to increase maintenance of appropriate responding in the natural environment (cf.. Phase 3). These modifications, however, can result in a temporary increase in problem behavior (i.e., resurgence) (Lattal & St. Peter Pipkin, 2009).

One of the first studies to document resurgence in application comes from Lovaas et al. (1965). Children with schizophrenia engaging in "self-destructive" behavior (e.g., hitting, SIB, etc.) were trained to respond appropriately to music (e.g., rocking in time, clapping in time, singing along) as an alternative response, which was reinforced with social praise. During a second extinction phase wherein social praise was withheld, however, researchers noted a renewed increase in self-destructive responding. Comparable pattens of resurgence were observed by Goh and Iwata (1994) wherein an individual's SIB was found to be maintained by escape from instructions. Initially, reinforcement was provided contingent upon finishing a specified task and following a sequence of prompts, which led to a substantial reduction in SIB. When the reinforcement condition was discontinued, a marked increase in SIB occurred.

Further examples of resurgence in applied research come from Lieving et al. (2004). In a study of two children engaging in multiple problem behaviors, Lieving and colleagues (2004) examined the degree to which separate topographies functioned as a response class. In the case of Sam, for example, all topographies of problem behavior, such as disruption (e.g., throwing, kicking objects), dangerous acts (e.g., standing on furniture, touching electrical sockets), and inappropriate language, were initially reinforced on an FR1 schedule. Disruption was then placed on extinction in the second phase. In the third phase, dangerous acts were no longer reinforced as extinction was maintained for disruption. Finally, reinforcement for inappropriate language was withheld as extinction continued for all other topographies. As dangerous acts were placed on extinction in phase 3, for example, resurgence of disruptive behavior occurred. Similarly, as inappropriate language was extinguished in phase 4, increases in both disruptive behavior and dangerous acts were observed.

Applied studies also suggest that resurgence of problem behavior may be influenced by the consistency of alternative reinforcement delivered during treatment (Hagopian et al., 2011; Volkert et al., 2009). During Functional Communication Training (FCT), for example, Hagopian et al. (2004) found that clinical goals were more quickly obtained during initially lean schedules of alternative reinforcement compared to initially dense schedules that were thinned over the course of treatment. Hagopian and colleagues (2004) suggested that resurgence during FCT may be influenced by high density alternative reinforcement in effect prior to schedule thinning. As a consequence, problem behavior may be prevented from sufficiently contacting extinction during earlier stages of treatment (Hagopian et al., 2004).

Variables Affecting Resurgence

Research on the reemergence of past behavior in both basic and applied settings has identified several features and variables affecting its occurrence. For example, resurgence has been observed with both single responses and sequences of responses (Epstein, 1983; Reed & Morgan, 2006), with effects further demonstrated across responses maintained by both positive (Leitenberg et al., 1970) and negative reinforcement (Bruzek et al., 2009). Evidence also suggests that resurgence occurs within response class hierarchies as shown by Lieving et al. (2004), described above.

Studies of resurgence have also revealed a variety of historical variables affecting its occurrence. In a study by Epstein (1983), for example, pigeons pecking one key in an initial training phase resulted in reinforcement while pecking another concurrently available key produced no consequences. An alternative response incompatible with key pecking (e.g., head turning, wing flapping, etc.) was then reinforced, which resulted in a substantial reduction of the initially trained response. When reinforcement for the alternative response was withheld in the test condition, an increase in key pecking was observed, but only on the key previously associated with reinforcement. Expanding upon these findings, da Silva et al. (2008) showed that resurgence was related to prior frequency of reinforcement for key pecking. Specifically, greater resurgence was observed for key pecking previously reinforced on a VI 1-minute schedule compared to a VI 6-minute schedule.

Further investigations also show how elements of the alternative reinforcement phase affect resurgence. Duration of exposure to alternative reinforcement, for example, affects resurgence. Specifically, longer exposure to alternative reinforcement results in lesser resurgence (Harding et al., 2009; Lieving & Lattal, 2003; Wacker et al., 2011). Experiment 4 of Leitenberg et al. (1975), for example, demonstrated that rats experiencing 27 days of alternative reinforcement showed significantly lesser resurgence compared to animals experiencing nine or three sessions of alternative reinforcement. Resurgence can be further influenced by the topography of the alternative response as shown by Doughty et al. (2007). They found a greater and earlier onset of resurgence in pigeons when an alternative response was topographically different (treadle-press) than an initially reinforced response (key peck).

In addition to resurgence being induced by the termination of alternative reinforcement (Lattal et al., 2017), changes to the rate of alternative reinforcement can also generate patterns of resurgence (Cançado et al., 2015). Shahan et al. (2020), for example, showed that resurgence of target responding increased as the rate of alternative reinforcement was thinned from a VI 10s to VI 80s schedule. Similarly, Lieving and Lattal (2003) observed increases in initially reinforced key-pecking when rates of reinforcement for alternative treadle pressing were reduced from a VI 30s to a VI 360s.

Imposing delays to reinforcement delivery is also shown to affect resurgence. Jarmolowicz and Lattal (2014), for example, exposed pigeons to progressively increasing unsignaled delays of reinforcement imposed upon the alternatively reinforced key peck. During this condition, rates of responding on the alternative key decreased and responding on the initially reinforced key increased as a function of delay to reinforcement. Comparable results were demonstrated in an unpublished study by Nighbor et al. (2017) wherein delivery of reinforcement for alternative responding only occurred following a 60-second signaled delay. Resurgence of target responding in this condition occurred for all six pigeons in the study (Lattal et al., 2017). Interestingly, the mechanisms behind delay's effects on resurgence are not fully understood. Although delay has a functional effect of reducing rates of reinforcement, Jarmolowicz and Lattal (2014) note that such reductions may be a confound to resurgence observed during delays of alternative reinforcement. Rather, Jarmolowicz and Lattal (2014) suggest that progressively increasing delays create longer periods of nonreinforcement (i.e., local extinction; Jarmolowicz & Lattal, 2014, p. 192) and that resurgence occurs due to a disruption of the relation between the response and reinforcer.

Resurgence Methodology

Through continued studies in basic and applied literatures, procedures used to study resurgence have become standardized in form of three and four-phase designs. In three-phase resurgence procedures, Phase 1 begins with the reinforcement of a target response. Then, in Phase 2, the target response is placed on extinction while an alternative response is concurrently reinforced. Finally, in the test phase, the alternative response is also placed on extinction and the reemergence of the target response is observed (Bruzek et al., 2009; Cook & Lattal, 2019; Kimball et al., 2018; Podlesnik et al., 2006; Sweeney & Shahan, 2013; Volkert et al., 2009).

In four-phase resurgence procedures, Phase 1 begins in similar fashion with the reinforcement of a target response. In Phase 2, however, the target response is placed on extinction without the concurrent introduction of alternative reinforcement. Then, in Phase 3, the target response remains on extinction while an alternative response is concurrently reinforced. Finally, Phase 4 involves the extinction of the alternative response to observe the reemergence of the target behavior (Berg et al., 2015; Epstein, 1983; Lieving & Lattal, 2003; Reed & Morgan, 2006)

The use of both three and four-phase procedures has contributed a wealth of data to the resurgence literature. Some debate exists, however, as to whether the inclusion of additional response elimination, as seen in Phase 2 of the four-phase procedure, impacts resurgence. Although, to current knowledge, no direct comparisons of three and four-phase resurgence outcomes exist within the literature, findings from some related studies suggest the significance of additional response elimination. Leitenberg et al. (1975), for example, compared effects of high-rate alternative reinforcement, low-rate alternative reinforcement, and extinction in Phase 2 on resurgence observed during the test phase. Although animals receiving high rates of alternative reinforcement showed greater suppression of target responding in Phase 2, greater resurgence in Phase 3 was observed when compared to low-rate alternative reinforcement and extinction alone groups. Given higher rates of unreinforced responding during Phase 2 among low-rate alternative and extinction groups, these findings may suggest that greater contact with extinction was a significant factor in lesser resurgence observed during Phase 3.

Relatedly, Cleland et al. (2000) found that the level of resurgence for a target response was a function of the number of sessions spent contacting extinction prior to alternative reinforcement. Their study involved six hens divided into two groups: one initially reinforced for a door-pushing response and the other for a head bobbing response. Following this initial phase, the first response was placed on extinction before reinforcing the opposite behavior. The time spent in extinction before alternative reinforcement varied across subjects, with some conditions including zero, two, or nine sessions. Then, after 4 sessions of alternative reinforcement, the opposite response was then placed on extinction. Results showed significantly greater resurgence during the test phase following zero sessions of extinction before alternative reinforcement compared to the nine-session conditions. Broadly, these results may suggest that the duration of extinction prior to alternative reinforcement is an important driver of reductions in target responding during resurgence tests.

Although these examples show the potential for reducing resurgence via additional response elimination, similar studies have failed to generate the same effects. Lieving and Lattal (2003), for example, examined the effects of alternative reinforcement phase duration on resurgence in pigeons. Following phase 1, an initially reinforced response (key pecking) was placed on extinction while subjects experienced either five or 30 sessions of alternative reinforcement (treadle pressing) prior to the resurgence test phase. Results showed no significant or systematic differences in resurgence of key pecking between alternative reinforcement groups. Similarly, Winterbauer and Bouton (2010), failed to demonstrate significant relations between the frequency of a target behavior (lever pressing) during response elimination and subsequent levels of resurgence in a series of experiments with rats. In Experiment 1, for example, rats' lever pressing was initially reinforced on an RI 30s schedule. During phase 2, subjects were divided into three groups: one experiencing alternative lever pressing on an RI 10s schedule, another on an RI 30s schedule, and the third experiencing extinction for both lever responses. Although animals in the RI 30s group emitted more unreinforced lever presses during response elimination, greater resurgence was observed in this group compared to the RI 10s and extinction alone groups. These results would appear to suggest that the target response's additional contact with extinction had no effect on resurgence. Of note, however, this study does not provide a direct comparison between procedures where extinction occurs absent of alternative reinforcement, as seen in a four-phase resurgence model.

The conflicting examples above coupled with a lack of direct comparisons between three and four-phase procedures show that the debate on whether additional response elimination affects resurgence is largely unresolved. Procedures aimed at reducing levels of resurgence may be of importance to multiple disciplines within behavioral-analytic research. In applied settings, for example, employing procedures that reduce resurgence may have a substantial impact on the success of a problem behavior intervention (Ringdahl & St. Peter, 2017). Considering substance abuse interventions, programs aimed at establishing alternative behavior may be strengthened if the reemergence of maladaptive behavior can be limited following treatment (Silverman et al., 2012). The current study, therefore, seeks to add to the literature by directly comparing levels of resurgence obtained from three and four-phase resurgence procedures via within-subjects design.

Methods

Subjects

Twelve experimentally naïve male Long Evans rats obtained from Charles River Laboratories (Raleigh, NC) (45 days old on receipt) were used in the current study. Animals were pair-housed and maintained on 22-hour food restriction with ad-libitum access to water in their home cages. All animals were housed in a husbandry room within the Animal Care Unit at the University of Kansas. The husbandry room operated on a 12hr:12hr light/dark cycle. All procedures were approved by the University of Kansas Institutional Animal Care and Use Committee (IACUC).

Apparatus

Behavioral testing sessions occurred in standard operant conditioning chambers (Med Associates, Inc., St. Albans, VT; 33.50cm x 24.10cm x 21.0cm). A pellet receptacle (3.0cm x 4.0cm) was centered on the front wall of each chamber (1.0cm from the floor) into which 45mg grain-based pellets (Bio-Serv, Frenchtown, NJ) were dispensed. Retractable levers, requiring approximately 5.0g of force to operate, were located on either side of the pellet receptacle. Retractable levers were spaced 11.0cm apart and positioned 5.0cm above the floor. A 28-volt DC house-light was centered on the back wall of each chamber (19.0 cm from the floor), which provided general illumination during session. Stimulus lights were located above each retractable lever but were not activated for any portion of the study. Chambers were housed in sound-attenuating cubicles with fans to reduce extraneous noise. All experimental procedures were programmed using MED-PC-IV software and controlled via Dell desktop PC. Sessions were conducted six to seven days per week and occurred at approximately the same time each day.

Pretraining

Because animals were experimentally naïve at the beginning of the current study, pretraining began with one session of magazine training wherein pellets were delivered on a VT30 schedule (19 value distribution based on Fleshler and Hoffman (1962)). Magazine training sessions ended after 50 pellets were delivered. If all pellets were consumed during magazine training, as was the case for each subject in the current study, animals moved into the next stage of pretraining. This included one lever pressing acquisition session during which both levers were inserted into the chamber and operated on an FR1 schedule. Lever pressing acquisition sessions ended after 6 hours. Next, animals completed three sessions responding on an FR5, FR10, and FR20, respectively, prior to entering Phase 1. These sessions lasted 1 hour or after 100 pellets were delivered (50 on each lever). Levers were inserted into the chamber randomly during each reinforcement trial. Two animals required additional pretraining sessions due to low levels of responding. Specifically, rat 3R completed two additional sessions: one at the FR5 and FR10 requirements. Rat 3C also completed one additional session at the FR10 requirement.

Four-Phase Procedure

During Phase 1, rats' lever pressing was trained on an FR20 schedule on the right lever while pressing the left lever produced no consequences. Sessions lasted 1 hour or after 60 pellets were earned. Phases were run for at least 13 sessions and until lever pressing was stable, which was judged by examining overall rates of responding on the active lever during the last 6 sessions. Calculations of overall rates of responding were performed by dividing the total number of target lever responses by the elapsed session time (excluding 5 s consumption periods following pellet delivery). If overall rates of responding in the first three and last three sessions did not differ from the grand mean of all six sessions by more than 10%, responding was deemed stable.

Prior to beginning Phase 2, animals were yoked to a subject in the three-phase group based on overall rates of responding in Phase 1. Once calculated, overall rates of responding in Phase 1 were visually compared and matched to another subject based on similarities in trend and magnitude during the last six sessions. Additionally, sessions for each pair in Phase 2 were run for a fixed amount of time. This fixed time was matched to the average duration of the last six session in Phase 1 of the animal assigned to the four-phase procedure. During Phase 2, animals experienced an extinction condition wherein both levers were inserted into the chamber but produced no consequences when pressed. Phase 2 was run for approximately 40 sessions or until one session with zero responses on the right lever was recorded.

Prior to beginning Phase 3, all animals completed two booster sessions to reestablish lever pressing. During these sessions, the left lever (alternative response) operated on an FR1 for two reinforcers, then an FR2 for two reinforcers, FR4 for two reinforcers, FR8 for two reinforcers, and FR16 for two reinforcers, before increasing to an FR20 for the remainder of the 1-hour session.

In Phase 3, animals responded on an FR20 schedule active on the left lever while the right lever produced no consequences. Sessions in Phase 3 were run until overall rates of target responding were stable, as defined by the above criteria. In Phase 4, both levers were inserted into the chamber, but lever pressing resulted in no consequences. Phase 4 was run for approximately ten sessions. Additionally, the duration of each session during Phase 4 was fixed; matched to the duration of the last 6 session in Phase 3 (see Table 1 for phase duration in each subject pair).

Three-Phase Procedure

Animals assigned to this group completed Phase 1 under the same duration and stability conditions described above. In Phase 2, however, animals experienced a blackout condition wherein the house-light was not turned on and levers remained retracted during each session, providing no opportunity to respond. As described above, animals were yoked by session time to an animal in the four-phase group during Phase 2. Phase duration was also held constant, lasting approximately 40 sessions or until one session with zero target responses occurred for the four-phase partner.

Animals progressed through Phase 3 in the same way, completing two booster sessions before responding on an FR20 active on the left lever. Sessions in Phase 3 were also run to stability based on the above criteria. Lastly, reinforcement for alternative lever pressing was terminated during Phase 4, which was run for approximately 10 sessions. As in Phase 2, each session in Phase 4 was run for a fixed duration based on the average time elapsed in the last 6 sessions of Phase 3 (see Figure 1 for schematic representation of study design).

Lever Reversal

Following the end of Phase 4 (i.e., test phase), all animals completed two booster sessions wherein pellets were delivered for left lever pressing. All conditions were then replicated with the right lever now serving as the alternative response during Phase 3. Additionally, individual yoked pairs were reversed, such that animals originally in the four-phase group would now be in the three-phase group (and vice-versa).

Data Analysis

Statistical significance tests were conducted using GraphPad Prism version 8.4.3 (GraphPad Software, Inc., San Diego, CA) and IBM SPSS Statistics (Version 27). Area Under the Curve (AUC) analyses were conducted based on the approach by Myerson et al. (2001) for calculating AUC in delay discounting curves. First, vertical lines were drawn from the first 5 data points in Figures 2 and 3, which divided each figure into a series of trapezoids. Next, the area of each trapezoid was calculated using the following equation:

$$AUC = (x_2 - x_1)[(y_1 + y_2)/2] \tag{1}$$

Wherein x values correspond to the base of each trapezoid and the proportion of target responding observed during the test phase relative to Phase 1 are entered as y values (height).

Results

During both initial (right lever resurgence) and reversal (left lever resurgence) conditions of the current study, animals demonstrated greater resurgence during the three-phase procedure (Phase 2 blackout) than when the four-phase procedure was in effect (Phase 2 extinction).

Figure 2 shows individual pair data from the initial test phase (right lever resurgence). The proportion of target overall rates of responding relative to baseline (BL) (Y-axis) are shown in the first 10 sessions (X-axis) of the test phase. A higher proportion of BL overall rates of responding were observed during the three-phase procedure (open symbols with dashed lines) than during the four-phase procedure (closed symbols with solid lines). These effects are shown in 5 of 6 cases, with pair 4C + 1G representing the one case where the proportion of BL overall rates of responding were higher for the four-phase group during sessions 1 and 2. In pairs 3R + 3G, 2R + 2C, 4R + 1C, and 3C + 4G, differences in the proportion of BL overall rates were maintained for multiple sessions before data paths converged.

Figure 3 shows the proportion of BL overall rates of responding observed during the lever reversal condition (left lever resurgence). Like the results displayed in Figure 2, a greater proportion of BL overall rates of responding were observed amongst animals in the three-phase group. Based on visual inspection, these effects are demonstrated in 5 of 6 pairs. The proportion of BL overall rates of responding were initially higher in the four-phase group for pair 3R + 3G. Also, like Figure 2, differences in proportions of BL responding between groups were maintained for multiple sessions before data paths converged (see panels for pairs 2R + 2C, 1R + 2G, 4R + 1C, 3C + 4G, and 4C + 1G).

Figure 4 shows patterns of overall response rates during each phase of the current three-phase procedure. Solid symbols represent overall response rates on the target lever and open symbols represent overall response rates on the alternative lever. Each panel shows the last six sessions during Phases 1 and 2. All sessions are shown for the test phase (Phase 3).

Figure 5 shows patterns of overall response rates in each phase when the four-phase procedure was in effect. Solid symbols represent overall response rates on the target lever and open symbols represent those on the alternative lever. The last six sessions of overall response rates are shown for Phases 1 and 3 while all sessions are shown for Phases 2 and 4.

Figure 6 summarizes the first five sessions of the test phase during both initial and lever reversal conditions as Area Under the Curve (AUC). Lower AUC indicates lesser target responding in the test-phase while a higher AUC indicates greater target responding during the test phase. Each set of data points joined by a line represents an individual rat. Results of the current study show a higher AUC, on average, when animals experienced the three-phase resurgence arrangement and a lower AUC, on average, when experiencing the four-phase arrangement. Results of a Wilcoxon Signed Rank test showed that differences in AUC were statistically significant ($T = 66.00$, $n = 12$, $z = 2.12$, $p = 0.03$).

Figure 7 shows the first session of the test phase wherein resurgence is represented as latency to the first target response. During the four-phase procedure, an average of 95.97 seconds elapsed before the first resurgent response occurred. During the three-phase procedure, an average of 35.91 seconds elapsed prior to the occurrence of the first resurgent response. Results of a Wilcoxon Signed Rank test showed that differences in mean latency were statistically significant ($T = 4.00$, $n = 12$, $z = -2.75$, $p = 0.006$).

Figure 8 shows a correlational analysis between the number of target responses emitted during alternative reinforcement and the test phase when animals experienced the three-phase procedure. Results of a Spearman's Rho test showed a significant positive correlation such that a greater number of target responses emitted during alternative reinforcement corresponded to a greater number of target responses (i.e., resurgence) emitted during the test phase (r_s (10) = .622, p = 0.03)

Figure 9 shows a correlation between the number of target responses emitted during extinction (Phase 2), alternative reinforcement (Phase 3), and the test phase in the four-phase procedure. Results of a Spearman's Rho test showed a significant positive correlation in that a greater number of target responses during Phases 2 and 3 related to a greater amount of target responding during the test phase (r_s (10) = .594, p = 0.04).

Figure 10 shows a correlation between average overall response rates on the target lever during Phase 3 (extinction + alternative reinforcement) and the test phase when the three-phase procedure was in effect. Results of a Spearman's Rho test did not yield a significant correlation between overall response rates observed during Phase 3 and during the test phase (r_s (10) = .330, p = 0.295)

Figure 11 shows a correlation between average overall response rates on the target lever during Phase 2 (extinction), Phase 3 (extinction + alternative reinforcement), and the test phase when the four-phase procedure was in effect. Results of a Spearman's Rho test did not yield a significant correlation between overall response rates observed during Phase 3 and during the test phase (r_s (10) = .189, p = 0.555)

Figure 12 shows a correlation between the duration of Phase 3 (extinction + alternative reinforcement) and resurgence in the test phase (shown as AUC) when the three-phase procedure was in effect. Results of a Spearman's Rho test did not yield a significant correlation between Phase 3 duration and resurgence (r_s (10) = .483, p = 0.111).

Figure 13 shows a correlation between the duration of Phase 3 (extinction + alternative reinforcement), and resurgence (shown as AUC) during the four-phase procedure. Results of a Spearman's Rho test did not yield aa significant correlation between the duration Phase 3 and resurgence (rs (10) = .330, p = 0.295).

Figure 14 shows the average number of target responses recorded during the last six sessions of extinction (Phase 2) and the first six sessions of alternative reinforcement (Phase 3) during the four-phase procedure. A Wilcoxon Signed-Rank test showed a significant difference in target responding between the last session of extinction and the first session of alternative reinforcement, observed in 10 of 12 animals (T = 70.05, n = 12, z = 2.47, p = 0.013).

Discussion

Results of the current study demonstrated significantly greater resurgence in the test phase when animals experienced the three-phase resurgence procedure (Phase 2 blackout) compared to when animals experienced the four-phase resurgence procedure (Phase 2 concurrent extinction). Differential resurgence was observed both through visual inspection of target responding relative to baseline (Figures 2 and 3) and by calculating AUC wherein higher AUC indicates greater Phase 4 resurgence (Figure 6). Additionally, animals experiencing the three-phase resurgence procedure demonstrated a significantly shorter latency to the first target response compared to when the four-phase procedure was in effect (Figure 7). These data have several implications for current theoretical interpretations of resurgence.

Although observations of differential resurgence have been noted previously in the literature (e.g., Cleland et al. (2000); Leitenberg et al. (1975)), the mechanisms behind its occurrence are not well understood. In one attempt to explain such mechanisms, Leitenberg et al. (1975) described these sorts of data through the Response Prevention Hypothesis (RPH). This hypothesis, also described as “deferred extinction” (Cleland et al. 2001, p. 257), argues that the concurrent reinforcement of an alternative response in Phase 2 of a three-phase procedure interferes with the target response’s contact with the extinction process. It is further argued that once the alternative response is also placed on extinction in the test phase, the removal of this interference allows for the reoccurrence of the target response (i.e., resurgence).

In addition to some basic research studies lending credibility to the RPH (e.g., Cleland et al. 2000), studies of resurgence within application have also demonstrated effects that may add further support. Specifically, some studies have shown an inverse relation between alternative reinforcement and a target behavior wherein longer treatment duration results in lesser resurgence (Nevin & Wacker, 2013). Harding et al. (2009), for example, demonstrated significant reductions of destructive behavior when FCT regimens were maintained for 7 months compared to probes conducted at one and two-month timepoints. Similar findings were noted by Wacker et al. (2011), wherein the persistence of destructive behavior was more effectively reduced following longer exposures to DRA treatment. Through the lens of the RPH, longer exposure to alternative reinforcement would allow more opportunities for the target response to contact extinction.

Relating the RPH to the current data, it would suggest that the target response contacted extinction for a longer period during the four-phase procedure compared to the three-phase, wherein animals experienced a blackout prior to establishing alternative reinforcement. As a result of less time spent contacting extinction during the three-phase procedure, target responding encountered more interference from the alternative response in Phase 3, which contributed to greater resurgence in Phase 4.

Despite the current data and examples within the literature (e.g., Leitenberg et al. 1975; Cleland et al. 2000) appearing to support the RPH, interpretations are clouded both by publications claiming the insignificance of response prevention on resurgence (e.g., Lieving et al. 2003; Winterbauer & Bouton, 2010) and an overall lack of studies directly comparing three and four-phase procedures. In the previously described Experiment 1 of Winterbauer and Bouton (2010), for example, animals assigned to the RI 10s group emitted fewer unreinforced lever presses during alternative reinforcement compared to the RI 30s group. From the perspective of the RPH, there should be a greater resurgence effect in the RI 10s group given that the initial response made lesser contact with extinction. Instead, however, the opposite effect was observed.

Further, Shahan and Sweeney (2011) cast doubt on the RPH in noting that resurgence of target responding still occurs during four-phase procedures despite contacting additional response elimination. The current study also shows resurgence occurring when the four-phase procedure was in effect. Processes of response prevention, however, may not necessarily be precluded by the appearance of resurgence during a four-phase procedure. Rather, lesser resurgence during the four-phase procedure, observed in the current data, may indicate mitigation of response prevention given the target response's additional contact with extinction.

Of note, however, data from the current four-phase procedure also show that a greater number of target responses emitted during extinction (Phases 2 and 3) significantly correlated with a greater number of target responses observed during the resurgence test, which runs counter to the RPH (see Figure 9). This effect was also observed when the three-phase procedure was active (see Figure 8). Interestingly, Figures 10 and 11 showing nonsignificant correlations between average overall response rates on the target lever during extinction and the test phase (in both three and four-phase procedures) suggest that the absolute number of target lever presses was a more significant factor influencing this effect than the rate at which they were emitted. Collectively, the issues associated with interpreting the role of the RPH signal that its relevance to differential resurgence remains ambiguous. In attempting to better account for mechanisms underlying differential resurgence, it may be helpful to understand other existing theoretical structures.

One such attempt to explain resurgence has its bases in Behavioral Momentum Theory (BMT) (Nevin et al., 1983). Behavioral Momentum Theory characterizes the strength of free operant behavior and its resistance to change in the presence of a discriminative stimulus as analogous to the velocity and inertial mass of a moving object. Within this framework, response strength is defined by its resistance to change rather than traditional conceptualizations of strength in terms of response rate or probability of occurrence (Nevin & Shahan, 2011). Further, BMT suggests that resistance to change is directly related to the rate of reinforcement encountered in the presence of a discriminative stimulus. When a disruptor (e.g., extinction) is exerted on a current behavior, decreases in response rates are directly related to the magnitude of the disruptor and inversely related to the behavioral mass of the response. These interactions are expressed via the following equation:

$$\Delta B = \frac{-x}{m} \tag{2}$$

Where ΔB denotes changes in response rate, x represents the value of an active disruptor, and m represents behavioral mass as defined by an organism's prior history of reinforcement.

Adapting BMT to resurgence, Shahan and Sweeney (2011) argue that decreases in target responding during Phase 2 result from a disruption in the stimulus-reinforcer relation established in Phase 1. Further, the concurrent reinforcement of an alternative response during

Phase 2 serves two important functions: it serves as an additional disruptor of the stimulus-reinforcer relation for the target response and strengthens the stimulus-reinforcer relation for the alternative response within the context of Phase 2. Upon terminating reinforcement for the alternative response in Phase 3, its disruptive effects are removed, and the target behavior reoccurs in its absence. This adaptation of BMT to resurgence is expressed as:

$$\log\left(\frac{B_t}{B_0}\right) = \frac{-t\ (kR_a + c\ + dr)}{(r + R_a)^b} \tag{3}$$

In this equation, B_t represents the rate of a response during a given time (t) in extinction, B_0 corresponds to response rates prior to extinction, R_a represents alternative reinforcement with k scaling its disruption, c denotes the disruptive effects of terminating the response to reinforcer contingency, d scales the disruption caused by the termination of reinforcement, r denotes the rate of reinforcement in the presence of a discriminative stimulus established during baseline, and b relates to the sensitivity to rates of reinforcement.

Considering the current data, BMT predicts that during Phase 2 of a three-phase procedure, for example, the impact of extinction on target responding coupled with the presentation of alternative reinforcement (R_a) increases over time. Consequently, as the duration of exposure to extinction during alternative reinforcement increases, resurgence decreases (Shahan & Sweeney, 2011, p. 97). Contrary to this prediction, however, present results showed nonsignificant correlations between the duration of Phase 3 (extinction + alternative reinforcement) and resurgence during both three-phase and four-phase procedures (see Figures 12 and 13).

Related to four-phase resurgence procedures (i.e., Epstein-type resurgence; Shahan & Sweeney, 2011), BMT describes that during extinction in the absence of alternative reinforcement, R_a in the above equation (3) is reduced to zero. Later, when alternative reinforcement is introduced, R_a is added to the numerator as a source of disruption to target responding and to the denominator as source of reinforcement. Further, as R_a appears in the denominator, the BMT equation predicts a small increase in target responding (Shahan & Sweeney, 2011, p. 102). Consistent with this prediction, the current study showed a significant increase in target responding between the last session of extinction (Phase 2) and the first session of alternative reinforcement (Phase 3) during the current four-phase procedure (see Figure 14). This effect was observed for 10 of 12 animals in the study.

Along with the mixed findings noted above, other inconsistencies with the BMT account of resurgence have been described in the literature. Craig and Shahan (2016), for example, found that BMT did not adequately predict reinforcer rate effects. According to BMT, high rates of reinforcement for the target response during Phase 1 should increase the response's resistance to change moving into Phase 2 compared to lower rates of reinforcement. Further, given the disruptive nature of the alternative response, higher rates of alternative reinforcement during Phase 2 should suppress target responding more than lower rates of alternative reinforcement. Contrary to these assumptions, however, Craig and Shahan (2016) found that animals experiencing low-rate alternative reinforcement demonstrated greater persistence of target responding during Phase 2 compared to high-alternative reinforcement groups. Further, limited differences in responding were observed during the test phase when comparing high-rate alternative and low-rate alternative reinforcement groups. Nonsignificant differences in resurgence between animals experiencing rich and lean alternative reinforcement were also observed by Cançado and Lattal (2013). A review of these predictive discrepancies and others led Nevin et al. (2017) to conclude that, "…accounts of resurgence based on Behavioral Momentum Theory are fundamentally flawed" (p. 9).

Given these conflicts, discussions of resurgence through the lens of BMT have largely been replaced by more recent theoretical models, such as Resurgence as Choice (RaC; Shahan & Craig, 2017). Introduced by Shahan and Craig (2017), RaC asserts that resurgence occurs due to differences in valuation between target and alternative responses. More specifically, RaC proposes that the probability of occurrence of some target behavior is a function of the value obtained from past outcomes relative to those obtained by a more recently acquired alternative behavior. This interaction between the value of a target response and the value of an alternative response is expressed as:

(4)

$$pT = \frac{V_T}{V_T + V_{ALT}}$$

Wherein pT represents the probability of occurrence of the target response, V_T represents the current value of the target response and V_{Alt} represents the current value of the alternative response.

A central component of RaC in describing how the value of the target response changes moving from Phases 1 through 3 is the Temporal Weighting Rule (TWR; Devenport and Devenport (1994)). The TWR asserts that the influence of past events diminishes over time while more recent experiences carry a greater weight of influence on current behavior. This influence of a prior reinforcement history on current responding is expressed via the equation:

(5)

$$W_x = \frac{1/t_x}{\sum_{i=1}^{n} 1/t_i}$$

Wherein W_x represents the weight allocated to a given experience, $1/t_x$ in the numerator represents the time elapsed between a past experience and the present, and the sum of all the weights of past experiences is represented in the denominator.

Applied within the framework of RaC, the TWR suggests that, during Phase 2 of a three-phase resurgence model, extinction of the target response and concurrent introduction of an alternative source of reinforcement causes a decline in the value of engaging in the target response. This decline in valuation of the target response first happens precipitously, but then declines more slowly over time (i.e., across sessions) given the hyperbolic form of the temporal weighting function. Simultaneously, the value of the alternative response increases during Phase 2 as reinforcement continues to be presented. When alternative reinforcement is terminated during Phase 3, however, the value of the alternative response declines in the same hyperbolic manner as the target response during Phase 2. As the value of the alternative response continues to decline across sessions in Phase 3, the probability of the target response increases due to changes in its relative value. Through the TWR, RaC asserts that the history of Phase 1 reinforcement for the target response is carried through Phases 2 and 3 as V_T. The remaining value of V_T carried through phases can be detected when V_{ALT} begins to decline, resulting in an increase in pT during Phase 3. Taken together, increases in V_T and pT during Phase 3 constitute resurgence according to RaC (see Figure 15 for an illustration of this process).

As well as being a key component of RaC, the TWR has also been applied to other phenomena observed during choice behavior procedures, such as spontaneous recovery. Mazur (1996), for example, assessed the TWR's ability to account for differences in magnitude of spontaneous recovery, defined in the study as, "…a reversion to a previously reinforced choice proportion" (Mazur, 1996, p. 2). In Experiment 2, pigeons responded on two available keys, each delivering approximately 50% of reinforcement during session. After consecutive days of training, some animals moved immediately into a transition phase wherein one of the response keys delivered reinforcement on a richer schedule, providing either 70% or 90% of total reinforcement during session. Another group of pigeons experienced a 3-day pause in training between the end of baseline sessions and the beginning of the same transition phase.

Recapitulating, the TWR suggests the influence of past experiences on current choice behavior diminishes with the passage of time. Further, Mazur (1996) states that the decreasing influence of past events occurs, "…regardless of what events fill the intervening time" (Mazur, 1996, p. 7). Consistent with these assumptions, Mazur (1996) showed that animals experiencing a 3-day rest between baseline and transition phases demonstrated less spontaneous recovery than those who immediately experienced the transition phase following baseline. According to the TWR, observations of lesser spontaneous recovery occur in the 3-day rest group because the influence of baseline sessions (50% reinforcement on each key) is more distant.

Results of the current study present an interesting challenge when considering the changes in V_T and V_{ALT} described by RaC and integrated assumptions of the TWR. Although the current study involved separate resurgence procedures, both groups entered the alternative reinforcement phase at the same time. Moreover, durations of the alternative reinforcement phase were held approximately equal between groups. From the perspective of RaC, we would therefore expect to observe an approximately equal increase in the value of the alternative response and concurrent decrease in the value of the target response during Phase 3. Further, individual session times and phase durations were also balanced during the test phase. Here, we should expect an approximately equal depreciation in value of the alternative response and, simultaneously, an approximately equal increase in both V_T and pT.

Of note, phase duration was also balanced during Phases 1 and 2 in each group. According to the TWR, we would expect that the influence of past reinforcement for target responding be approximately equal for each group given the similar distance between Phase 1 and the onset of alternative reinforcement. Further, as noted above, the TWR asserts that events filling any intervening time should not affect the rate at which the influence of past reinforcement diminishes (Mazur, 1996). Thus, regardless of whether animals experienced extinction for lever pressing or the blackout condition during Phase 2, the weight of influence of past reinforcement experiences in Phase 1 should be equal upon establishing alternative reinforcement in Phase 3.

Taken together, the equal weighting of past reinforcement history across Phases 1 and 2, equal increases in V_{ALT} during Phase 3, and later depreciation of V_{ALT} coupled with increases in V_T and pT during Phase 4 should yield approximately equal levels of resurgence in target lever pressing. Results of the current study, however, are inconsistent with these expectations. Rather, to reiterate, the current study yielded significant differences in resurgence between three and four-phase procedure groups.

The current study has some limitations that warrant consideration for future research. First, the current study only involved 12 animals and future research would likely benefit from using a larger sample. Although small, however, the current study used a within-subjects approach and replication, which may lend additional support to the findings. Second, the current study only examined resurgence during FR schedule performance. Future research may look to compare resurgence procedures using a wider range of reinforcement schedules during initial and alternative reinforcement phases. Third, the lack of house lighting during the blackout condition in Phase 2 of the three-phase procedure represents a stimulus and context change that may have affected later observation of resurgence. Fourth, phase durations for some subject pairs were unequal due to factors including computer and equipment malfunctions, unexpected stoppages to experimental sessions, and researcher error. Although differences in phase duration were not statistically significant, such discrepancies may have affected the reinforcement history of lever responses and their relative value as described by RaC and imbedded TWR. Future iterations may seek to replicate the current methods while ensuring equal phase duration throughout.

Conclusion

The current study has potential implications both for the selection of resurgence procedures and theoretical interpretations of the mechanisms behind resurgence itself. Of note, the current study may represent the first direct comparison of three and four-phase procedures in the resurgence literature. Broadly, results showed lesser resurgence among subjects when a four-phase procedure was in effect compared to levels observed during the three-phase arrangement. Using procedures that reduce levels of resurgence may stand to make a substantial impact in areas of applied (Ringdahl & St. Peter, 2017) and translational research (Silverman et al., 2012). Further, the current results are, in some ways, at odds with contemporary theoretical models of resurgence behavior, such as RaC (Shahan & Craig, 2017). This may suggest a need for an update or refinement of current models to account for differences in resurgence observed between three and four-phase procedures. As this is beyond the scope of the current study and interpretation of results, however, future research should seek how to best address this and other elements of current theoretical modeling to provide a more thorough account of differential resurgence and its underlying mechanisms.

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Initial:

Subject Pair (Four-Phase, Three-Phase)	Phase 1	Phase 2	Phase 3	Phase 4
1R, 2G	24	17, 18*	17	21, 20*
2R, 2C	18	48, 49*	22	21
3R, 3G	21, 24*	42, 43*	22	19, 20*
4R, 1C	18	48, 49*	15	27
3C, 4G	21, 24*	34	22, 25*	18
4C, 1G	18	48, 49*	31, 30*	13

Lever Reversal:

Subject Pair (Three-Phase, Four-Phase)	Phase 1	Phase 2	Phase 3	Phase 4
1R, 2G	34	24, 23*	33	12
2R, 2C	20	31	14	11
3R, 3G	14	49	46	11
4R, 1C	13	25	44	11
3C, 4G	33, 32*	22	42	11
4C, 1G	18	42, 41*	19	11

Table 1. Session numbers per phase for each subject pair. The top panel represents phase duration during the initial condition (right-lever resurgence) while the bottom panel shows phase duration during the reversal condition (left-lever resurgence). Asterisks (*) denote instances where phase durations were unequal between three and four-phase pairs. A two-way ANOVA showed these differences were not statistically significant during phases 1, 2, or 3 (Respectively, $F(11,11) = 2.146$, $p = 0.11$); $F(11,11) = 2.618$, $p = 0.06$); $F(11, 11) = 1.099$, $p = 0.43$).

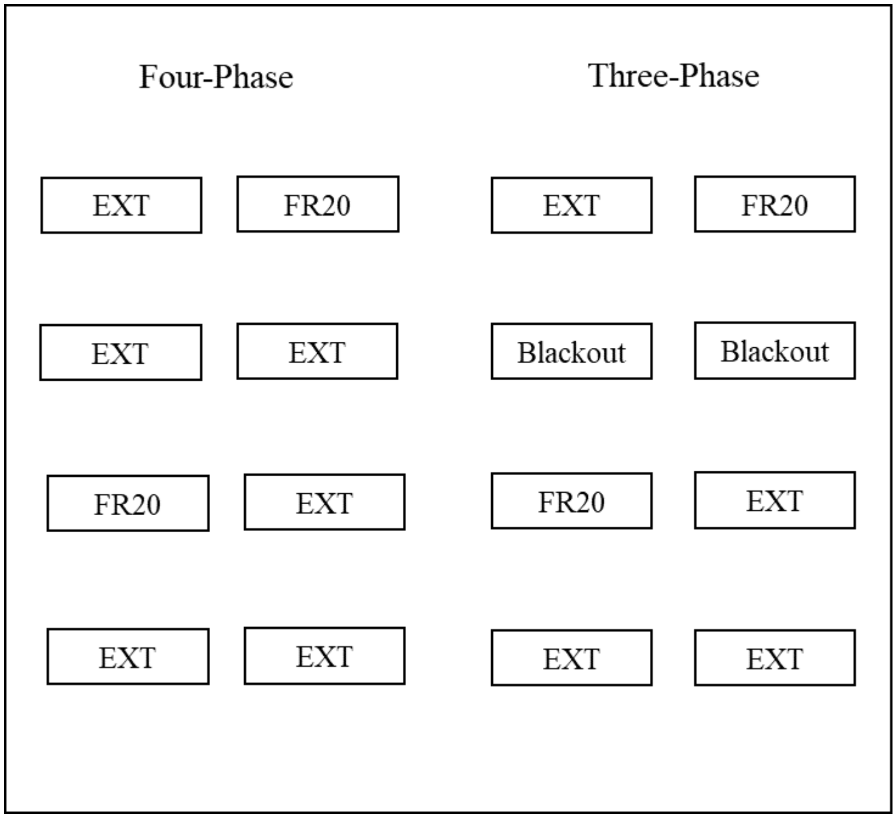


Figure 1. Schematic representing the current study design. The left-hand column shows the four-phase procedure. During phase 1, the right lever was active on an FR20 schedule while the left lever produced no consequences. In phase 2, right lever pressing was placed on extinction. In phase 3, left lever pressing was reinforced on an FR20 schedule. In phase 4, left lever pressing was placed on extinction. The three-phase procedure was identical in phases 1, 3, and 4. During phase 2, animals experienced a blackout condition wherein levers remained retracted outside of the chamber, providing no opportunity to respond.

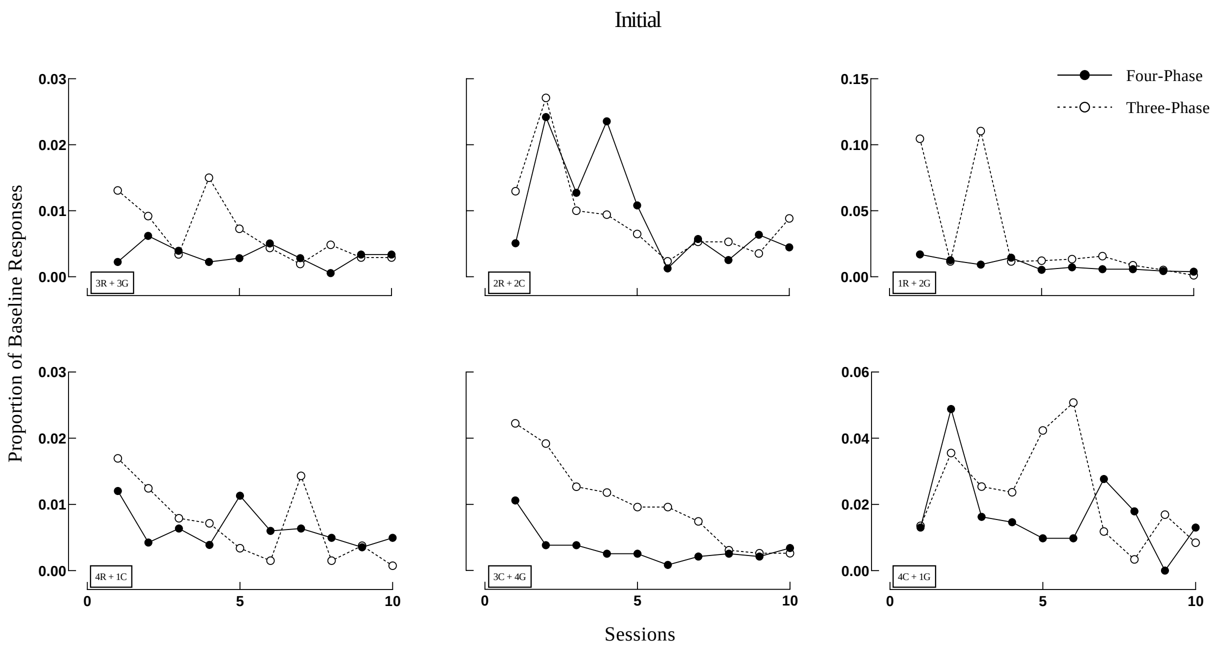


Figure 2. Pair data from the initial test phase (right lever resurgence). The Y-axis shows the proportion of overall rates of responding on the right lever (relative to baseline) during the first 10 sessions of the test phase (X-axis). A higher proportion of baseline (BL) overall response rates were observed for subjects in the three-phase group compared to those in the four-phase group; shown in 5 of 6 subject pairs. Subject pair, 4C + 1G, represents one instance where the proportion of BL overall rates was higher in the four-phase procedure during sessions 1 and 2. In other subject pairs (e.g., 3R + 3G, 2R + 2C, 4R + 1C, 3C + 4G) differences in the proportion of BL overall rates were maintained for multiple sessions before data paths converged.

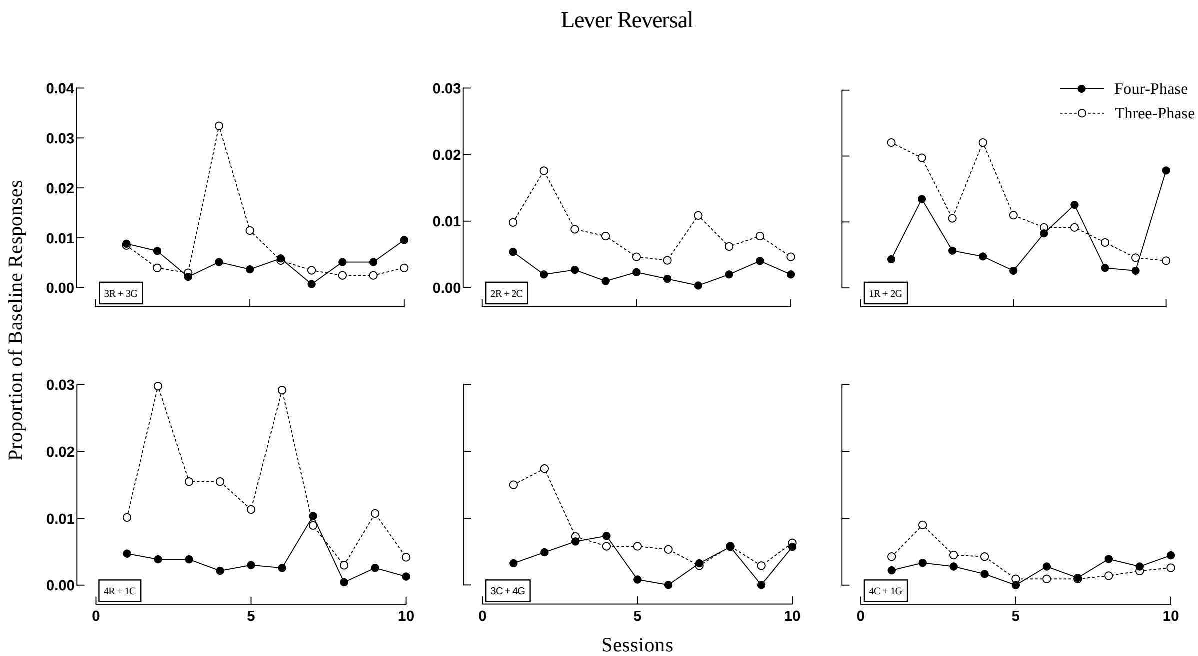


Figure 3. Pair data from the first 10 sessions of the test phase during lever reversal. As shown in Figure 2, a greater proportion of baseline overall rates of responding were observed amongst animals in the three-phase group; also shown in 5 of 6 subject pairs. In subject pair 3R + 3G, proportions of bas overall rates were higher in the four-phase procedure during test phase sessions 1 and 2. In other subject pairs (e.g., 2R + 2C, 1R + 2G, 4R + 1C, 3C + 4G, 4C + 1G) differences in the proportion of baseline overall rates were maintained for multiple sessions before data paths converged.

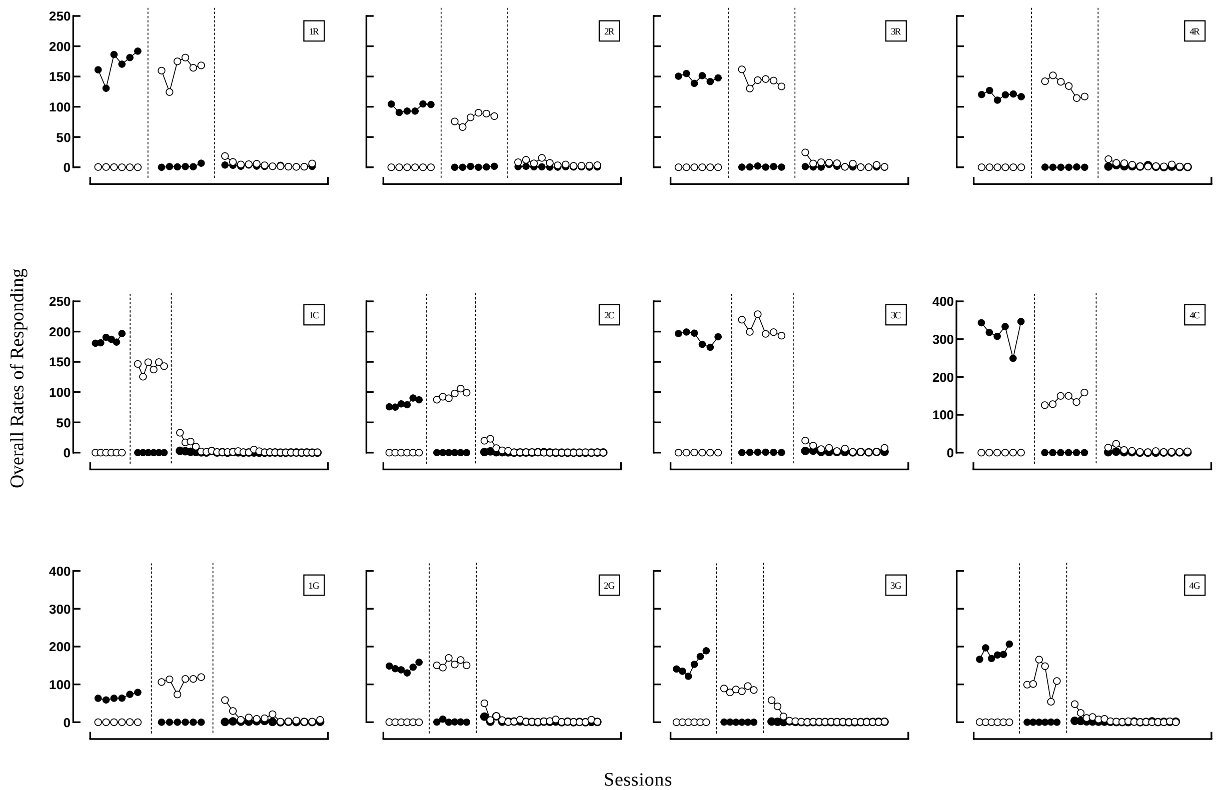


Figure 4. Patterns of overall response rates during each phase of the three-phase procedure. The last six sessions are shown for Phases 1 and 2. Closed symbols represent overall response rates on the target lever and open symbols represent overall response rates on the alternative lever.

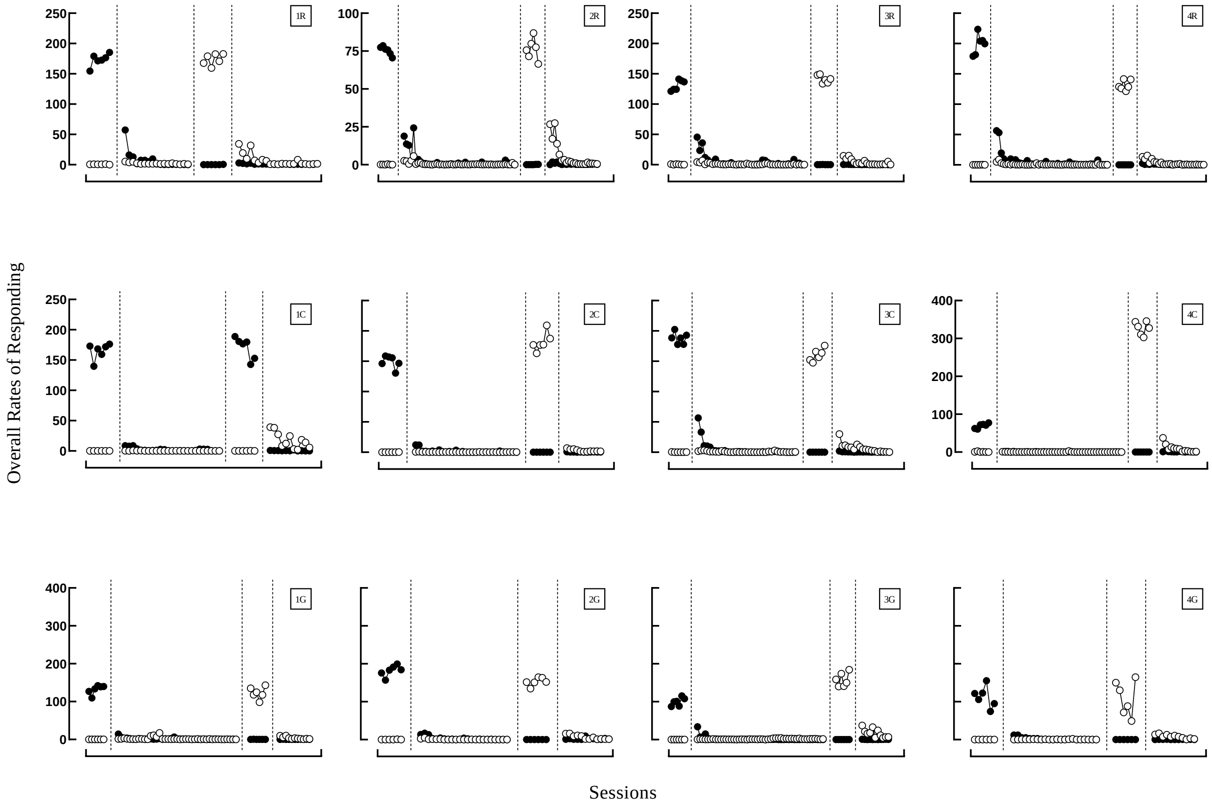


Figure 5. Patterns of overall response rates during each phase of the four-phase procedure. The last six sessions are shown for Phases 1 and 3. Closed symbols represent overall response rates on the target lever and open symbols represent overall response rates on the alternative lever.

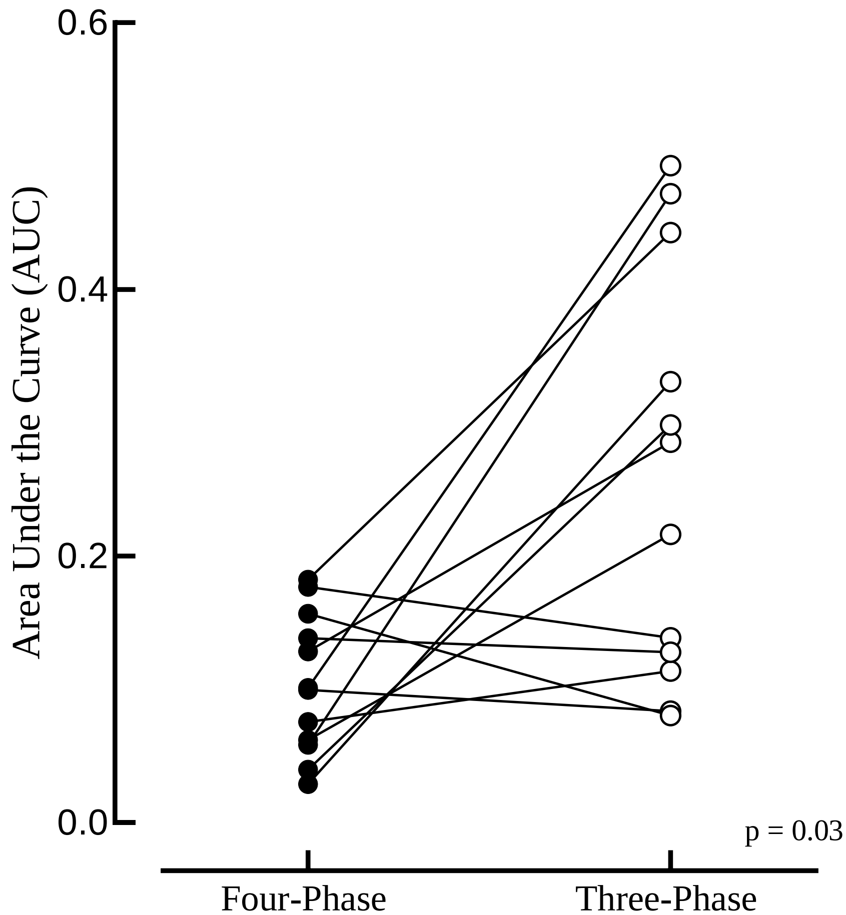


Figure 6. Area Under the Curve (AUC) calculated for each animal during the first 5 sessions of the test phase. Each set of joined data points represents one animal's AUC during exposure to the three and four-phase procedure. Lower AUC indicates lesser target responding in the test phase while higher values indicate greater responding during the test phase. A higher AUC, on average, was observed when animals experienced the three-phase procedure compared to the four-phase procedure. Differences in AUC were statistically significant, shown by a Wilcoxon Signed Ranks Test (T = 66.00, z = 2.12, n = 12, p = 0.03).

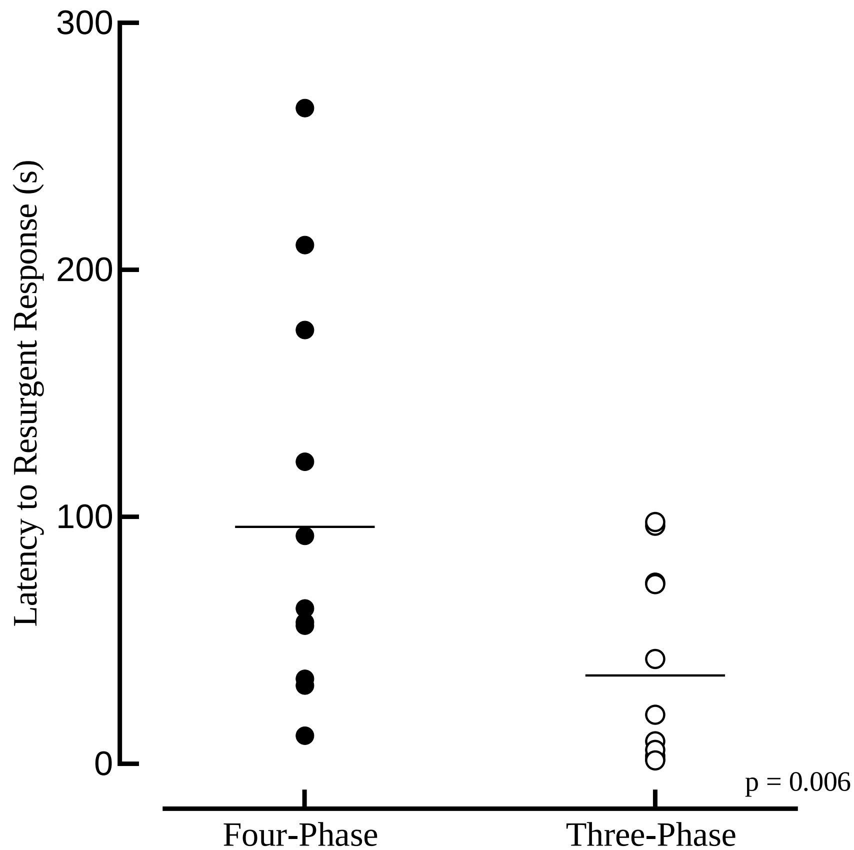


Figure 7. Latency to the first resurgent response in the first session of the test phase, collapsed across initial and lever reversal conditions. During the four-phase procedure, an average of 95.97 seconds elapsed before the first resurgent response occurred. During the three-phase procedure, an average of 35.91 seconds elapsed prior to the occurrence of the first resurgent response. Differences in mean latency were shown to be statistically significant via a Wilcoxon Signed Ranks Test (T = 4.00, z = -2.75, n = 12, p = 0.006).

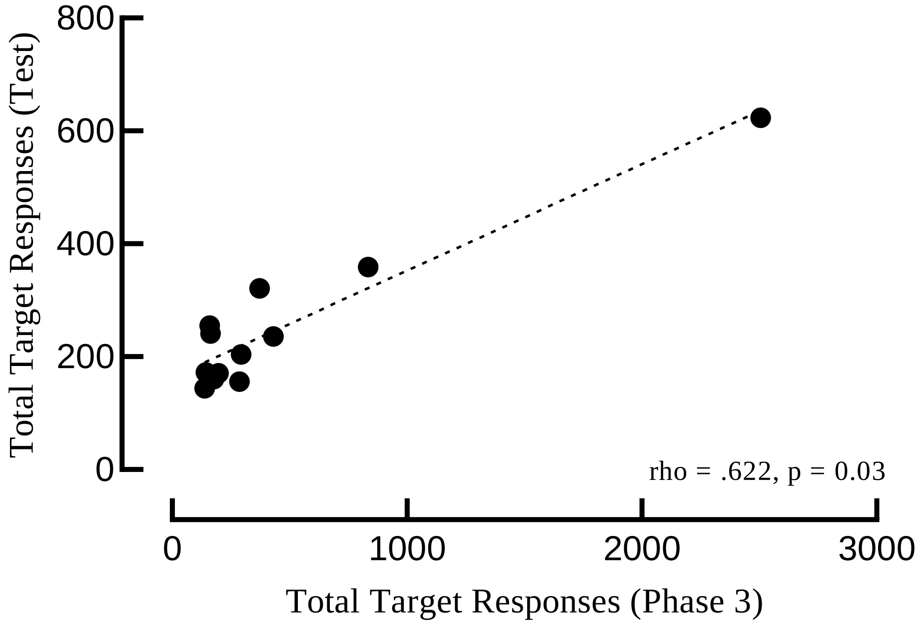


Figure 8. Spearman's Rho correlation of the number of target responses emitted in the alternative reinforcement and test phases during the three-phase procedure. A significant positive correlation was observed such that a greater number of target responses occurring during alternative reinforcement corresponded to a greater number of target responses (i.e., resurgence) during the test phase (r_s (10) = .622, p = 0.03)

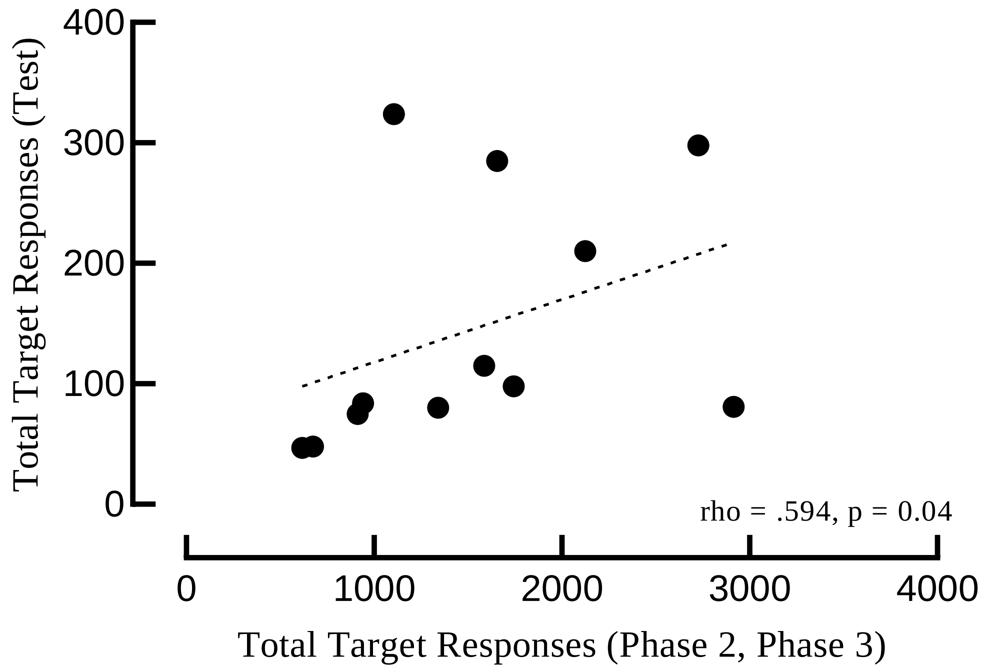


Figure 9. Spearman's Rho correlation of the number of target responses emitted during extinction (Phase 2), alternative reinforcement (Phase 3), and test phases during the four-phase procedure. A significant positive correlation was found in that a greater number of target responses occurring during both extinction and alternative reinforcement corresponded to a greater number of target responses (i.e., resurgence) during the test phase (r_s (10) = .594, p = 0.04)

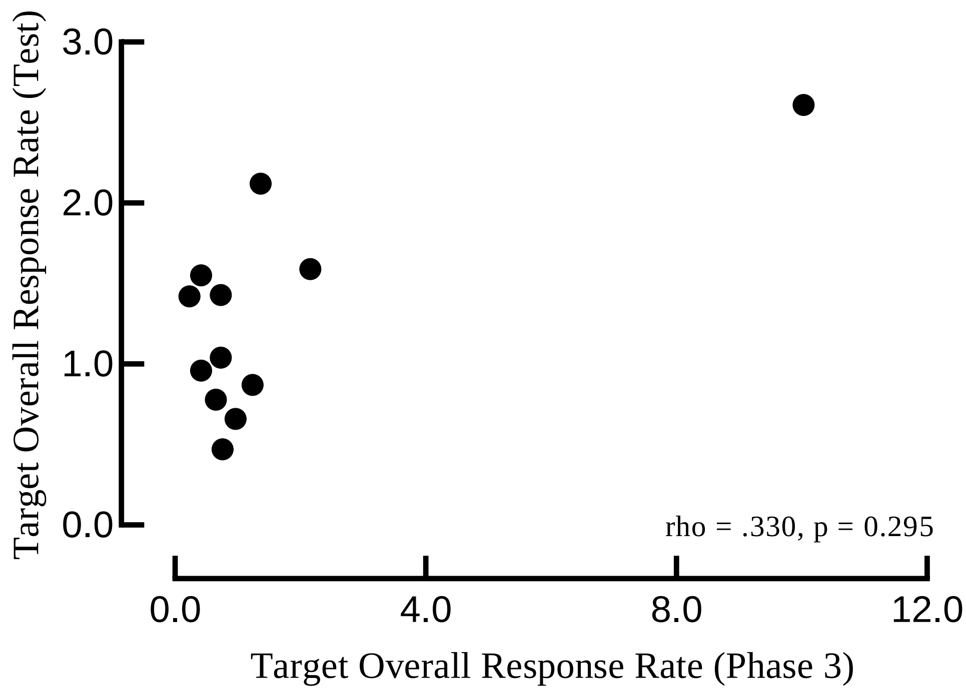


Figure 10. Spearman's Rho correlation of the average overall rate of target responding in the alternative reinforcement and test phases during the three-phase procedure. A non-significant correlation was observed (rs (10) = .330, p = 0.295).

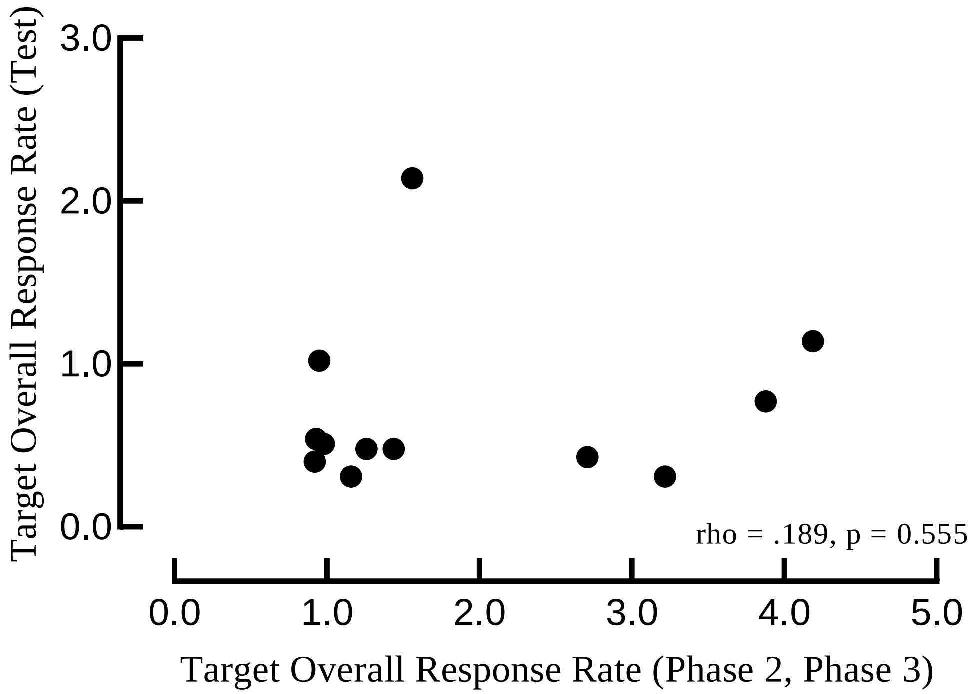


Figure 11. Spearman's Rho correlation of the average overall rate of target responding during Phase 2 (extinction), Phase 3 (extinction + alternative reinforcement), and test phase during the four-phase procedure. A non-significant correlation was observed (r_s (10) = .189, p = 0.555).

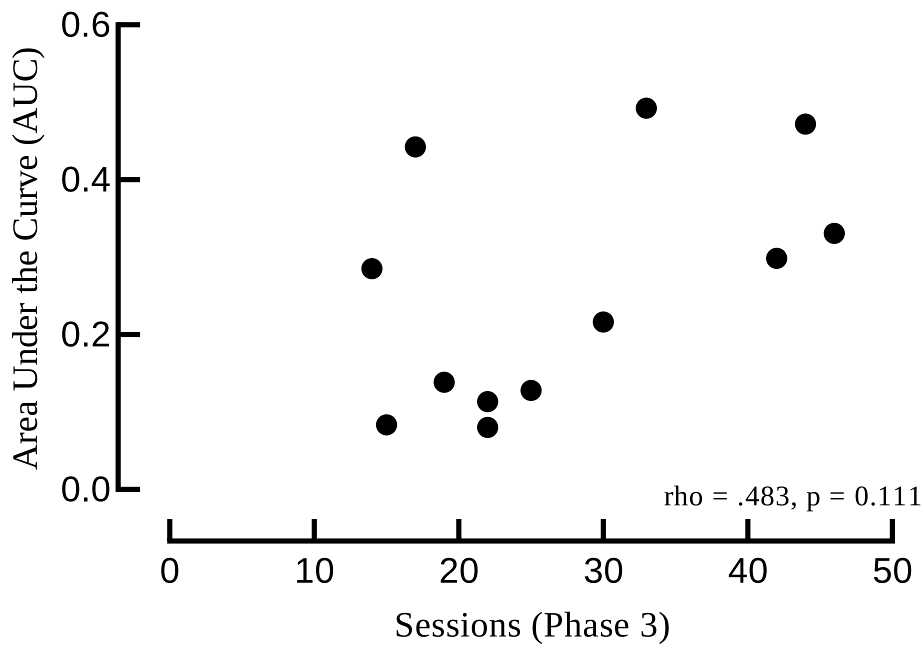


Figure 12. Spearman's Rho correlation of the duration of Phase 3 (extinction + alternative reinforcement) and resurgence (shown as AUC) in the test phases during the three-phase procedure. There was no significant correlation observed between phase duration and resurgence (*rs* (10) = .483, *p* = 0.111).

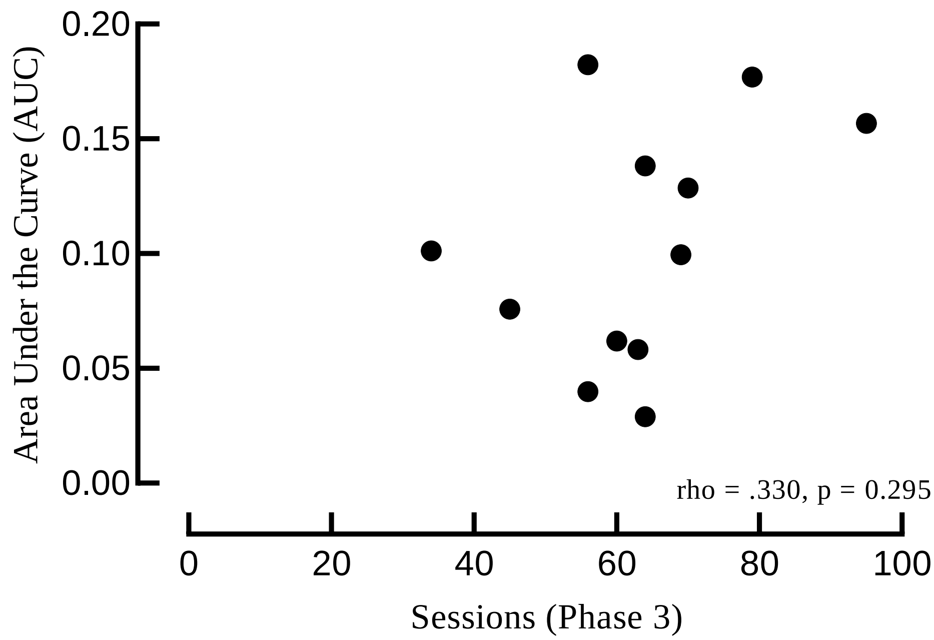


Figure 13. Spearman's Rho correlation of the duration of Phase 3 (extinction + alternative reinforcement) and resurgence (shown as AUC) in the test phases during the four-phase procedure. There was no significant correlation observed between phase duration and resurgence (r_s (10) = .330, p = 0.295).

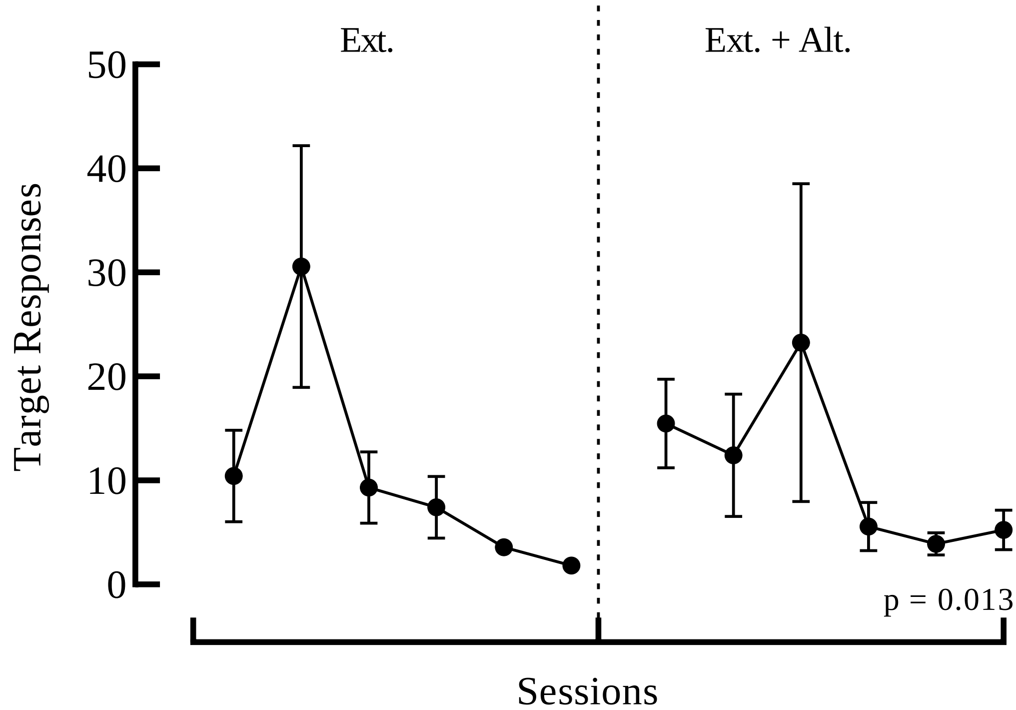
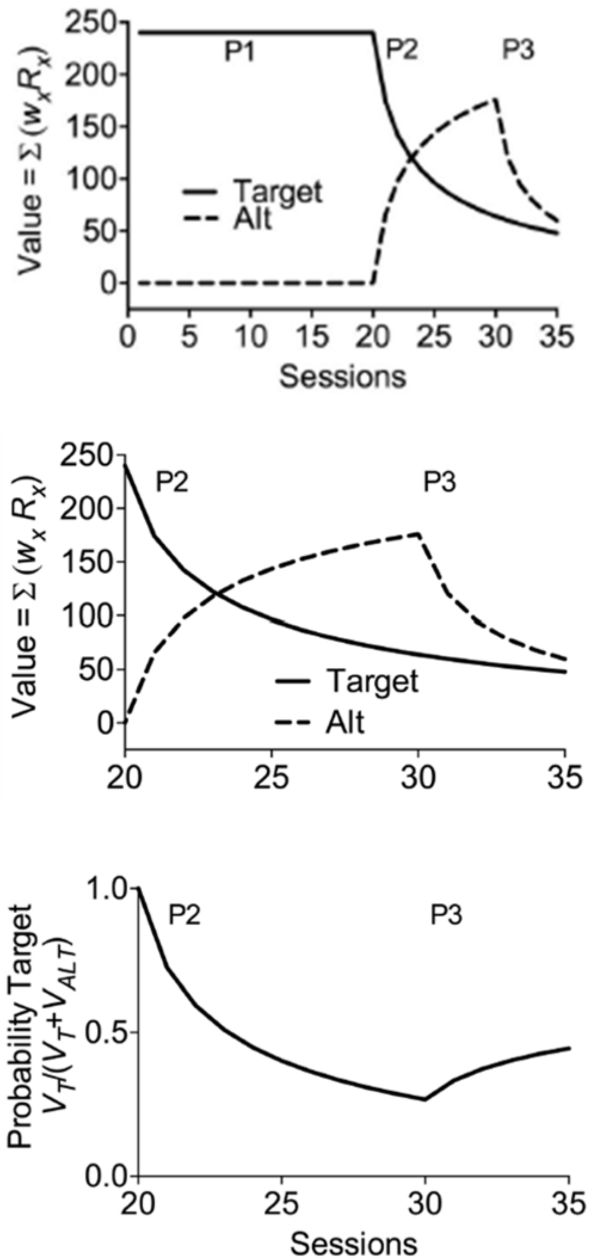


Figure 14. Average number of target responses emitted during the last six sessions of extinction (Phase 2) and alternative reinforcement (Phase 3) in the four-phase procedure. A Wilcoxon Signed Ranks Test showed a significant increase in target responding between the last session of extinction and the first session of alternative reinforcement in 10 of 12 animals (T = 70.05, n = 12, z = 2.47, p = 0.013).



(Shahan & Craig, 2017)

Figure 15. Changes to the valuation of target (V_T) and alternative responses (V_{ALT}) across phases as described by RaC (Shahan & Craig, 2017). During phase 1 (top panel), V_T is high as reinforcement is delivered for target responding. Upon extinction of the target response in phase 2 (middle panel), however, V_T declines and V_{ALT} increases as alternative reinforcement is delivered. During phase 3 (middle panel), V_{ALT} declines as the alternative response contacts extinction. V_T is carried through phases and is detected when V_{ALT} declines, resulting in an increase in *pT* (i.e., resurgence) during phase 3 (bottom panel).