Examination of alternative-response discrimination training and resurgence in rats

Kaitlyn O. Browning[1] · Timothy A. Shahan[1]

Abstract

Resurgence is an increase in a previously reinforced behavior following a worsening of conditions for a more recently reinforced behavior. Discrimination training is incorporated into treatment for problem behavior to prevent treatment adherence failures that may result in resurgence. There is evidence that resurgence may be reduced when a stimulus that signals alternative-response extinction is present compared with absent; however, the generality of this effect is unknown given the limited testing conditions. The goal of the present experiments was to further examine the effects of such stimuli in a reverse-translational evaluation using rats. Target responding was reinforced in baseline and then placed on extinction in the following discrimination-training phase. An alternative response was differentially reinforced in a two-component multiple schedule where one stimulus (i.e., S^D) signaled alternative-response reinforcement and the other (i.e., S^Δ) signaled extinction. Experiment 1 assessed resurgence in both the S^Δ and S^D when alternative reinforcement was removed. Experiment 2 evaluated resurgence under conditions that better approximated those used in the clinic in which the alternative-response S^Δ was present or absent. The S^Δ failed to suppress target responding during resurgence testing in both experiments. These findings suggest that the conditions under which an alternative-response S^Δ will successfully mitigate resurgence may be limited and require further research.

Keywords Resurgence · Discriminative stimulus · Operant behavior · Discrimination training · Rats

Individuals with neurodevelopmental disorders may engage in severe forms of problem behavior (Emerson et al., 2001; Harvey et al., 2009), and such behavior may threaten the safety and well-being of the individual and their caregivers (e.g., Iwata et al., 1994). The most commonly used and empirically validated treatment for problem behavior in this population is functional communication training (FCT; Durand & Moskowitz, 2015; Greer et al., 2018; Kurtz et al., 2011; Tiger et al., 2008). During FCT, the problem behavior is placed on extinction, and the client is taught an alternative functional communicative response (FCR) to request the reinforcer that had previously maintained the problem behavior. As a result, problem behavior decreases and rates of the FCR increase (e.g., Carr & Durand, 1985).

Despite the efficacy of FCT for reducing problem behavior, such behavior is susceptible to resurgence. Resurgence refers to the increase of a previously reinforced behavior following a worsening of conditions for a more recently reinforced alternative behavior (Epstein, 1985; Lattal & Wacker, 2015; Shahan & Craig, 2017). Resurgence of problem behavior may occur if the conditions of FCR reinforcement are worsened in some way. For example, resurgence of problem behavior has been observed following FCR extinction (e.g., Volkert et al., 2009), temporary failures in treatment adherence (e.g., Marsteller & St Peter, 2012; St. Peter Pipkin et al., 2010), and reductions in FCR reinforcement rate (e.g., Briggs et al., 2018). Thus, resurgence poses a serious concern for maintaining positive treatment effects. Importantly, research on resurgence is critical to the development of more effective treatment approaches for problem behaviors in clinical populations (Greer & Shahan, 2019; St. Peter, 2015).

In addition to evaluating resurgence during FCT in clinical settings, resurgence may be examined in the basic laboratory with nonhuman subjects such as rats or pigeons. Given the procedural similarities between those used in treatment and those used in the laboratory, such research has direct implications for the development of effective clinical treatments. In the laboratory, resurgence may be studied using a three-phase procedure. First, a target response is reinforced in baseline (e.g., pressing the right lever). Second, the target response is

✉ Kaitlyn O. Browning
  kaitlynobrowning@gmail.com

[1] Utah State University, 2810 Old Main Hill, Logan, UT 84321-2810, USA

placed on extinction while reinforcement is made available for an alternative behavior (e.g., pressing the left lever) in the treatment phase. Finally, resurgence of target responding may be assessed by placing the alternative response on extinction. Resurgence is evident if rates of the target response increase in the final phase relative to those at the end of the second phase (e.g., Craig & Shahan, 2016; Shahan et al., 2020; Winterbauer & Bouton, 2010). Given the clinical significance of resurgence, a considerable amount of research using both human participants and nonhuman subjects has been conducted to identify variables that may be used to mitigate this effect (Wathen & Podlesnik, 2018).

Several basic laboratory experiments have shown that alternating periods of alternative-response reinforcement with extinction during treatment reduces resurgence compared with treatment with constant alternative reinforcement (Schepers & Bouton, 2015; Shahan et al., 2020; Thrailkill et al., 2019; Trask et al., 2018; but see Sweeney & Shahan, 2013b). For example, Shahan et al. (2020) compared the effects of such on/off alternative reinforcement to constant alternative reinforcement available for a range of treatment durations. Resurgence systematically decreased across successive alternative-response extinction sessions and was significantly smaller compared with resurgence following all five durations of constant alternative reinforcement. To explain this effect, Shahan et al. (2020) expanded on previous arguments (i.e., Trask et al., 2018) that on/off alternative-reinforcement results in smaller resurgence effects as the result of improved discrimination of the current response-reinforcer contingencies signaled by the presence and absence of alternative reinforcers. Importantly, this conclusion suggests that improved discrimination of alternative response-reinforcer contingencies may be a promising variable in mitigating resurgence.

Discrimination of response-reinforcer contingencies is traditionally established through discrimination training. In discrimination training, a particular response is reinforced only in the presence of an S^D stimulus, and that response is extinguished in the presence of the S^Δ stimulus (e.g., Rilling, 1977). That is, the S^D signals that reinforcement *is* available for a particular response while the S^Δ signals that reinforcement *is not* available. Effective discrimination is evident by differential responding in the presence of these stimuli (e.g., Balsam, 1988), such that the behavior may occur more frequently in the presence of the S^D stimulus and less frequently in the presence of the S^Δ stimulus.

Importantly, there is evidence that stimuli paired with reinforcement or extinction may mitigate resurgence and other forms of behavioral relapse. For example, Craig, Browning, and Shahan (2017) observed reduced resurgence of lever pressing in rats when a discrete visual stimulus previously paired with target and alternative reinforcement (i.e., the light in the food aperture) was presented response dependently when the alternative response was placed on extinction during testing. Similarly, Trask (2019) found that presentation of a tone (response dependently or response independently) previously paired with both target–response extinction and alternative reinforcement mitigated resurgence of target responding in rats. Additionally, presentation of discrete stimuli associated with target-response extinction has also been shown to reduce other forms of relapse in rats, including reinstatement, spontaneous recovery (Bernal-Gamboa et al., 2017), and renewal (Nieto et al., 2017; Willcocks & McNally, 2014). However, a clear gap in this literature is evaluation of a stimulus paired with alternative-response extinction.

Alternative-response discrimination training is often incorporated into FCT in the clinic in order to increase the feasibility of treatment implementation and to reduce the risk of failures in treatment adherence. That is, the FCR is typically reinforced according to a dense schedule of reinforcement to facilitate response acquisition early in treatment; however, this may result in unmanageably high rates of responding. If the FCR occurs at a rate too high for the caregivers or therapists to consistently reinforce, the FCR may contact extinction resulting in resurgence. To reduce this possibility, discriminative stimuli may be used to differentially signal when FCR reinforcement is or is not available. This discrimination is typically established during FCT by use of a two-component multiple schedule in which the FCR is reinforced in one component signaled by the S^D and the FCR is extinguished in the other component signaled by the S^Δ, while problem behavior is placed on extinction in both components (Saini et al., 2016). The duration of the S^Δ component may also be increased to reduce the overall rate of FCR reinforcement to further control the rate of the FCR (e.g., Betz et al., 2013; Hanley et al., 2001).

Expanding on the discrete stimuli and relapse literature reviewed above, there is evidence to suggest that FCR discrimination training may be used to reduce resurgence. Two studies have demonstrated significant reductions in resurgence of destructive behavior in the presence of the FCR S^Δ stimulus following FCR discrimination training. The first study, Fuhrman et al. (2016) assessed resurgence of destructive behavior in two children following FCT with and without FCR discrimination training. During discrimination training, the FCR was reinforced in the S^D component (signaled by a green index card) and not in the S^Δ component (signaled by a red index card) of a two-component multiple schedule, and problem behavior was placed on extinction in both components. Resurgence was then tested during extended exposure to the S^Δ stimulus in which reinforcement for the FCR was never available. In the control condition, traditional FCT was conducted without discrimination training in which problem behavior was placed on extinction while the FCR was reinforced. Following this traditional FCT, resurgence was tested by placing the FCR on extinction and no discriminative stimuli were presented. Resurgence of destructive behavior was substantially reduced in the S^Δ condition following

FCT with discrimination training compared with resurgence following traditional FCT. These findings suggest that presentation of a stimulus that signals extinction of the alternative response may reduce or prevent resurgence of the target behavior.

It is important to note that one limitation of this study makes interpretation of their findings difficult. That is, the obtained rate of reinforcement for the FCR was lower in the discrimination FCT treatment condition compared with the traditional FCT condition. While Fuhrman et al. (2016) intentionally thinned the rate of reinforcement for the FCR by increasing the duration of the S^Δ component relative to the S^D component during discrimination training, there is substantial evidence to suggest that lower rates of alternative reinforcement generate less resurgence than higher rates when removed (Bouton & Trask, 2016; Craig et al., 2016; Craig & Shahan, 2016; Sweeney & Shahan, 2013a).

In a follow-up study, Fisher et al. (2020) extended these findings and addressed this limitation. Prior to treatment proper, FCR discrimination was trained using the multiple-schedule FCT procedure. That is, the FCR was reinforced in the S^D component but not in the S^Δ component, and the rate of FCR reinforcement was reduced by increasing the duration of the S^Δ component. Following this pretraining, FCT was evaluated in two separate contexts using a multielement design. The overall FCT procedures were identical across contexts such that problem behavior was reinforced during baseline, problem behavior was extinguished while the FCR was reinforced during treatment, and resurgence was tested by placing the FCR on extinction. The contexts differed by the presence or absence of the discriminative stimuli previously established in pretraining. In the first context, only the S^D stimulus was presented during the treatment phase, and only the S^Δ stimulus was presented during resurgence testing. In the second context, the discriminative stimuli were not present during treatment or testing. Importantly, the researchers controlled for the rate of FCR reinforcement across contexts. Consistent with the findings of from the initial study, resurgence of destructive behavior was substantially reduced in the presence of the S^Δ stimulus compared with in its absence. Because Fisher et al. (2020) controlled for the rate of alternative reinforcement across conditions, this experiment provides more compelling evidence that resurgence may be prevented by a stimulus that signals extinction of the alternative response.

However, given the limited testing conditions, the generality of these findings is unknown. That is, Fuhrman et al. (2016) and Fisher et al. (2020) assessed resurgence only in the presence and absence of the alternative-response S^Δ and did not include tests under S^D conditions. Thus, it is not surprising that resurgence did not occur under conditions in which the alternative response was never reinforced. To extend these findings, the procedures reported in Fuhrman et al.

(2016) and Fisher et al. (2020) were approximated in two reverse-translational experiments. The purpose of Experiment 1 was to determine whether resurgence would be mitigated in the S^Δ if the alternative response contacts extinction under conditions in which it was previously reinforced (i.e., the S^D). The purpose of Experiment 2 was to evaluate resurgence in the presence of the S^D alone, the S^Δ alone, and in the absence of discriminative stimuli altogether and to compare these to the multiple-schedule test condition of Experiment 1.

Experiment 1

The purpose of Experiment 1 was to determine whether resurgence would be mitigated in the presence of the alternative-response S^Δ stimulus if the alternative response is also placed on extinction in the presence of the S^D stimulus that had previously signaled availability of alternative reinforcement. The general procedures reported by Fuhrman et al., (2016) and Fisher et al. (2020) were approximated in a reverse-translational experiment with rats as subjects. Following baseline in which target lever pressing was reinforced, rats received discrimination training in which alternative lever pressing was reinforced in one component of a multiple schedule signaled by the S^D stimulus and extinguished in the second component signaled by the S^Δ stimulus, while target lever pressing was placed on extinction in both. In the final phase, resurgence of target responding was examined in the presence of both S^Δ and S^D when the alternative response was also placed on extinction in the S^D component.

Method

Subjects

Five experimentally naïve male Long-Evans rats served as subjects. Rats were approximately 71–90 days old upon arrival and were individually housed in a temperature and humidity controlled colony room with a 12:12/hr light–dark cycle (lights on at 7:00 a.m.). Throughout the experiment rats had ad libitum access to water in the home cages and were maintained at 80% of their free-feeding weights by supplemental postsession feeding. All experimental procedures described below were conducted in accordance with Utah State University's Institutional Animal Review Committee guidelines.

Apparatus

Five identical Med Associates (St. Albans, VT) operant chambers were used. Chambers measured 30 cm × 24 cm × 21 cm and were housed in sound and light attenuating cubicles. Each

chamber was constructed of two aluminum side panels, and a clear Plexiglas ceiling, door, and back wall. Two retractable levers on the right-side panel, with stimulus lights above them, were positioned on either side of a food receptacle that was illuminated when 45-mg grain-based food pellets (Bio Serv, Flemington, NJ) were delivered. A house light positioned at the top center of the left-side panel was used for general chamber illumination. A 2900 Hz tone generator positioned to the right of the house light was used to emit a 65-dB tone. A white noise generator positioned adjacent to the chamber cubicles was used to emit white noise and mask extraneous sound during each experimental session. All experimental events and data collection were controlled by Med-PC software run on a computer in an adjacent control room.

Procedure

Experimental sessions were conducted seven days per week during the light cycle at approximately the same time each day. All sessions were at least 30 min, excluding time for reinforcement delivery with the exception that session time during the discrimination training and test phases could exceed 30 min (see below). During reinforcement deliveries, all experimental timers were paused for 4 s, the pellet dispenser dropped a single food pellet into the illuminated food receptacle, the lever stimulus lights darkened, and, when applicable, the discriminative stimuli remained present.

Training Rats were first trained to consume pellets from the lit food aperture for three 30-min sessions. Food pellets were delivered response independently according to a variable time (VT) 60-s schedule, such that a single food pellet was delivered, on average, every 60 s. The VT schedule and all variable-interval (VI) schedules described below consisted of 10 intervals derived from Fleshler and Hoffman's (1962) constant-probability distribution. Levers remained retracted and lever-stimulus and house lights were darkened throughout training.

Phase 1: Baseline Sessions during baseline began with insertion of the target lever (right–left, counterbalanced across rats) and illumination of the target-lever stimulus light. To facilitate target-response acquisition, the first response in the first Baseline session immediately produced a food pellet (i.e., fixed-ratio 1 schedule). Thereafter, target responding was reinforced according to a VI 30-s schedule, such that a single food pellet was delivered following the target response, on average, every 30 s, for the remainder of the session and phase. This phase lasted 20 sessions.

Phase 2: Target extinction + alternative discrimination training Sessions during this phase began with insertion of both the target and alternative levers and illumination of both lever stimulus lights. A two-component multiple schedule,

comprised of an S^D and an $S^\triangle$ component, was used to train alternative-response discrimination. Components were signaled by either a constant house light and tone or flashing house light and pulsing tone (on/off every 0.5 s), counterbalanced across rats. Responses to the alternative lever were reinforced according to a VI 5 s schedule in the S^D component and were placed on extinction in the $S^\triangle$ component. Target responding was extinguished in both components. The VI timer only counted down during the S^D component, and if the VI timer did not elapse before the end of the S^D component, it was paused until the next S^D presentation, thereafter the timer continued. Additionally, if the VI timer elapsed and the rat did not earn the food pellet before the end of the S^D component, the food could not be earned until the next S^D component began. Each component was presented 15 times in strict alternation for a total of 30 component presentations per session, and component durations ranged from 10 to 110 s, averaging 1 min (components were programed in this manner based on previous research from our lab, see Shahan, 2002). In the first session, the S^D component was presented first, and the first alternative lever press immediately produced a food pellet, after which the VI timer began and components strictly alternated. During all subsequent sessions, the first component was selected with $p = .50$. A 3-s change over delay (COD) in the $S^\triangle$ component was arranged such that any alternative response made in the final 3 s of the $S^\triangle$ component delayed transition to the S^D component until an alternative response was not made for 3 s. The COD was included to avoid adventitious reinforcement of alternative responding in the $S^\triangle$ component by transition to the S^D component. Thus, time in $S^\triangle$ could exceed time in S^D, depending on individual rat's performance. This phase lasted 25 sessions.

Phase 3: Test Sessions during the Test phase were identical to those in the previous phase, with the exception that the alternative response was no longer reinforced in the S^D component. Thus, target and alternative behaviors were assessed during extinction during both the S^D and $S^\triangle$ components. This phase lasted five sessions.

Data analyses The primary dependent variables were target and alternative responses per min across sessions and between components. Additionally, a discrimination index (DI) was calculated to evaluate alternative response discrimination in each session of Phases 2 and 3 by dividing alternative responses in the S^D component by total alternative responses in the S^D and $S^\triangle$ components. For all analyses, the within-subject factors were session and component, and there was no between-subjects factor. Statistical significance was determined using $\alpha = .05$ and a Bonferroni adjustment was applied to all simple effects follow-up analyses.

Results

Table 1 provides a summary of mean response rates, discrimination indices, and reinforcer rates across phases.

Phase 1: Baseline

Target response rates increased across sessions of Phase 1 for all rats to an average of 24.21 responses per min (see Table 1).

Phase 2: Target extinction + alternative discrimination training

The top panel of Fig. 1 displays mean alternative response rates in the S^D and S^Δ components across sessions of Phase 2. A 2×25 (Component × Session) repeated-measures ANOVA conducted on these data revealed significant effects of Component, $F(1, 4) = 18.93$, $p = .01$, $\eta_p^2 = .83$, and Session, $F(24, 96) = 8.71$, $p < .001$, $\eta_p^2 = .69$, and a significant Component × Session interaction, $F(24, 96) = 8.06$, $p < .001$, $\eta_p^2 = .67$. A simple effects test conducted following the significant interaction revealed that alternative responding did not differ between S^D and S^Δ components in the first session of Phase 2 ($p = .21$) but responding was higher in the S^D relative to the S^Δ component in the final session ($p = .008$). These results suggest that alternative responding increased across sessions in the S^D component and remained relatively low in the S^Δ component.

Table 1 displays the average alternative-response DI from the last session of Phase 2. A DI greater than 0.50 indicates that responding was proportionally higher in the S^D component than in the S^Δ component. A one-sample t test conducted
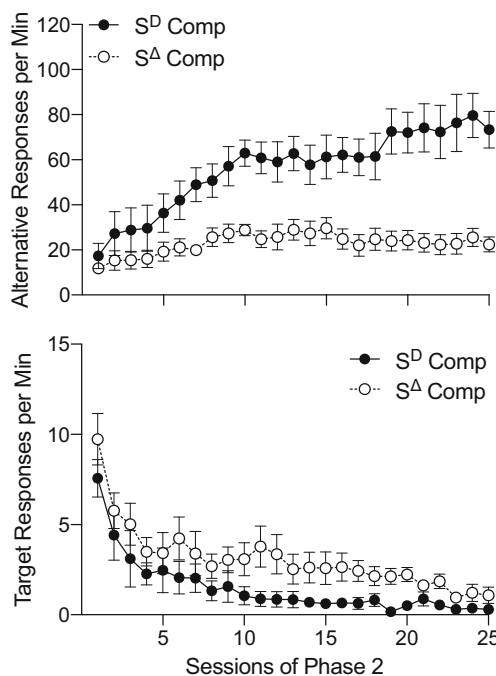

Fig. 1 Mean alternative (top panel) and target (bottom panel) responses per min in the S^D and S^Δ components across sessions of Phase 2 in Experiment 1. Error bars represent standard error of the mean

on these data against the test value of 0.50 suggested that the proportion of responding in the S^D was significantly greater than 0.50, $t(4) = 5.45$, $p = .003$, $d = 2.43$. Taken together, the data in the top panel of Fig. 1 and the alternative-response DIs suggest that rats effectively allocated alternative responding according to the arranged discriminative stimuli.

The bottom panel of Fig. 1 displays mean target response rates in the S^D and S^Δ components across sessions of Phase 2. A 2×25 (Component × Session) repeated-measures ANOVA conducted on these data revealed significant effects of Component, $F(1, 4) = 18.98$, $p = .01$, $\eta_p^2 = .83$, and Session, $F(24, 96) = 14.66$, $p < .001$, $\eta_p^2 = .79$, and a nonsignificant Component × Session interaction, $F(24, 96) = 1.33$, $p = .17$, $\eta_p^2 = .25$. Simple effect tests conducted following the significant effects of Session and Component revealed that target responding was lower in the final session of this phase relative to the first ($p = .002$), regardless of component, and was overall higher in the S^Δ compared with the S^D component ($p = .01$), regardless of session. Thus, target responding decreased across sessions of Phase 2 in both components but remained generally elevated in the S^Δ component (see Table 1 for Phase 2 terminal target response rates in both components).

Phase 3: Test

Figure 2 displays mean target response rates during the last session of Phase 2 and the first session of Phase 3 in the S^D and S^Δ components. A 2×2 (Component × Session)

Table 1 Mean (SEM) target and alternative response rates, discrimination indices, and reinforcer rates across phases of Experiment 1

| | Phase | | | | |
| | P1[a] | P2[b] | | P3[c] | |
		S^D	S^Δ	S^D	S^Δ
Target/min	24.21	0.29	1.09	2.00	3.23
SEM	*5.05*	*0.26*	*0.45*	*0.46*	*0.54*
Alt./min	–	73.33	22.45	26.94	10.82
SEM	–	*8.16*	*3.27*	*2.01*	*2.35*
DI	–		0.75		0.72
SEM	–		*0.05*		*0.03*
Rein./min	1.75	9.73	–	–	–
SEM	*0.05*	*0.39*	–	–	–

[a] Data from the average last three sessions of Phase 1 are shown

[b] Data from the last session of Phase 2 are shown

[c] Data from the first session of Phase 3 are shown

repeated-measures ANOVA conducted on these data revealed a significant effect of Component, $F(1, 4) = 14.76$, $p = .012$, $\eta_p^2 = .79$, and Session, $F(1, 4) = 18.09$, $p = .01$, $\eta_p^2 = .82$, and a nonsignificant Component × Session interaction, $F(1, 4) = 0.37$, $p = .58$, $\eta_p^2 = .08$. Simple effects tests conducted following the significant effects of Session and Component revealed that target responding increased between the last session of Phase 2 and the first session of Phase 3 ($p = .01$), regardless of component, and that responding was overall higher in the S^Δ compared with the S^D component ($p = .02$), regardless of session. Thus, resurgence was evident in both components but the overall level of responding differed between components.

The top panel of Fig. 3 displays mean target response rates in the S^D and S^Δ components across all sessions of Phase 3. A 2 × 5 (Component × Session) repeated-measures ANOVA conducted on these data revealed nonsignificant effects of Component, $F(1, 4) = 2.58$, $p = .18$, $\eta_p^2 = .39$, and Session, $F(4, 16) = 2.83$, $p = .06$, $\eta_p^2 = .41$, and a significant Component × Session interaction, $F(4, 16) = 3.63$, $p = .03$, $\eta_p^2 = .48$. Simple effects tests conducted following the significant interaction revealed that target responding was higher in the S^Δ compared with S^D component in session 2 ($p = .03$) but the difference between components did not reach significance in the remaining sessions ($p \geq .09$). Thus, there is not strong evidence to support differential target-response persistence across sessions of Phase 3.

The bottom panel of Fig. 3 displays mean alternative response rates across sessions of Phase 3. A 2 × 5 (Component × Session) repeated-measures ANOVA conducted on these data revealed significant effects of Component, $F(1, 4) = 49.64$, $p = .002$, $\eta_p^2 = .93$, and Session, $F(4, 16) = 32.23$, $p < .001$, $\eta_p^2 = .89$, and a significant Component × Session interaction, $F(4, 16) = 15.06$, $p < .001$, $\eta_p^2 = .79$. Simple effects tests conducted following the significant interaction revealed that alternative responding was higher in the S^D compared with the S^Δ component in the first ($p < .001$) and final ($p = .04$) sessions of Phase 3 and the mean difference between components was
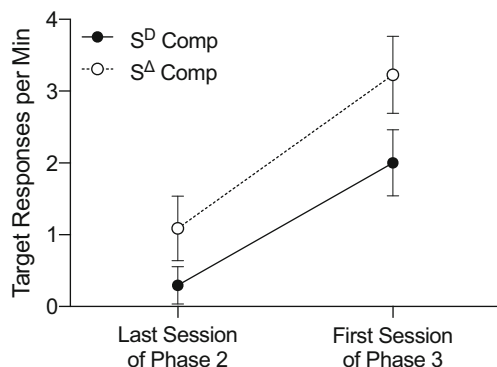

Fig. 2 Mean target responses per min in the last session of Phase 2 and the first session of Phase 3 in the S^D and S^Δ components in Experiment 1. Error bars represent standard error of the mean.
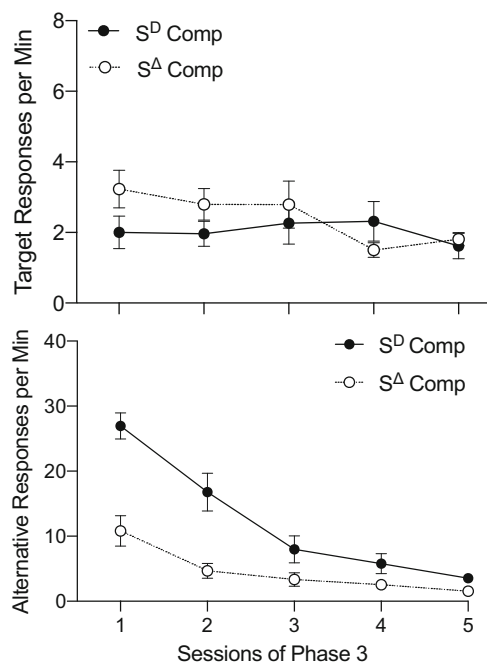

Fig. 3 Mean target (top panel) and alternative (bottom panel) responses per min across sessions of Phase 3 in the S^D and S^Δ components in Experiment 1. Error bars represent standard error of the mean

greater at the beginning of the phase ($MD = 16.12$, 95% CI [12.60, 19.64]) compared with the end ($MD = 2.00$, 95% CI [0.13, 3.87]). Thus, alternative responding was initially more elevated and subsequently decreased across sessions of Phase 3 in the S^D component compared with the S^Δ component.

To evaluate whether the alternative-response DI was significantly greater than 0.50 in Phase 3, DIs were first averaged across sessions of Phase 3 ($M = 0.71$, $SEM = 0.04$) to avoid conducting multiple analyses across sessions. Then, a one-sample t test was conducted on these data against the test value of 0.50. Alternative responding continued to be proportionally greater in the S^D component in Phase 3, $t(4) = 4.98$, $p = .008$, $d = 2.23$, (see Table 1 for alternative response rates and corresponding DIs in the first session of Phase 3). Thus, even in the absence of reinforcer deliveries in the S^D component during the resurgence test, rats continued to discriminate between the S^D and S^Δ components.

Discussion

The purpose of Experiment 1 was to determine whether an alternative-response S^Δ would mitigate resurgence if the alternative response is also placed on extinction in the presence of the S^D that had previously signaled alternative reinforcement availability. Following baseline in which target responding was reinforced, the target response was placed on extinction and discrimination of the alternative response was trained in a two-component multiple schedule in which alternative responding was reinforced in the S^D component

and extinguished in the S^{Δ} component. Resurgence of target responding was then assessed in both components by placing the alternative response on extinction in the S^D component.

Resurgence was observed in both components and was not reduced in the S^{Δ} component compared with in the S^D component. While it is not surprising that resurgence occurred following alternative-response extinction in the S^D component, it is unclear why resurgence occurred in the S^{Δ} component in which alternative reinforcement was never available. It seems unlikely that resurgence occurred in the S^{Δ} component as a result of failure to effectively discriminate the stimuli arranged in Phase 2 given that alternative responding was differentially allocated across components during discrimination training, as measured by the DI. While it is possible that rats allocated behavior according to the signaling effects of the presence and absence of alternative reinforcement, the fact that the DI remained above indifference when alternative reinforcers were removed in Phase 3 suggests that the discriminative stimuli were contributing to response allocation to some extent.

Instead, resurgence may have occurred in the S^{Δ} component as a result of the multiple schedule used during testing. That is, Fuhrman et al. (2016) and Fisher et al. (2020) evaluated resurgence in the presence or absence of *only* the S^{Δ} stimulus, and while the purpose of Experiment 1 was to compare resurgence in both S^D and S^{Δ} components, it is possible that this difference contributed to the discrepant findings. It is well established that manipulating the reinforcement rate in one component of a multiple schedule can impact the response rate in the other component (e.g., Williams, 1983). Specifically, positive contrast refers to when behavior increases in an unchanged component following a decrease in the rate of reinforcement in the altered component (Reynolds, 1961a, 1961b). Thus, removing alternative reinforcement in one component of the multiple schedule in Phase 3 may have resulted in positive contrast.

In further support of this possibility, there is evidence to suggest that contrast effects may occur across concurrently available response options within a multiple schedule. For example, Catania (1961) evaluated contrast effects in concurrent multiple schedules using pigeons. Following a baseline in which pigeons earned food for pecking concurrently available red and green keys, a multiple schedule was introduced in which pecking the green key was placed on extinction in the first component and reinforced in the second component, while pecking the red key was reinforced in both components. Not surprisingly, green-key pecking in the unchanged component increased when extinction of green-key pecking was introduced in the first component. Interestingly, pecking the red key in the unchanged component also increased despite no changes in the contingencies for that response. These findings suggest that contrast effects may not be isolated to only the response in which the contingency was altered but may have a more general impact on behavior allocation within multiple schedules.

Based on these data, it may be the case that the increase in target responding in the S^{Δ} component following extinction of the alternative response in the S^D component in Phase 3 was the result of positive contrast. That is, target responding increased in the unchanged S^{Δ} component following a decrease in the rate of reinforcement for the alternative response (i.e., VI 5 s to extinction) in the altered S^D component. In fact, there is evidence that resurgence may be related to behavioral contrast. For example, Pyszczynski and Shahan (2013) observed resurgence of alcohol seeking in one component of a multiple schedule following extinction of food-maintained responding in the second component using rats. Following a baseline in which lever pressing produced alcohol in one component and chain pulling produced food in the second component, lever pressing was placed on extinction in the alcohol component in Phase 2. In the final phase, chain pulling was also placed on extinction in the food component and lever pressing in the alcohol component subsequently increased. The authors suggested that the resurgence effect observed in the alcohol component may have been the result of positive contrast.

Whether or not behavioral contrast contributed to our results, these data suggest that an S^{Δ} stimulus may not mitigate resurgence if alternative-response extinction also occurs in the presence of the S^D stimulus under multiple-schedule conditions. Taken together, the findings of Experiment 1 and those of the previous applied research in which resurgence was not observed when the S^{Δ} was presented alone pose the question of what the necessary and sufficient conditions under which an S^{Δ} will mitigate resurgence are.

Experiment 2

The purpose of Experiment 2 was to evaluate resurgence in the presence of the S^D and S^{Δ} in isolation and in the absence of discriminative stimuli altogether and to directly compare the effects of these conditions with the multiple-schedule test condition of Experiment 1. As in Experiment 1, target responding was reinforced in the first phase, and alternative response discrimination training and target-response extinction occurred in the second phase. Resurgence of target responding was assessed in the third phase across four groups of rats: three single-stimulus test groups and one multiple-stimulus test group. For the three single-stimulus tests, resurgence testing occurred in the presence of only the S^{Δ} stimulus (i.e., S^{Δ} Alone group), in the presence of only the S^D stimulus (i.e., S^D Alone group), or in the *absence* of both S^{Δ} and S^D stimuli (i.e., the No Stim group). For the Mult Stim group, resurgence testing occurred as in Experiment 1, in which resurgence was evaluated in both S^{Δ} and S^D components by

placing the alternative response on extinction in the S^D component.

Method

Subjects

Twenty-eight experimentally naïve male Long-Evans rats served as subjects. Rats were housed and cared for under the same conditions as in Experiment 1.

Apparatus

Five identical Med Associates operant chambers in addition to the five chambers from Experiment 1 were used.

Procedure

Experimental sessions were conducted in the same manner as in Experiment 1.

Training, Phase 1: Baseline, and Phase 2: Target extinction + alternative discrimination training The procedures used in the training, and Phases 1 and 2 were identical to those described in Experiment 1 for rats in all groups. In brief, target lever pressing was reinforced on a VI 30-s schedule in Phase 1 for 20 sessions and then placed on extinction in Phase 2. During discrimination training, a two-component multiple schedule was introduced in which alternative lever pressing was reinforced on a VI 5-s schedule in the S^D component and extinguished in the S^Δ component. Components were differentially signaled by either a constant house light and tone or flashing house light and pulsing tone (on/off every 0.5 s), counterbalanced across rats. Phase 2 lasted 25 sessions.

Phase 3: Test Prior to the start of this phase, rats were divided into four equal groups ($n = 7$) such that target response rates during the last three sessions of Phase 1 and the last three sessions of Phase 2 (within component) were not statistically different between groups. For all groups, sessions during this phase began as in Phase 2 (i.e., insertion of both the target and alternative levers and illumination of both lever lights). The target response remained on extinction and the alternative response was also placed on extinction for all groups, but the particular discriminative stimulus conditions present varied by group. The S^Δ Alone, S^D Alone, and No Stim groups were tested under single-stimulus conditions, and the Mult Stim group was tested under the same multiple-stimulus conditions as in Phase 2. Specifically, the S^Δ stimulus established in discrimination training was presented continuously for the duration of the session for the S^Δ Alone group, the S^D stimulus was presented continuously for the S^D Alone group, and all alternative-response discriminative stimuli were absent for the No Stim group. For example, the flashing house light and pulsing tone stimuli may have served as the S^Δ stimulus and the constant house light/tone stimuli may have served as the S^D stimulus for a particular rat. If this rat was assigned to the S^Δ Alone group, the house light and tone would flash/pulse for the duration of the session, but if this rat was assigned to the S^D Alone group, the house light and tone would remain on for the duration of the session. The house light and tone remained off for the duration of the session in the No Stim Test group, regardless of previous discriminative stimulus assignment. This phase lasted five sessions.

Data analyses The primary dependent variables were target and alternative responses per min across sessions and between groups and components. Additionally, a discrimination index (DI) was calculated as in Experiment 1 to evaluate differential alternative-response allocation between discriminative stimuli during Phase 2 for all groups and during Phase 3 for the Mult Stim group. Greenhouse–Geisser corrections to degrees of freedom were applied when Mauchly's test indicated a violation of sphericity for the within-subject factors in the analyses of variance (ANOVA). For all analyses, the within-subject factors included session and component, and the between-subject factor was group/test condition. Statistical significance was determined using $\alpha = .05$ and a Bonferroni adjustment was applied to all simple effects tests.

Results

Table 2 provides a summary of mean response rates, discrimination indices, and reinforcer rates across phases for each group.

Phase 1: Baseline

Target responses per min increased across sessions of baseline to comparable levels for all groups. A one-way ANOVA conducted on the average target response rate from the last three sessions of baseline confirmed that there was no difference between groups, $F(3, 24) = 0.04$, $p = .99$, $\eta_p^2 < .01$ (see Table 2).

Phase 2: Target extinction + alternative discrimination training

The top panel of Fig. 4 displays alternative response rates in the S^D and S^Δ components across sessions of Phase 2 for all groups. A $25 \times 2 \times 4$ (Session × Component × Group) mixed-model ANOVA conducted on these data revealed significant effects of Session, $F(2.54, 61.06) = 41.53$, $p < .001$, $\eta_p^2 = .63$, and Component, $F(1, 24) = 141.36$, $p < .001$, $\eta_p^2 = .85$, and a significant Session × Component interaction, $F(2.64, 63.36) = 36.39$, $p < .001$, $\eta_p^2 = .60$. The effect of Group, $F(3, 24) =$

Table 2 Mean (*SEM*) target and alternative response rates, discrimination indices, and reinforcer rates for each group across phases of Experiment 2

	Group																		
	Mult Stim					S^D Alone				S^Δ Alone				No Stim					
	P1[a]	P2[b]		P3[c]		P1[a]	P2[b]		P3[c]	P1[a]	P2[b]		P3[c]	P1[a]	P2[b]		P3[c]		
		S^D	S^Δ	S^D	S^Δ		S^D	S^Δ			S^D	S^Δ			S^D	S^Δ			
Target/min	26.26	0.27	3.04	4.10	3.48	28.64	0.77	2.06	3.26	27.70	0.70	2.84	3.84	26.74	0.73	3.26	4.92		
SEM	6.29	0.06	0.93	0.95	0.56	4.36	0.28	0.59	0.97	3.70	0.40	1.33	1.43	6.95	0.30	1.25	1.83		
Alt./min	–	92.50	32.47	28.97	11.96	–	82.62	30.40	19.60	–	83.34	30.74	22.68	–	86.05	28.83	16.95		
SEM	–	14.75	4.48	2.23	2.52	–	8.29	5.47	3.83	–	10.49	5.16	3.60	–	16.50	6.95	3.71		
DI	–	0.72		0.72		–	0.72		–	–	0.72		–	–	0.74		–		
SEM	–	0.03		0.05		–	0.05		–	–	0.02		–	–	0.02		–		
Rein./min	1.77	10.21	–	–	–	1.81	10.06	–	–	1.79	10.25	–	–	1.78	9.96	–	–		
SEM	0.05	0.29	–	–	–	0.02	0.24	–	–	0.03	0.21	–	–	0.05	0.48	–	–		

[a] Data from the average last three sessions of Phase 1 are shown

[b] Data from the last session of Phase 2 are shown

[c] Data from the first session of Phase 3 are shown

0.12, $p = .95$, $\eta_p^2 = .01$, and the Session × Group, $F(7.63, 61.06) = 0.74$, $p = .94$, $\eta_p^2 = .09$, Component × Group, $F(3, 24) = 0.14$, $p = .93$, $\eta_p^2 = .018$, and Session × Component ×

Fig. 4 Mean alternative (top panel) and target (bottom panel) responses per min in the S^D (closed symbols and solid lines) and S^Δ (open symbols and dashed lines) components across sessions of Phase 2 for each group in Experiment 2. All groups depicted experienced the same multiple schedule conditions during Phase 2 presented here and the group names refer to conditions that only differed in the following Phase-3 test presented in subsequent figures. Error bars represent standard error of the mean

Group, $F(7.92, 63.36) = 0.50$, $p = .99$, $\eta_p^2 = .06$, interactions were not significant. Simple effects tests conducted following the significant interaction revealed that alternative responding was significantly higher in the S^D component in both the first ($p < .001$) and final sessions of Phase 2 ($p < .001$), but the mean difference between components was greater at the end of the phase ($MD = 55.20$, 95% CI [44.69, 66.35]) than the beginning ($MD = 4.85$, 95% CI [2.88, 6.82]). These results suggest that alternative responding increased across sessions to a higher level in the S^D component and remained relatively low in the S^Δ component, and this pattern did not vary by group (see Table 2 for Phase-2 terminal response rates). The lack of differences across groups was expected given that all groups were exposed to the same conditions in this phase.

Table 2 displays the alternative-response discrimination index (DI) for each group in the last session of Phase 2. A DI greater than 0.50 indicates that responding was proportionally higher in the S^D component than in the S^Δ component. To evaluate whether the DI for the last session of Phase 2 was significantly greater than 0.50, a one-way ANOVA was first conducted on these data to ensure no group differences, $F(3, 24) = 0.13$, $p = .94$, $\eta_p^2 = .02$. Then, DIs were collapsed across groups to avoid conducting multiple analyses and a one-sample t-test was conducted on these data against the test value of 0.50. Alternative responding was proportionally higher in the S^D component than in the S^Δ component at the end of this phase, $t(27) = 15.18$, $p < .001$, $d = 2.87$. Taken together, the data in the top panel of Fig. 4 and the alternative-response DIs suggest that rats effectively
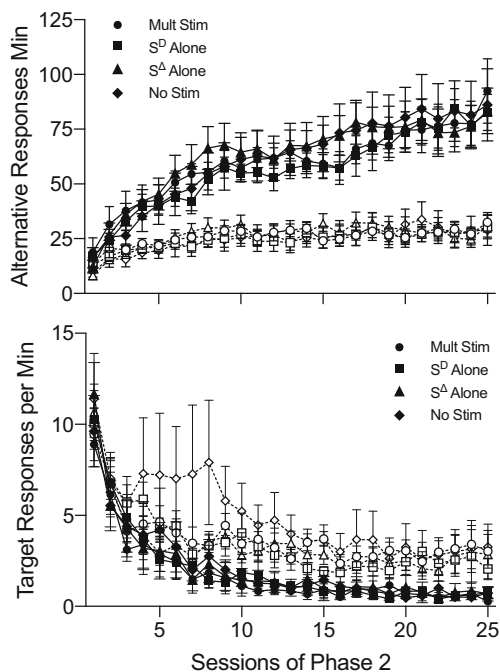
allocated alternative responding according to the arranged discriminative stimuli.

The bottom panel of Fig. 4 displays target response rates in the S^D and S^Δ components across sessions of Phase 2 for each group. A 25 × 2 × 4 (Session × Component × Group) mixed-model ANOVA conducted on these data revealed significant effects of Session, $F(3.28, 78.74) = 36.47$, $p < .001$, $\eta_p^2 = .60$, Component, $F(1, 24) = 27.80$, $p < .001$, $\eta_p^2 = .54$, and a significant Session × Component interaction, $F(5.08, 122.03) = 3.18$, $p = .009$, $\eta_p^2 = .12$. The effect of Group, $F(3, 24) = 0.35$, $p = .79$, $\eta_p^2 = .04$, and the Session × Group, $F(9.84, 78.74) = 0.63$, $p = .78$, $\eta_p^2 = .07$, Component × Group, $F(3, 24) = 0.87$, $p = .47$, $\eta_p^2 = .10$, and Session × Component × Group, $F(15.25, 122.03) = 1.03$, $p = .43$, $\eta_p^2 = .11$, interactions were not significant. Simple effects tests conducted following the significant Session × Component interaction revealed that target responding did not differ between components in the first session of Phase 2 ($p = .64$) but was significantly higher in the S^Δ compared with the S^D component in the final session ($p < .001$). These results suggest that target responding decreased relatively more in the S^D component (in which reinforcement was available for the alternative response) and was elevated in the S^Δ component (in which reinforcement for the alternative response was not available) at the end of this phase.

Phase 3: Test

Figure 5 displays target response rates in the last session of Phase 2 and the first session of Phase 3 across stimuli and groups. The left panel displays response rates in the S^D and S^Δ components during the last session of Phase 2 and the first session of Phase 3 for the Mult Stim group. The right panel displays response rates in the S^D and S^Δ components during the last session of Phase 2 and during the single stimulus condition in the first session of Phase 3 for the S^D Alone, S^Δ Alone, and No Stim groups.

The resurgence analyses reported below were conducted in a series of steps informed by the purpose of Experiment 2. First, to evaluate resurgence under conditions comparable to those of Experiment 1, resurgence was compared between components for the Mult Stim group alone. Second, to evaluate the effect of the testing condition (i.e., multiple- or single-stimulus presentation), resurgence was compared between the Mult Stim and single-stimulus groups. Finally, to determine the effect of presenting the S^D and S^Δ stimulus in isolation and removal of the discriminative stimuli altogether, target responding was compared between the S^D Alone, S^Δ Alone, and No Stim groups. It is important to note that these Phase-3 data could not be analyzed in a single ANOVA because the groups differ in the number of factors. That is, the Mult Stim group has two within-subject factors (i.e., Component and Session) and no between-subject factors, whereas the single-stimulus test groups have one within-subject factor (i.e., Session) and one between-subject factor (i.e., Group).

First, to evaluate resurgence in the Mult Stim group alone, a 2 × 2 (Session × Component) repeated-measures ANOVA was conducted on target response rates in the S^D and S^Δ components across the last session of Phase 2 and the first session of Phase 3 for this group specifically. The effects of Session, $F(1, 6) = 14.43$, $p = .008$, $\eta_p^2 = .71$, and Component, $F(1, 6) = 12.34$, $p = .01$, $\eta_p^2 = .67$, and the Session × Component interaction, $F(1, 6) = 6.87$, $p = .04$, $\eta_p^2 = .53$, were significant. Simple effects tests conducted following the significant Session × Component interaction revealed that target responding was significantly higher in the first session of Phase 3 relative to the last session of Phase 2 in the S^D component ($p = .005$) but not in the S^Δ component ($p = .60$). Thus, resurgence was only evident in the S^D component for the Mult Stim group.

Second, to evaluate the impact of the testing condition (i.e., multiple- or single-stimulus presentation) on resurgence, target responding in the last session of Phase 2 and the first session of Phase 3 was compared between groups separately
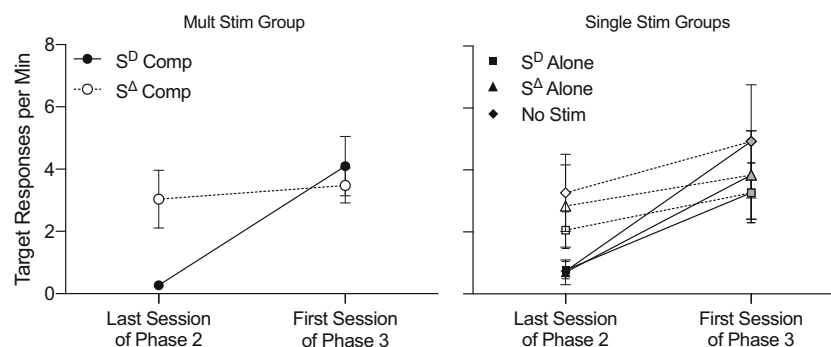

Fig. 5 Left panel: Mean target responses per min in the last session of Phase 2 and the first session of Phase 3 in the S^D and S^Δ components for the Mult Stim group. Right panel: Mean target responses per min in the last session of Phase 2 in the S^D (black symbols) and S^Δ components (white symbols) and the first session of Phase 3 under single stimulus testing (gray symbols) for the S^D Alone, S^Δ Alone, and No Stim groups. Solid line represents data paths between responding in S^D component and Phase 3. Dotted lines represent data paths between responding in S^Δ component and Phase 3. Error bars represent standard error of the mean

for S^D and S^Δ stimulus conditions. A 2×2 (Session × Group) mixed-model ANOVA was conducted on target response rates in the S^D component of the last session of Phase 2 for both groups and in first session of Phase 3 for the S^D Alone group and in the S^D component of the first Phase-3 session for the Mult Stim group. The effect of Session, $F(1, 12) = 22.25$, $p < .001$, $\eta_p^2 = .65$, was significant, and the effect of Group, $F(1, 12) = 0.05$, $p = .82$, $\eta_p^2 < .01$, and the Session × Group interaction, $F(1, 12) = 0.99$, $p = .34$, $\eta_p^2 = .08$, were not. A simple effects test following the significant effect of Session revealed that target responding was higher in the first session of Phase 3 relative to the last session of Phase 2 ($p = .001$), regardless of group. Thus, resurgence occurred under S^D conditions and did not differ between multiple- and single-stimulus testing.

For analysis of S^Δ conditions, a 2×2 (Session × Group) mixed-model ANOVA was conducted on target response rates in the S^Δ component of the last session of Phase 2 for both groups and in first session of Phase 3 for the S^Δ Alone group and in the S^Δ component of the first Phase-3 session for the Mult Stim group. The effects of Session and Group, and the Session × Group interaction were not significant ($p \geq .13$). These nonsignificant effects suggest that resurgence did not occur under either S^Δ test.

Finally, target response rates in the first session of Phase 3 were compared between the S^D Alone, S^Δ Alone, and No Stim groups to evaluate the level of target responding in the presence and absence of alternative-response discriminative stimuli. A one-way ANOVA conducted on these data revealed a nonsignificant effect of Group, $F(2, 18) = 0.34$, $p = .72$, $\eta_p^2 = .04$, suggesting that target response rates in the first session of resurgence testing were comparable between the three single-stimulus groups (see Table 2).

In summary of the above resurgence analyses, target responding did not differ by group at the end of Phase 2 but was overall higher in the S^Δ component than in the S^D component. Subsequently, resurgence occurred in the presence of the S^D stimulus and not the S^Δ stimulus, regardless of test condition. Additionally, presentation of the S^D and S^Δ stimulus alone, or removal of discriminative stimuli altogether did not differentially affect target responding in the first test session of Phase 3.

Figure 6 displays target and alternative response rates across all sessions of Phase 3, separated by multiple- and single-test conditions. The left panels show target and alternative responding in the S^D and S^Δ components for the Mult Stim group. The right panels show target and alternative responding for the S^D Alone, S^Δ Alone, and No Stim groups. Analyses of target and alternative responding across sessions of Phase 3 were conducted in a series of steps similar to the resurgence analyses reported above. First, responding was compared between components for the Mult Stim group alone. Second, responding was compared between the three

Single Stim groups. Finally, to evaluate the effect of testing condition, responding was compared between multiple- and single-stimulus conditions.

To evaluate target responding in the Mult Stim group alone, a 2×5 (Component × Session) repeated-measures ANOVA was conducted on target responding across sessions of Phase 3 for this group. The effect of Session, $F(1.53, 9.18) = 8.40$, $p = .01$, $\eta_p^2 = .58$, was significant, while the effect of Component, $F(1, 6) = 2.57$, $p = .16$, $\eta_p^2 = .30$, and the Component × Session interaction, $F(4, 24) = 1.29$, $p = .30$, $\eta_p^2 = .18$, were not. A simple effects test following the significant effect of Session revealed that target responding was higher in the first session relative to the last session of Phase 3 ($p = .02$), regardless of component. Thus, target responding significantly decreased across sessions in Phase 3 for the Mult Stim group, and this change did not differ between components.

To evaluate target responding under single-stimulus testing conditions, a 3×5 (Group × Session) mixed-model ANOVA was conducted on target responding across sessions of Phase 3 for the S^D Alone, S^Δ Alone, and No Stim groups. The effect of Session, $F(1.65, 29.67) = 11.44$, $p < .001$, $\eta_p^2 = .39$, was significant, and the effect of Group, $F(2, 18) = 0.26$, $p = .78$, $\eta_p^2 = .03$, and Group × Session interaction, $F(3.30, 29.67) = 0.88$, $p = .47$, $\eta_p^2 = .09$, were not. A simple effects test following the significant effect of Session revealed that target responding was higher in the first session relative to the last session of Phase 3 ($p = .01$), regardless of group. Thus, target responding significantly decreased across sessions in Phase 3 under single-stimulus test conditions, and this change did not differ between the S^D Alone, S^Δ Alone, and No Stim groups.

To evaluate target responding across sessions of Phase 3 between the multiple- and single-stimulus testing conditions, target response rates were collapsed across components for the Mult Stim group and across groups for the S^D Alone, S^Δ Alone, and No Stim groups. These data were collapsed in this manner given the nonsignificant effects of Component for the Mult Stim group and the nonsignificant effects of Group for the single-stimulus groups reported above. A 2×5 (Test Condition × Session) mixed-model ANOVA conducted on these data revealed a significant effect of Session, $F(1.72, 44.70) = 13.97$, $p < .001$, $\eta_p^2 = .35$, and a nonsignificant effect of Test Condition, $F(1, 26) = 0.21$, $p = .65$, $\eta_p^2 < .01$, and Test Condition × Session interaction, $F(1.72, 44.70) = 0.22$, $p = .77$, $\eta_p^2 < .01$. A simple effects test following the significant effect of Session revealed that target responding was higher in the first session relative to the last session of Phase 3 ($p = .003$), regardless of test condition. Thus, target responding significantly decreased across sessions in Phase 3 and did not differ between multiple- and single-stimulus testing conditions.

To evaluate alternative responding in the Mult Stim group alone, a 2×5 (Component × Session) repeated-measures
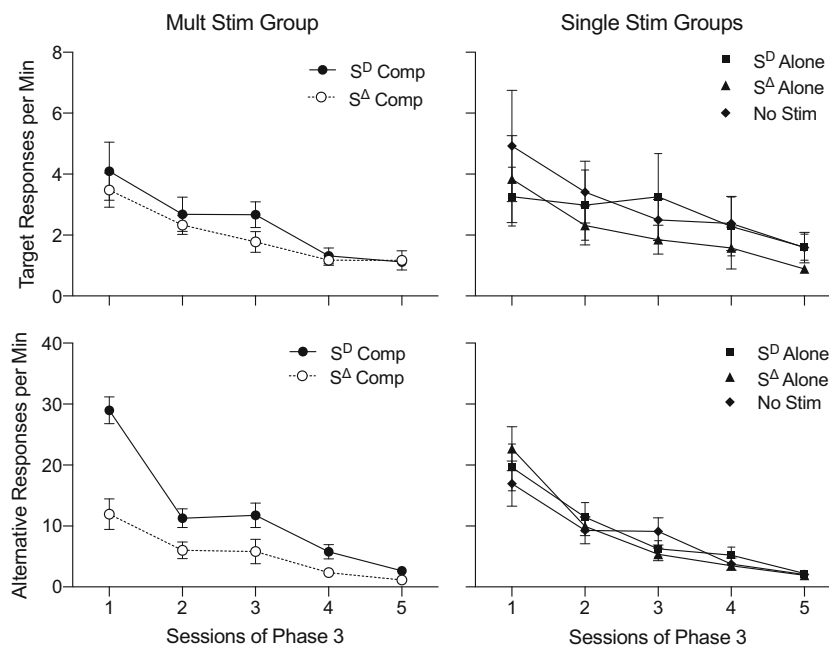
Fig. 6 Mean target (top panels) and alternative (bottom panels) responses per min across sessions of Phase 3 in the S^D and S^Δ components for the Mult Stim group (left panels) and for the S^D Alone, S^Δ Alone, and No Stim single-stimulus test groups (right panels). Error bars represent standard error of the mean

ANOVA was conducted on alternative responding across sessions of Phase 3 for this group. The effects of Component, $F(1, 6) = 30.14$, $p = .002$, $\eta_p^2 = .83$, and Session, $F(4, 24) = 40.87$, $p < .001$, $\eta_p^2 = .87$, and the Component × Session interaction, $F(4, 24) = 11.40$, $p < .001$, $\eta_p^2 = .66$, were all significant. Simple effects tests conducted following the significant interaction revealed that alternative responding was significantly higher in the S^D compared with the S^Δ component in both the first ($p = .004$) and last sessions of Phase 3 ($p = .02$), and the mean difference between components was greater at the beginning of the phase ($MD = 17.02$, 95% CI [7.89, 26.16]) compared with the end ($MD = 1.51$, 95% CI [0.41, 2.61]). Thus, alternative responding was initially more elevated and subsequently decreased more steeply across sessions of Phase 3 in the S^D component than in the S^Δ component for the Mult Stim group. Additionally, the DI averaged across these sessions ($M = 0.70$, $SEM = 0.04$) was statistically greater than 0.50, $t(6) = 5.28$, $p < .001$, $d = 1.99$, suggesting that differential alternative responding between components continued during Phase 3 for the Mult Stim group.

To evaluate alternative responding under single-stimulus testing conditions, a 3 × 5 (Group × Session) mixed-model ANOVA was conducted on alternative responding across sessions of Phase 3 for the S^D Alone, S^Δ Alone, and No Stim groups. The effect of Session, $F(1.61, 28.93) = 54.19$, $p < .001$, $\eta_p^2 = .75$, was significant, and the effect of Group, $F(2, 18) = 0.06$, $p = .94$, $\eta_p^2 < .01$, and the Group × Session interaction, $F(3.21, 28.93) = 1.27$, $p = .31$, $\eta_p^2 = .12$, were not. A simple effects test following the significant effect of Session revealed that alternative responding was higher in the first

session relative to the last session of Phase 3 ($p < .001$), regardless of group. Thus, alternative responding significantly decreased across sessions in Phase 3 under single-stimulus test conditions, and this change did not differ between the S^D Alone, S^Δ Alone, and No Stim groups.

To evaluate the impact of multiple-stimulus and single-stimulus testing conditions on alternative responding during extinction, alternative response rates across sessions of Phase 3 were compared between groups under comparable stimulus conditions. A 2 × 5 (Group × Session) mixed-model ANOVA was conducted on alternative responding across sessions of Phase 3 in the S^D component of the Mult Stim group and across sessions in the S^D Alone group. The effect of Session, $F(4, 48) = 63.30$, $p < .001$, $\eta_p^2 = .84$, and the Group × Session interaction, $F(4, 48) = 3.87$, $p = .008$, $\eta_p^2 = .24$, were significant, and the effect of Group, $F(1, 12) = 2.52$, $p = .14$, $\eta_p^2 = .17$, was not. Simple effects tests conducted following the significant interaction revealed that alternative responding was significantly higher in the Mult Stim group compared with the S^D Alone group during the first session of Phase 3 ($p = .04$) and that responding did not differ between groups at the end of the phase ($p = .60$). These results suggest that alternative responding in the presence of the S^D stimulus was initially more elevated and subsequently decreased across sessions of Phase 3 in the multiple-stimulus test compared with the single-stimulus test.

For analysis of S^Δ conditions, a 2 × 5 (Group × Session) mixed-model ANOVA was conducted on alternative responding across sessions of Phase 3 in the S^Δ component of the Mult Stim group and across sessions in the S^Δ Alone

group. The effect of Session, $F(1.69, 20.23) = 37.46, p < .001$, $\eta_p^2 = .76$, and the Group × Session interaction, $F(1.69, 20.23) = 4.84, p = .02, \eta_p^2 = .29$, were significant, and the effect of Group, $F(1, 12) = 3.96, p = .07, \eta_p^2 = .25$, was not. Simple effects tests conducted following the significant interaction revealed that alternative responding was significantly lower for the Mult Stim group compared with the S^Δ Alone group during the first session of Phase 3 ($p = .03$), and that responding did not differ between groups at the end of the phase ($p = .22$). These results suggest that alternative responding in the presence of the S^Δ stimulus was less persistent in the multiple-stimulus test than in the single-stimulus test. Thus, differential alternative-response extinction in the presence of the S^D and S^Δ stimuli was only evident in the multiple-stimulus test condition and not under single-stimulus testing (see Table 2 for alternative response rates across stimulus conditions in the first session of Phase 3).

Discussion

The purpose of Experiment 2 was to compare resurgence under the multiple-stimulus testing condition of Experiment 1 in which the S^D and S^Δ were presented in a multiple schedule to single-stimulus testing conditions in which the S^D and S^Δ were presented in isolation or removed altogether. Baseline and alterative-response discrimination training occurred as in Experiment 1, and resurgence of target responding was assessed in a multiple-schedule for one group of rats and, for the remaining three groups, resurgence was tested in presence of either the S^Δ stimulus alone, the S^D stimulus alone, or no discriminative stimuli.

The results of Experiment 2 suggest that target behavior was not differentially impacted by testing condition. That is, regardless of testing under a multiple-schedule or in the presence of a single discriminative stimulus, resurgence was evident in the S^D, but target responding did not significantly increase across phases in the S^Δ. These resurgence results are inconsistent with the findings from Experiment 1, in which target responding did significantly increase across phases in both the S^D and S^Δ. Given that the discrimination training procedures were identical between experiments, as well as the testing procedures in Experiment 1 and for the Mult Stim group of Experiment 2, it is unclear what contributed to this discrepancy. It should be noted that the sample size in Experiment 2 ($N = 28$) was larger than that of Experiment 1 ($N = 5$), and as a result, it is possible that differences in sampling contributed to this inconsistent finding.

While resurgence was not evident under S^Δ conditions in Experiment 2, it is important to note that target responding was significantly elevated in the S^Δ component relative to the S^D component during the last session of Phase 2 (see Figs. 4 and 5). Further, target response rates were not different between stimuli across sessions of resurgence testing (see Fig.

6). Thus, while target responding did not necessarily *increase* across phases, it is clear that the S^Δ did not significantly reduce target responding during resurgence testing.

This pattern of target responding resembles those reported in which parameters of alternative reinforcement, such as rate and magnitude, are manipulated (Bouton & Trask, 2016; Craig et al., 2016; Craig, Browning, Nall, et al., 2017; Craig & Shahan, 2016; Sweeney & Shahan, 2013a). For example, Craig and Shahan (2016) reported elevated target response rates during Phase 2 in rats that received a relatively lean rate of alternative reinforcement compared with rats that received a relatively rich rate. Further, the groups that had received rich alternative reinforcement showed resurgence while the groups that had received lean reinforcement did not, but target responding did not differ between groups in Phase 3. Thus, parameters of alternative reinforcement as well as stimuli that differentially signal alternative reinforcement both contribute to levels of target responding across Phases 2 and 3. Additionally, the extent to which target responding is elevated during treatment is related to whether or not target responding necessarily increases (Shahan & Craig, 2017).

Additionally, target response rates in Phase 3 for the No Stim group were also comparable to those in the Single and Mult S^D and S^Δ conditions, suggesting that overall levels of target responding during testing was not differentially affected by the presence or absence of alternative-response discriminative stimuli. From an applied perspective, this may suggest that a treatment adherence failure in which the FCR discriminative stimuli are completely absent may not necessarily result in greater resurgence when the FCR contacts extinction. This finding is somewhat surprising given that there is evidence to suggest that removing both alternative reinforcers and discriminative stimuli produces greater relapse. For example, Podlesnik and Kelley (2014) observed greater resurgence of key pecking in pigeons following removal of alternative reinforcement when the alternative-response discriminative stimulus (i.e., an illuminated key) was absent (i.e., key was darkened) compared with when it remained present during resurgence testing. More broadly, the results of Podlesnik and Kelley (2014) may be related to experiments in which resurgence and renewal procedures are combined. That is, renewal refers to the increase in behavior following a change in the context in which that behavior was previously extinguished (Bouton et al., 2011). In ABA renewal, a response is reinforced during baseline in a particular context (i.e., Context A), that response is placed on extinction in a separate context (i.e., Context B), and relapse is tested in the original baseline context. There is some evidence to suggest that superimposing such contextual manipulations onto a resurgence procedure results in greater relapse effects (Kincaid et al., 2015; Trask & Bouton, 2016).

In relation to Experiment 2, the Phase 3 test for the No Stim group might approximate a return to the baseline context (i.e.,

Context A) because the alternative-response discriminative stimuli were absent in both phases. Further, the presence of discriminative stimuli during discrimination training could be characterized as Context B. Based on the findings described above, resurgence might be expected to be largest in this group. While the average target response rate in the first session of Phase 3 was numerically highest in this group (see Table 2), this effect was not significant. Whether or not this is inconsistent with the resurgence + renewal literature is unclear given the mixed results reported in the literature (e.g., Nighbor et al., 2018; Sweeney & Shahan, 2015).

While testing condition did not have an effect on target response rates in Phase 3, persistence of alternative responding during extinction was differentially impacted by multiple- and single-stimulus test conditions. Specifically, alternative response rates across sessions of Phase 3 were more elevated in the S^D component than in the S^Δ component in the Mult Stim group, but alternative-response extinction was comparable between the S^D Alone, S^Δ Alone, and No Stim groups. Furthermore, alternative response rates were higher in the S^D component and lower in the S^Δ component for the Mult Stim group compared with the single-stimulus groups. Thus, the discriminative stimuli contributed to differential alternative-response allocation during extinction in the multiple schedule, but this differentiation was not evident between groups in the single-stimulus conditions.

These results may be related to the differential resistance to extinction observed in multiple schedules, but not in single schedules. Cohen (1998) reported more resistance to extinction in a stimulus context associated with a richer rate of reinforcement compared with a stimulus context associated with a leaner rate only if the stimuli were presented within a multiple schedule but not when presented in isolation in a single schedule. These findings suggest that the comparison of discriminative stimuli inherent in a multiple schedule may be important for differential response allocation under extinction. Thus, it is possible that comparison of S^D and S^Δ stimuli within the multiple schedule contributed to differential alternative-response persistence in Phase 3 in the Mult Stim group compared with the single stimulus presentation (or absence) in the other groups.

Given that one of the goals of discrimination training in the clinic is to control the overall rates of the FCR and prevent resurgence of challenging behavior (Saini et al., 2016), it would be ideal that the FCR persists during extended periods of extinction under S^D but not S^Δ conditions. Fisher et al. (2020) observed lower rates of the FCR during the extinction challenge when the S^Δ stimulus was present compared with when it was absent for three participants and found no difference for the fourth participant, and Fuhrman et al. (2016) observed differential rates of the FCR between conditions in one participant, but not the other. Thus, there is generally more evidence that following FCT, the FCR is less

persistent when the S^Δ stimulus is presented alone compared with when it is absent, but S^D tests were not included. Additionally, the nondifferential alternative-response extinction obtained in the single-stimulus tests of the current experiment is not entirely consistent with these findings. As a result, it is unclear whether to expect greater FCR persistence in the face of extinction under S^D conditions.

In summary, the results of Experiment 2 suggest that target behavior was not significantly reduced in the presence of a stimulus that signaled alternative-response extinction regardless if that stimulus was presented in isolation or alternated with a stimulus that signaled alternative reinforcement. This conclusion is overall consistent with the results from Experiment 1, but are inconsistent with those reported in the applied literature. Thus, this discrepancy is not likely due to the difference in the testing condition between studies. Instead, differences in the discrimination training procedures may be responsible.

General discussion

Previous applied research has reported significant reductions in resurgence of severe destructive behavior in the presence of a stimulus that signals alternative-response extinction (i.e., an S^Δ). The purpose of Experiment 1 was to test the generality of this finding by determining whether an alternative-response S^Δ would mitigate resurgence of target responding when the alternative response also contacts extinction under S^D conditions that had previously signaled the availability of reinforcement for the alternative response. Resurgence of target responding was comparable in the S^D and S^Δ stimulus conditions. These results conflict with those previously reported and suggest that the conditions under which an S^Δ stimulus may prevent or mitigate resurgence are limited; however, given the testing conditions used in the applied research, it is possible that an S^Δ stimulus may only prevent resurgence when presented in isolation, and not when presented in close temporal proximity to the S^D stimulus within a multiple schedule.

The purpose of Experiment 2 was to determine the independent effects of alternative-response discriminative stimuli on resurgence of target responding, and to compare these effects to those produced by discriminative-stimuli presented within a multiple schedule. Resurgence was evident in the S^D, but target responding remained elevated and did not increase across phases in the S^Δ, and this effect was consistent in both the single-stimulus and multiple-stimulus test conditions. Additionally, rates of target responding during resurgence testing were not differentially affected by the S^D stimulus, S^Δ stimulus, or the absence of discriminative stimuli altogether.

The overall pattern of target and alternative responding during discrimination training was consistent between Experiments 1 and 2. That is, alternative responding was allocated according to the arranged discrimination as measured by the discrimination index (DI), but target responding remained generally elevated in the S^{Δ} component compared with the S^D. Additionally, resurgence occurred under S^D conditions in both experiments, but resurgence occurred under S^{Δ} conditions only in Experiment 1. It is possible that the effect observed in Experiment 1 was due to positive contrast; however, because this effect was not evident in the Mult Stim group of Experiment 2, the exact role of behavioral contrast remains unclear. As mentioned in the discussion of Experiment 2, this discrepancy between experiments may be due to differences in the sample size.

Importantly, the failure to observe an increase in target responding across phases in the S^{Δ} in Experiment 2 was not likely the result of any mitigating effect of the S^{Δ}, but rather the significantly elevated levels of target responding in the S^{Δ} component at the end of Phase 2. In contrast, target response rates at the end of Phase 2 in both Fuhrman et al. (2016) and Fisher et al. (2020) were zero or near zero prior to resurgence testing. It is important to note that a changeover delay (COD) for switching from the S^{Δ} to the S^D component was programmed for *both* alternative and target responses in these studies. As a result, the S^{Δ} may have come to signal both alternative-response and target-response extinction thereby contributing to the reduction of target responding and it is unclear whether the S^{Δ} mitigated resurgence because it signaled extinction of the alternative response, target response, or both. To avoid this confound and to evaluate the effects of a discriminative stimulus that *only* signaled alternative-response extinction, a COD for switching from the S^{Δ} to the S^D component was programmed for only the alternative response, and not the target response in Experiments 1 and 2.

Overall, it is clear that the alternative-response S^{Δ} stimulus did not significantly reduce target responding during resurgence testing in either experiment. That is, across experiments, target responding was either higher in the S^{Δ} compared with the S^D, or comparable between S^{Δ} and S^D stimuli across sessions of Phase 3. Importantly, it is not likely that this finding was due to a failure to effectively discriminate the S^D and S^{Δ} stimuli during resurgence testing. Specifically, alternative responding continued to be differentially allocated according to the discriminative stimuli (i.e., DI > 0.50) when alternative reinforcement was removed in Phase 3 in Experiment 1 and in the Mult Stim group of Experiment 2. Thus, the question remains: what are the necessary and sufficient conditions under which an S^{Δ} will mitigate resurgence following discrimination training?

In addition to teaching the client to discriminate when FCR reinforcement is and is not available, discrimination training is an effective means to thin the rate of FCR reinforcement, thereby further increasing the feasibility of treatment implementation (e.g., Betz et al., 2013). Fuhrman et al. (2016) and Fisher et al. (2020) included FCR reinforcement rate thinning during discrimination training by increasing the duration of the S^{Δ} component. Initially the duration of the components were 60 s and 30 s and were increased to 60 s and 240 s for the S^D and S^{Δ} components, respectively. As a result, participants in both studies experienced an S^{Δ} component that was relatively longer than the S^D component by the time resurgence was tested.

Further, there is evidence to suggest that the duration of exposure to the S^{Δ} stimulus contributes to effective discrimination. For example, Andrzejewski et al. (2007) evaluated the impact of the length of exposure to the S^{Δ} stimulus on the acquisition of a discriminated responding in rats. In a two-component multiple schedule, the duration of the S^D component was held constant at 2 min and the duration of the S^{Δ} component was either 1 or 4 min. Regardless of the rate of reinforcement in the S^D component, the speed of acquisition of the discrimination (as evident by proportion of responding in S^D) was substantially faster when the duration of the S^{Δ} component was 4 min compared with 1 min. Additionally, Kalmbach et al. (2019) evaluated the effect of S^{Δ} duration on response suppression in the presence of the S^{Δ} relative to its absence in mice. The duration of the S^{Δ} component was either 20, 40 or 80 s across groups, and the duration of the absence of the S^{Δ} was held at an average of 40 s. Similarly, to the findings reported by Andrzejewski et al. (2007), response suppression was a direct function of the S^{Δ} duration such that longer durations produced greater suppression and better discrimination.

In light of these data, it is possible that increasing the duration of the S^{Δ} component during FCT as a means of thinning rate of FCR reinforcement contributed to the reduced resurgence observed by Fuhrman et al. (2016) and Fisher et al. (2020). Importantly, in the present experiments, the duration of the S^{Δ} component was the same as the S^D component and was not increased at any point during discrimination training. Further, there is some evidence for increased alternative-response discrimination in the applied studies compared with the present experiments. For example, rates of the FCR decreased for all but one participant across the two applied studies when the duration of the S^{Δ} component increased during discrimination training, suggesting further response suppression, whereas alternative response rates in the S^{Δ} component remained constant across Phase 2 in Experiments 1 and 2. Additionally, rates of the FCR were lower during extinction in the presence of the S^{Δ} stimulus compared with in its absence in the applied studies while alternative responding during extinction in the present experiments was not differentially affected by the S^D or S^{Δ} stimuli alone or by the

absence of discriminative stimuli altogether. However, these comparisons only provide tentative evidence to suggest the increased S^Δ duration is a critical variable. Currently, there is no empirical evidence for a *casual* relation between S^Δ duration, alternative-response discrimination, and subsequent resurgence. Future research may be directed toward systematically evaluating the effects of increasing the duration of alternative-response S^Δ stimulus presentation on resurgence.

Along with the duration of the S^Δ, other procedural differences between the present and applied experiments may have also contributed to the discrepant findings. In both Fuhrman et al. (2016) and Fisher et al. (2020), participants were given verbal descriptions of the contingencies signaled by the S^D and S^Δ stimuli prior to each session during discrimination training, and more extensive training was administered for individual participants if necessary. Fisher et al. also conducted pretraining procedures to program errorless acquisition of the FCR and to establish discriminative control of the S^D and S^Δ *prior* to the resurgence procedure and no such pretraining was implemented in the present experiments. Lastly, the length of Phase 2 in Experiments 1 and 2 was longer than the length of FCT across participants in both applied studies. While increased in treatment duration produces small decreases in resurgence in rats (Shahan et al., 2020), this effect is not evident in the clinic (Greer et al., 2020). Overall, the extent to which these differences contributed to the obtained findings is unknown and warrants future investigation.

Translational research considers the applicability of fundamental behavioral principles to issues of social significance. Specifically, bidirectional translational research uses clinically significant questions to inform basic research which in turn improves future clinical research and practice (Mace & Critchfield, 2010). The present experiments provide additional support for the utility of translational research, and the obtained findings suggest that the conditions under which an alternative-response S^Δ stimulus will successfully prevent resurgence are limited. While future research is certainly warranted, the present experiments are an initial step toward a more comprehensive understanding of the relation between alternative-response discrimination training and resurgence.

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