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Multiple control responses and resurgence of human behavior

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ABSTRACT

Behavior that was previously extinguished may reoccur, or resurge, when an alternative response contacts extinction or when reinforcement conditions worsen. Researchers have studied resurgence of human responding in laboratory settings with procedures commonly used with nonhumans. In contrast to nonhuman responding, researchers have failed to observe resurgence of the target response at rates that differ from an inactive control response with verbally competent humans. But this may have been the result of using a single control response. The current study examined this possibility by randomly allocating participants ($N = 20$) to a condition with either two or four control responses. When the alternative response contacted extinction, having more control responses did not reduce overall responding to control options, and aggregated responding to control options were similar to target response rates. Interestingly, most participants responded more to one control response over all other control responses when the alternative response contacted extinction. This study provides additional support for previous research that finds consistent differences between human and nonhuman responding during resurgence procedures. Two potential reasons for variability in human responding during resurgence tests include less time in experimental sessions and the influence of verbal behavior.

1. Introduction

The reoccurrence of a clinical problem following successful intervention (i.e., relapse) is a significant problem in many areas of healthcare. For example, researchers have estimated relapse occurs with hypertension (≈ 24% of cases), substance abuse (40–60% of cases), psychosis (54% of cases), and major-depressive disorder (80% of cases; Alvarez-Jimenez et al., 2012; Burcusa and Iacono, 2007; McLellan et al., 2000; Sandhu et al., 2015). The prevalence of relapse has led researchers to develop laboratory models to study the conditions under which relapse occurs and interventions that may prevent or mitigate relapse (e.g., Craig et al., 2018; Liggett et al., 2018).

One behavioral model of relapse is called resurgence. The term “resurgence” is used to describe the reoccurrence of a previously extinguished behavior when reinforcement for an alternative response is withheld or reinforcement conditions worsen (Epstein, 1983; but, see Lattal et al., 2017, for a variety ways previous authors have defined resurgence). A common procedure to study resurgence reinforces some target response in Phase I (e.g., left lever press). In Phase II, the target response is placed on extinction, but an alternative response is reinforced (e.g., right lever press). In Phase III, both responses are placed on extinction. The beginning of Phase III is sometimes referred to as a “resurgence test” because the researcher tests whether the organism will emit higher target response rates at the beginning of Phase III compared to the end of Phase II.

One goal of laboratory research on resurgence is to identify the behavioral processes that lead to responding during resurgence tests. For example, researchers have included an inactive control response to help determine the extent to which resurgence is part of general increases in behavior expected from extinction-induced variability (e.g., Doughty and Oken, 2008; Sweeney and Shahan, 2016; Wathen and Podlesnik, 2018). Extinction-induced variability refers to increased variation in response topography, location, or force when a previously reinforced response is extinguished (e.g., Neuringer and Jensen, 2013). Resurgence effects may be better described as arising from extinction-induced variability if target and control response rates increase during resurgence tests. Here, one might expect stimulus control strength to determine the degree to which variability is directed toward the target response over control responses (Liggett et al., 2018). The stronger the stimulus control, the greater the difference in response rates between target and control responses. The weaker the stimulus control, the lesser the difference in response rates between target and control responses. Conversely, the term resurgence, and not extinction-induced variability, is sometimes used to distinctly describe response rates

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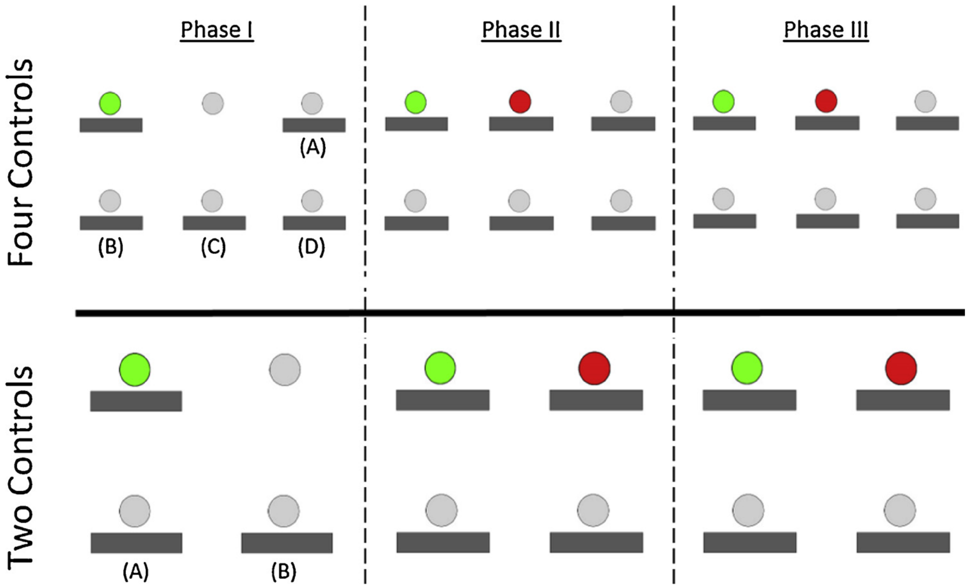

Fig. 1. Screenshots of the stimuli and levers presented in each phase for each group. Screen shots in the top panels were presented to participants allocated to the four-control responses group. Screen shots in the bottom panels were presented to participants allocated to the two-control responses group. The letters correspond to the control response number outlined in the text and were not shown to participants.

increasing on the target with limited or no increase on the control during resurgence tests – regardless of reference to stimulus control (Doughty and Oken, 2008; Sweeney and Shahan, 2016).

Interestingly, humans have responded differently than nonhumans during resurgence tests with control responses. Nonhumans typically show elevated responding on the target and little-to-no responding on the control (e.g., Nall et al., 2018). In contrast, humans have shown elevated response rates on both the target and controls during the resurgence test, with little difference between the two (e.g., Bolívar et al., 2017; Sweeney and Shahan, 2016). These studies seem to suggest that there may be different variables (explicitly programmed or otherwise) that affect the reoccurrence of responding in laboratory resurgence tests for humans compared to nonhumans.

One potential confound exists with human participants in the above procedures. The confound is a correspondence between the number of responses and the number of phases. The resurgence procedure described above involves three phases and three responses. One of the three responses is reinforced in Phase I and a second response is reinforced in Phase II. Based on these experiences, it seems reasonable that a verbally competent human might learn to switch to the next response when a new phase starts or both previously reinforced alternatives are no longer reinforced. Responding relative to a faulty rule based on the correspondence between responses and phases might lead to increases in control responding at the beginning of Phase III. But, an increase in responding on the control would also be predicted if responding were the result of extinction-induced variability, and not self-generated rules. Thus, the use of a single control response has not yet allowed researchers to determine what process may control human responding in resurgence procedures. Including multiple control responses throughout all three phases removes the correspondence between the number of phases and the number of responses.

The purpose of this experiment was to examine human responding during resurgence procedures when multiple inactive control responses were available throughout the experiment. Increasing the number of control responses eliminated the correspondence between the number of phases and number of available responses. One arrangement maintained the spatial layout of levers from Bolívar et al. (2017) and added an additional row of three control levers (i.e., four control levers in total). This arrangement allowed us to examine if the left-to-right pattern of reinforcement across Phases I and II led participants to choose the control response to the right of the alternative response. The second arrangement included two control levers, one located spatially below the target response and one located spatially below the alternative response. This arrangement allowed us to examine responding when the left-to-right pattern of reinforcement across Phases I and II were not predictive of any specific control response in Phase III.

2. Methods

2.1. Subjects

Twenty undergraduate students (average age = 19.8 yrs, range 18–23) were recruited from the undergraduate psychology participant pool and randomly assigned to one of the two experimental conditions. Fourteen of the participants self-identified as female, two self-identified as Black or African American, and fifteen self-identified as White or Caucasian American. All participants received course credit for participating.

2.2. Apparatus

All experimental tasks were presented on a desktop or laptop computer in a campus laboratory room. Participants used a computer mouse to complete all tasks. All conditions were coded using Visual Basic Community Edition 2013.

2.3. Setting and instructions

Participants initially completed an informed consent document followed by a demographic questionnaire before beginning the experiment. After answering any general questions, the research assistant instructed the participant to attend to the computer screen which would guide them through the experimental task. The instructions on the screen were as follows: “You will see several images on the screen. Manipulating these images may or may not result in points. Please ask the research assistant if you have any questions about the experiment before it starts. When you are ready to begin, please click this box.” Phase I of the experiment began immediately after clicking the instruction box.

2.4. Experimental stimuli

Fig. 1 contains screenshots for how different responses were presented to participants in each experimental group. The letters placed below levers in Fig. 1 were not visible to participants and are included to allow for easy discussion of results in the Results section. Each lever was visible on the computer screen and located approximately 0.25 cm below a colored circle (hereafter referred to as 'signals'). Signals were 1.7 cm in diameter, spaced 6.4 cm apart horizontally within rows, and spaced 6.4 cm apart vertically within columns. All levers were grey and were presented against a white background in all phases. Levers were 6 x 1.3 cm in perimeter and centered below the corresponding signal. Lastly, a text box was located in the upper right corner of the screen and labeled "Bank." A second label below the Bank displayed the points participants had earned in each phase.

2.5. Experimental task

The task consisted of three phases identical to previous research (Bolívar et al., 2017). Participants made responses to the virtual levers in each phase. One response consisted of six consecutive clicks on a lever which moved down the screen by 0.6 cm with each click. Following the sixth click, the lever reset to the starting location and another six clicks were required to complete another response. We required multiple clicks as an attempt to increase response effort and decrease the likelihood of rapid switching between levers. If a partial response was made to one lever and the participant then switched to a different lever, the initial lever would reset to its starting location. All levers and signals disappeared from the screen each time a schedule requirement was met followed by an image and button appearing on the screen. The image read "+5 points" and the button read "Collect Points." Clicking the button added five points to the participant's bank and re-presented the levers and signals for continuation of the phase. Participants transitioned from Phase I to II and from Phase II to III once responding was stable or a maximum duration of 16 min in the phase elapsed (see Bolívar et al., 2017, for how response stability was programmed). The average (SD) duration of phases for the two-control group were 14.60 min (2.50 min) and for the four-control group were 13.8 min (2.57 min).

Reinforcement was delivered using variable-interval (VI) durations sampled from 15 intervals calculated using the Fleshler-Hoffman procedure (Fleshler and Hoffman, 1962). In Phase I, the signal above the target response was green and the program delivered points for responding on the target lever on a VI-20 s schedule. That is, the first completion of the sixth click following the elapsed reinforcement interval was followed by point delivery. The signal above the alternative response was grey and the alternative response was not available during Phase I. In Phase II, the alternative lever became available and was reinforced on a VI-10 s schedule. The signal above the alternative response was red; the signal above the target response remained green; and, target responding was placed on extinction. Reinforcement was denser in Phase II than Phase I to reduce responding to the target lever as much as possible in Phase II. In Phase III, all stimuli and responses were identical to Phase II, however, responding to the target and alternative levers were placed on extinction. Throughout all three phases, any responding to control levers did not lead to differential consequences.

2.6. Condition differences

Participants were randomly assigned to a condition with two or four control levers (Fig. 1). The six levers in the four-control responses group (i.e., target, alternative, and four controls) were arranged visually in a 3×2 rectangle (top panel, Fig. 1). The top row of three responses was identical to Bolívar et al. (2017). Three control responses were added as a second row below the top row. The four levers in the two-control responses group (i.e., target, alternative, and two controls) were arranged visually in a square pattern (bottom panel, Fig. 1). This arrangement was identical to the six levers group except we removed the two control levers in the far-right column. For both groups, the target response was the upper left lever and the alternative response was the second-from-left lever in the top row.

2.7. Data analysis

All statistical analyses were conducted using IBM SPSS Statistics Version 24 (IBM Corporation, 2016). Alpha levels were set to 0.05 for all analyses and Greenhouse-Geisser corrections were used where Mauchly's test indicated data sphericity assumptions for mixed-model ANOVAs had been violated (denoted by non-integer degrees of freedom below). Responding was discretized into 2-min bins for all analyses and graphing.

3. Results

3.1. Number of control responses

We first determined whether different numbers of controls influenced response rates on the target and controls using a mixed model three-way ANOVA. The between groups variable was the number of control responses (2 or 4) and the within-subjects variables were phase (reinforcement schedule) and lever (target or controls). Response rates analyzed were from the final bin of Phase II and the first bin of Phase III for all participants. To account for different numbers of controls (2 or 4), we collapsed all control responding into a single control response rate for each participant for this analysis only.

We did not observe any difference in overall response rates between the two groups ($F(1, 19) = 1.84$, $p = 0.191$, $\eta p^2 = 0.088$). This suggests that the number of available controls did not influence the overall amount of responding that was distributed among all response options. The only within-subject significant interaction observed was between target or collapsed control responding and the number of control responses available ($F(1, 19) = 4.55$, $p = 0.041$, $\eta p^2 = 0.193$). This indicates that response allocation to the target and to controls, in total, differed as a function of the number of control responses available.

3.2. Resurgence tests

We tested for differences in response rates at the group level by conducting separate two-way repeated measures ANOVAs for each group while keeping the different control response rates separate. To do this, we first rank-ordered all control responses for each participant based on rate of responding during the first bin of Phase III (e.g., the control response with the most responses was labeled "highest control" and the control response with the least responses was labeled as "lowest control").

Fig. 2 shows the mean data for participants with four controls (left panel). We observed different overall rates of responding in Phases II and III ($F(1, 10) = 36.73$, $p < 0.001$, $\eta p^2 = 0.79$), different rates of responding depending on the lever ($F(4, 19.87) = 5.72$, $p = 0.011$, $\eta p^2 = 0.36$), and an interaction between phase and lever (i.e., different rates of responding depending on the phase and lever under consideration; $F(4, 18.01) = 3.82$, $p = 0.01$, $\eta p^2 = 0.28$). Post-hoc tests using Bonferroni corrections indicated that participants emitted: higher rates of target responding at the beginning of Phase III compared to the beginning of Phase II ($t_{10} = 4.21$, $p = 0.002$, $d = 1.80$); higher rates of target responding compared to the 2nd highest, 2nd lowest, and lowest controls at the beginning of Phase III ($t_{10} = 2.17$, $p = 0.05$, $d = 0.93$; $t_{10} = 2.42$, $p = 0.04$, $d = 1.03$; and $t_{10} = 2.85$, $p = 0.02$, $d = 1.22$, respectively); and higher response rates on the highest control compared to all other controls ($t_{10} = 2.31$, $p = 0.04$, $d = 0.98$; $t_{10} = 2.50$, $p = 0.03$, $d = 1.07$; $t_{10} = 2.94$, $p = 0.02$, $d = 1.25$ – for 2nd highest, 2nd lowest, and lowest controls, respectively). However, no difference was found between the target and highest control ($t_{10} = 0.03$, $p = 0.80$, $d = 0.11$) or between any of the other control responses. These data suggest elevated rates of target responding relative to all control responses except one.

Fig. 3 shows target and control responding during the last bin of Phase II and the first bin of Phase III for each participant in the four-

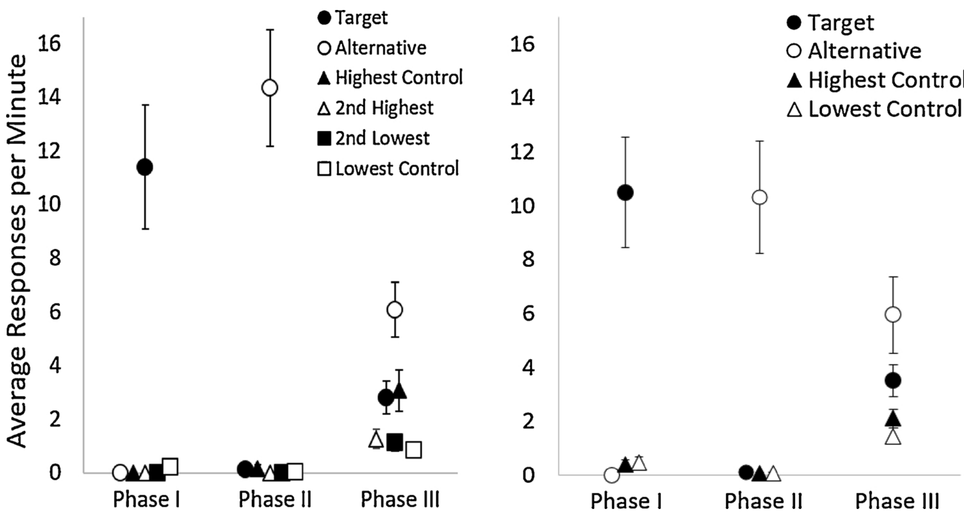

Fig. 2. Average responding across the final 2-min bins of Phases I and II, and the first 2-min bin of Phase III. The panel on the left is for participants allocated to the four-control responses group. The panel on the right is for participants allocated to the two-control responses group. Error bars represent standard error of the mean.

control responses group. At the individual level, allocation of responding among the control responses largely coincided with the group analysis above. All participants displayed higher rates of target responding at the beginning of Phase III compared to the end of Phase II. In addition, four of the participants displayed approximately twice as many responses to the highest control response compared to all other control responses (P2, P3, P4, P6), four more displayed higher responding to one control compared to the other control responses (P1, P7, P9, P10), with the remaining two showing equal responding to all control responses (P5, P8).

We next tested for differences in response rates during the resurgence test for participants with two controls (right panel, Fig. 2). We observed overall differences in responding between Phases II and III ($F(1, 9) = 46.01$, $p < 0.001$, $\eta p^2 = 0.84$), differences in responding to different levers ($F(2, 9.97) = 7.94$, $p = 0.017$, $\eta p^2 = 0.47$), and an interaction between phase and specific lever (i.e., rates of responding differed as a function of phase and which lever is being considered; $F(2, 9.96) = 6.73$, $p = 0.025$, $\eta p^2 = 0.43$). Specifically, we observed a difference in responding between: the target at the end of Phase II and beginning of Phase III ($t_9 = 5.50$, $p < 0.001$, $d = 2.59$), the target and lowest control at the beginning of Phase III ($t_9 = 3.25$, $p = 0.01$, $d = 1.53$), and both controls at the beginning of Phase III ($t_9 = 3.55$, $p = 0.006$, $d = 1.67$). However, no difference was observed between the target and highest control at the beginning Phase III ($t_9 = 2.05$, $p = 0.07$, $d = 0.97$). Similar to the four control responses group, these results suggest target responding during the resurgence test was elevated relative to one control response, but not the second.

Fig. 4 shows target and control responding during the last bin of Phase II and the first bin of Phase III for each participant in the two-control responses group. Similar to the four-control responses group, allocation of responding among the control responses at the individual level largely coincided with the group analysis above. All participants

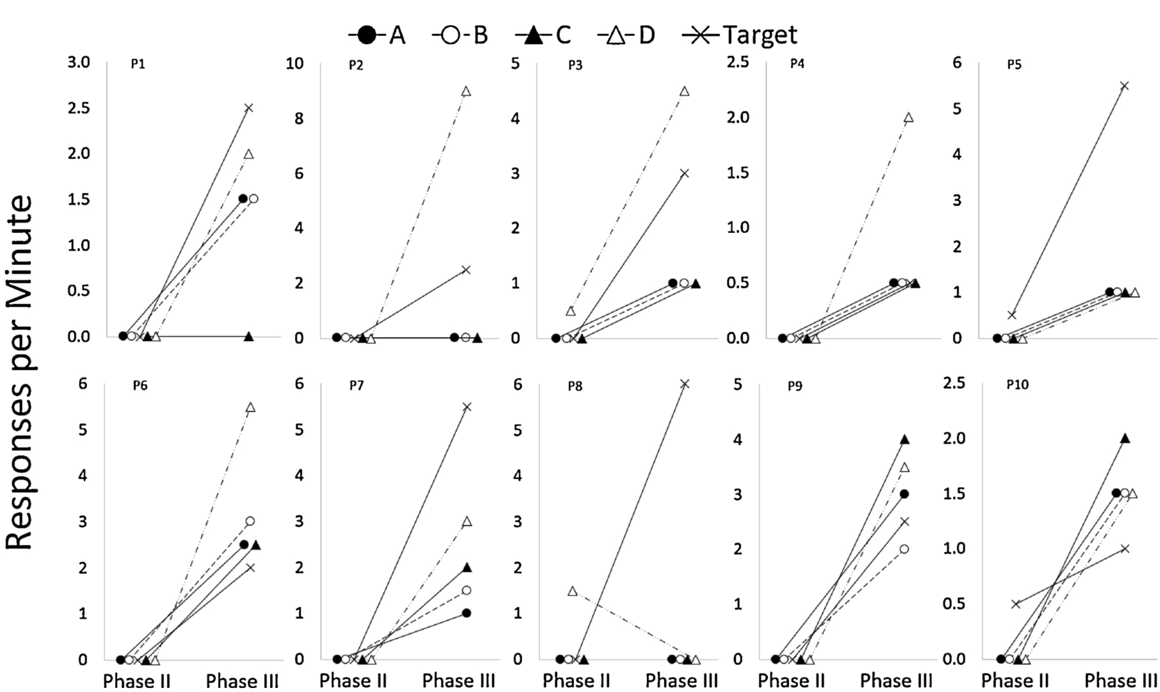

Fig. 3. Individual participant rates of target and control responding across the final 2-min bin in Phase II and the first 2-min bin in Phase III for participants randomly allocated to the four-control responses group. Different markers represent the different control levers from Fig. 1. *Note:* the *y*-axis scale differs across participants.

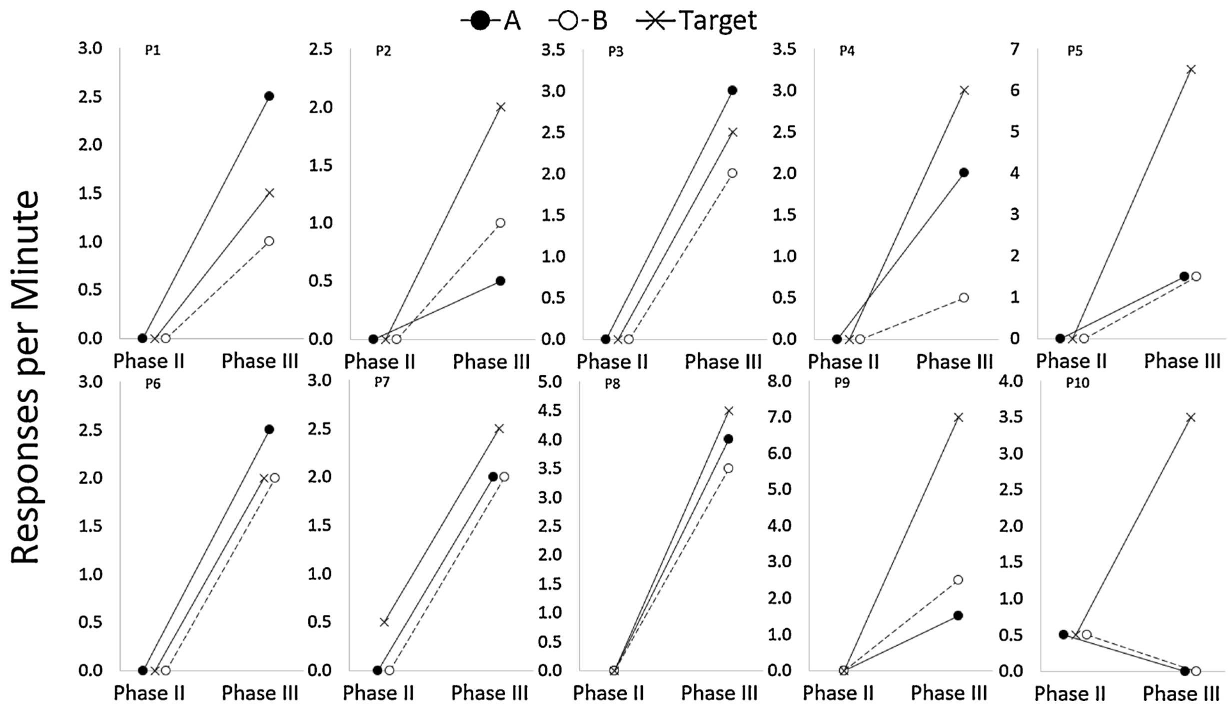

Fig. 4. Individual participant rates of target and control responding across the final 2-min bin in Phase II and the first 2-min bin in Phase III for participants randomly allocated to the two-control responses group. Different markers represent the different control responses from Fig. 1. *Note:* the *y*-axis scale differs across participants.

in this group showed higher rates of target responding at the beginning of Phase III compared to the end of Phase II. Four of the participants displayed at least twice as many responses to one control response compared to the other with two showing greater preference for control A (P1, P4) and two for control B (P2, P9). Of the remaining participants, three more participants showed greater responding to one control over the other (P3, P6, P8), and three showed no difference in rate of responding between the control responses (P5, P7, P10).

4. Discussion

The current study sought to investigate the influence of multiple control responses on responding in a laboratory resurgence procedure with humans. We randomly assigned participants to a condition with two or four control responses. Eight of the 10 participants in the four-control response group showed some degree of preference for one control response over the remaining three control responses, and 7 of the 10 participants in the two-control response group showed preference for one control response over the other. Lastly, all participants showed higher rates of target responding at the beginning of Phase III compared to the end of Phase II.

These data suggest that a faulty rule may have influenced responding during resurgence tests in previous research using a single control with humans (Bolívar et al., 2017; Sweeney and Shahan, 2016). In these studies, reinforcers were delivered for a new response in each of the first two phases. A verbally competent human might have learned an inaccurate rule to "switch to the next response" when a new phase started or the target and alternative were placed on extinction. In previous research, only one option fit this pattern at the beginning of Phase III (Bolívar et al., 2017; Sweeney and Shahan, 2016). Following this rule would result in higher response rates on the one control response – the only "next response" available. In this experiment, there were two or four possible "next responses" available.

We maintained the left-to-right pattern of reinforcement across Phases I and II for the four-control responses group (similar to the "Sequential" group in Bolívar et al., 2017). Reinforcing responses in a left-to-right sequence across Phases I and II left one potential "next response" to be lever A (top panel, Fig. 1). While eight of the participants in this group displayed higher rates of responding to one specific control lever, surprisingly, 6 of the participants displayed highest rates of control responding on lever D during the first minute of Phase III (Fig. 4). This suggests the assumed "next response" was not based on a left-to-right sequence of reinforcement.

In the two-control responses group, we located one control response below the target response and the second control response below the alternative response. This removed the left-to-right pattern of reinforcement across Phases I and II leaving the "next response" in Phase III to be potentially ambiguous. If responding was influenced only by a faulty "next response" rule, we might expect greater responding to one control lever compared to the other at the very beginning of Phase III. Seven participants displayed higher rates of responding to one control response (although the degree of difference varied). In addition, the difference in rate of responding between the highest and 2nd highest control lever was three times lower in the two-control responses group (0.65 responses per min, 95% CI = ± 0.37) compared to the four-control responses group (1.82 responses per minute, 95% CI = ± 1.75). This suggests responding was more evenly distributed between the control responses in Phase III by: controlling for the left-to-right sequence of reinforcement in Phases I and II; having only two control responses; or a combination of both. Future research could differentiate these potential causes by using the same procedures but with all response options moving around the computer screen (e.g., Marstellar and St. Peter, 2012; Sweeney and Shahan, 2016). This would allow the researcher to remove the left-to-right pattern of reinforcement across Phases I and II and isolate the influence of multiple control responses.

The above results should be interpreted with caution. Almost all participants eventually responded on all control responses during Phase III (see Appendix A and Appendix B) and many participants displayed some responding to all controls at the beginning of Phase III. That is, variable control responding across all control responses did eventually occur during Phase III. This suggests rule-governance and extinction-induced variability may have interacted to influence responding during these resurgence tests with verbally competent humans. Nevertheless, the data presented in this experiment add to a growing literature where responding by verbally competent humans during resurgence tests that include inactive control responses differs from nonhuman responding (e.g., Bolívar et al., 2017; Nall et al., 2018; Sweeney and Shahan, 2016).

One limitation to this study, and others that examine resurgence in laboratory contexts with verbally competent humans, is the duration that participants contact experimental conditions. Nonhumans in most laboratory resurgence studies contact dozens of experimental sessions leading to hours of exposure to experimental conditions (e.g., Craig et al., 2018). In contrast, humans in most laboratory resurgence studies contact a single experimental session leading to minutes of exposure to experimental conditions (e.g., Bolívar et al., 2017; Sweeney and Shahan, 2016; c.f., Kuroda et al., 2016). This difference in exposure to experimental conditions may lead to different degrees of stimulus control due to reinforcement for target responding and the absence of reinforcement for control responding. Previous discussions of operant variability suggest that resurgence may be one type of extinction-induced variability (Neuringer and Jensen, 2013), and that the degree of stimulus control may determine the degree to which variability is directed toward the target response over control responses (Liggett et al., 2018). If true, then it is possible humans and nonhumans would display more similar patterns of responding under two conditions: if humans contacted experimental conditions for significantly longer durations, or if nonhumans contacted experimental conditions for significantly shorter durations. Such transspecies research would contribute significantly to understanding how human and nonhuman responding differs in laboratory studies of resurgence.

Another important characteristic of this study, and others that examine human operant behavior in laboratory settings, is the availability of alternative reinforcers for non-experiment-related responding. Nonhumans responding in operant chambers will often show a variety of non-experiment-related responses that contact non-experiment-related reinforcers (e.g., rats may scratch, groom, sniff, or explore the operant chamber). When responding is placed on extinction in Phase III of resurgence preparations, nonhumans can contact known but unmeasured reinforcement for engaging in a variety of known but unmeasured responses (Herrnstein, 1970).

Reinforcers for human responding in operant laboratory experiments are often restricted to the computer task. Humans are often in a laboratory room without access to their cell phones, the Internet, other people, music, or reading material. They could scratch, groom, sniff, or explore the laboratory room. But, to our knowledge, humans have not been reported to show these behaviors. Most people arrive at the laboratory after observing recruitment materials that promise money or class credit for participation, and they are specifically directed to engage in a computer task where the reinforcers that maintain responding within the experiment are delivered only for responses made to the computer task (e.g., points delivered to an on-screen bank). Participants may, therefore, perceive a non-existing contingency between continuing to click the mouse and receiving money or class credit. In addition, many participants likely have a long history of reinforcement for mouse clicking and interacting with computer interfaces. A lack of alternative reinforcement for non-experiment-related responses combined with reinforcement for responding only to the computer task might be why human behavior persists during extinction in Phase III of resurgence studies whereas nonhumans typically do not (e.g., Appendix A, Bolívar et al., 2017; King and Hayes, 2016; Kuroda et al., 2016; Sweeney and Shahan, 2016).

Examining the role of verbal behavior processes is an important area for future research on resurgence. Studies that have failed to observe a difference between target and control responding have primarily used verbally competent adults in their late teens to early twenties (e.g., undergraduate psychology students). Research on resurgence using young children with low-to-moderate verbal functioning has found rates of target responding in Phase III that largely exceed rates of other, functionally equivalent behaviors that were never reinforced in the experimental context (Liggett et al., 2018). Empirically disentangling the impact of unprogrammed verbal behavior from explicitly programmed experimental manipulations can be difficult (e.g., Catania et al., 1982; Matthews et al., 1985; Rosenfarb et al., 1992). However, studies that successfully manipulate verbal behavior and better isolate its role in resurgence might inform preventive measures of relapse in verbally competent humans (e.g., substance abuse populations).

5. Conclusion

We examined behavioral reoccurrence in a resurgence preparation with verbally competent humans. We exposed participants to resurgence procedures involving either two or four inactive control responses. The majority of participants in both groups responded more to one control response compared to all others at the onset of Phase III. This suggests unprogrammed, self-generated rule-governed behavior may have influenced responding in both groups. However, the variability in responding throughout Phase III for many participants indicates a more complex picture where faulty rules and extinction-induced variability interact. Future research will need to devise better methods for isolating rule-governed behavior and extinction-induced variability in studies of resurgence with verbally competent humans.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.beproc.2018.12.003.

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