EVALUATING THE EFFECTS OF CONTINUOUS VS. PARTIAL REINFORCEMENT ON EXTINCTION PERFORMANCE IN THE HUMAN LABORATORY

Maysarah Mohamed[1], William E. Sullivan[1], Nicole M. DeRosa[2], Beatriz Elena Arroyo Antúnez[1], Jacqueline DeBartelo[1], Caroline Cahill[1], & Andrew R. Craig[1]

[1] SUNY UPSTATE MEDICAL UNIVERSITY
[2] THE KELBERMAN CENTER

Recent human-laboratory analyses of extinction performance have demonstrated a lack of sensitivity of human behavior to extinction contingencies. The current experiment aimed to evaluate whether arranging high (continuous reinforcement, CRF) vs. low (partial reinforcement, PRF) rates of reinforcement for human behavior in the laboratory affected extinction performance. Five adults pressed buttons for point reinforcers in two laboratory visits. During each visit, button pressing produced reinforcers for ten, 2-min baseline sessions after which pressing was placed on extinction for twenty, 2-min sessions. During one visit (the CRF condition), every press to a target button resulted in points in baseline. During the other (the PRF condition), target-button pressing produced points according to a variable-interval 10-s schedule in baseline. Button pressing tended to persist across sessions of extinction, but it persisted more in the PRF condition than in the CRF condition for most participants. Extinction also was associated with elevated levels of pressing to inactive buttons that were never associated with reinforcement. Additional work is needed to better understand why human behavior persists during extinction when evaluated in laboratory settings.

Keywords: human laboratory; extinction; persistence; continuous reinforcement; partial reinforcement; button press; humans

The term "extinction" may be used to describe both a procedure and a behavioral outcome (Lattal & Lattal, 2012). Procedurally, extinction refers to suspending delivery of a reinforcer that previously maintained a specified behavior. As a result, behavior undergoes extinction – the rate at which it occurs is reduced over time with continued exposure to conditions of nonreinforcement. Extinction is a fundamental principle in experimental psychology. Behavior during extinction is thought to reveal important information about the way an organism's learning history is brought to bear on current performance (Craig et al., 2015; Craig & Shahan, 2016b, 2018; Gallistel, 2012; Nevin, 2012). Moreover, extinction often is incorporated as a component of interventions aimed at reducing socially significant behavior in human populations (Greer et el., 2016; Lerman & Iwata, 1996; Petscher et al., 2009). Therefore, a thorough understanding of extinction mechanisms may have important implications for both the science and practice of behavior analysis.

The human laboratory has been an invaluable resource for researchers to answer questions that are related to basic behavior outcomes, like extinction learning, for at least two reasons. First, when a functional relation is discovered in the laboratory using nonhuman animals as subjects, it is prudent to evaluate that relation in the human laboratory before it is evaluated in the context of socially significant behavior. Second, relative to other research settings like the behavior clinic or non-human animal laboratory, the human laboratory affords researchers several practical advantages. Often, an entire dataset may be collected in one or a few laboratory visits whereas it may take weeks or months to collect a complete dataset in clinical settings or in the non-human animal laboratory. Participant recruitment often is convenient for researchers, especially for those who work in traditional academic settings with access to classes full of undergraduate students. Further, human-laboratory research may be conducted with a modest budget – simple operant tasks may be arranged with inexpensive materials such as response buttons or microswitches and

Author Note: Address correspondence to: Andrew R. Craig; Golisano Center for Special Needs; SUNY Upstate Medical University; 475 Irving Ave., Suite 300; Syracuse, NY 13202; Email: craig.andrew.ryan@gmail.com

This experiment was completed in partial fulfillment of the first author's MS degree in Behavior Analysis Studies from SUNY Upstate Medical University.

https://doi.org/10.17605/OSF.IO/MCQX8

using inexpensive or free reinforcers like preferred edible items or points.

The utility of human-laboratory research depends on the extent to which the procedures that researchers arrange to study behavior outcomes query the behavior processes that are associated with those outcomes in the natural environment. If, on the one hand, the behavior of participants in the human laboratory responds to environmental manipulations in the same way that the behavior of participants or subjects in other settings does, it is reasonable to believe that similar behavior processes are at play across research settings. On the other hand, if behavior outcomes differ across research settings, correspondence of behavior process across research settings may be less clear. Recent human-laboratory experiments that incorporate extinction offer an illustrative example of what is on the other hand.

For example, Saini et al. (2021, Experiment 2) attempted to study extinction-induced resurgence of adults' button pressing. Three response buttons were placed on a table in front of each participant. Contingencies of reinforcement for button pressing varied across three phases, all of which were experienced in a single laboratory visit. In Phase 1, pressing a specifically colored button (the "target" button) produced points according to a variable-interval (VI) 10-s schedule, and no consequences were arranged for pressing the other two buttons. In Phase 2, target-button presses were placed on extinction, and pressing a second, "alternative", button produced points according to a VI 10-s schedule. Finally, extinction was arranged for presses to all buttons during Phase 3. Based on research on resurgence from other research settings (e.g., Craig & Shahan, 2016a; Sullivan et al., 2020), Saini et al. expected to see: 1.) target behavior initially increase during Phase 3 relative to the level at which it occurred at the end of Phase 2 (i.e., resurgence); 2.) target behavior decrease to low levels as Phase 3 progressed; and 3.) alternative-button pressing decrease to low levels across sessions of Phase 3. Instead, participants' button pressing persisted at stable rates across the ten, 2-min sessions of Phase 3, and participants allocated responses indiscriminately across response options. Similar outcomes have been reported by a growing number of human-laboratory researchers (e.g., Bolívar et al., 2017; Bolívar & Dallery, 2020; Cox et al., 2019; Sweeney & Shahan, 2016; Thrailkill & Alcalá, 2022).

Outcomes such as those described above suggest behavior may come under the control of factors other than its programmed consequences during human-laboratory analyses of extinction. For example, human behavior may come under the control of experimenter- or self-imposed rules that promote persistence of responding and allocation of behavior between response alternatives. Indeed, rule governance and instructional control have been shown to strongly influence human behavior in laboratory settings (Baron & Galizio, 1983; Galizio, 1979; Weiner, 1970). For example, based on a history of reinforcement and extinction for multiple operant responses within the experimental setting, participants may self-impose a rule such as, "try different responses when the most-recently productive response stops producing reinforcement" that might encourage persistent and undifferentiated responses. Demand characteristics associated with human-laboratory tasks may also influence participants' behavior (Baron & Perone, 1982), as may the reactivity of human behavior to observation during these tasks. Participants may, for example, perceive an expectation on the part of the experimenter that they will continue engaging in task-specified operant behavior even after reinforcement for that behavior is suspended. They may also change their behavior in a way that is inconsistent with prevailing contingencies simply because they are being observed (the Hawthorne effect; Adair, 1984).

These outcomes may also be related to specific experimental parameters that are used to study extinction learning. For example, a widely documented finding in the extinction literature is that, when behavior is trained under a simple schedule of reinforcement (i.e., not a multiple schedule) and subsequently extinguished, resistance to extinction is negatively related to the rate at which reinforcers previously were delivered (e.g., Baum, 2012; Cohen, 1998; Craig & Shahan, 2016a; Shull & Grimes, 2006). A special case of this functional relation is the "partial-reinforcement extinction effect," which is the name given to the finding that behavior previously maintained by a partial-reinforcement (PRF) schedule tends to persist to a greater degree during extinction relative to behavior previously maintained by a continuous-reinforcement (CRF) schedule (e.g., Nevin & Grace, 2005). The partial-reinforcement extinction effect has been documented in a variety of settings, including the human laboratory (e.g., Gray et al., 2002; Miyao & Meyers, 1973; Svartdal, 2000; Thrailkill, 2023).

Each of the studies cited earlier that have demonstrated atypical extinction performance in the human laboratory used PRF schedules. Bolívar et al. (2017), Bolívar and Dallery (2020), Cox et al. (2019), and Saini et al. (2021) used VI schedules with mean interreinforcer intervals ranging from 10 – 20 s; Sweeney and Shahan (2016) used a discrete-trial procedure with the probability of reinforcement per trial ranging from .8 to .1; and Thrailkill and Alcalá (2022) used a variable-ratio 24 schedule. These reinforcement schedules are certainly not atypical when compared to the reinforcement schedules used in laboratory analyses of extinction with non-human animals. It may be the case, however, that such schedule arrangements when used in the human laboratory with the specific procedures these authors arranged are sufficiently thin to promote persistence during extinction.

The current experiment explored this possibility. Adult participants completed a human-laboratory task like the one used by Saini et al. (2021). The major difference between the current procedure and the Saini et al. procedure is that the current experiment used only two phases (baseline and extinction) instead of the three-phase resurgence preparation used by Saini et al. A phase of extinction plus alternative reinforcement was omitted from the current experiment for two reasons. First, the major outcome of interest in this study was resistance to extinction, not resurgence. A phase of extinction plus alternative reinforcement was not necessary to explore this outcome. Second, as described earlier, it is reasonable to believe that a history of reinforcement and extinction for multiple responses may result in at least partial control of behavior during extinction by self-imposed rules that promote persistent responding and/or response variability. Focusing the analysis on a single operant response instead of several serially trained responses thus may permit clearer assessment of the effects of reinforcer rates on resistance to extinction using procedures otherwise like those reported by Saini et al.

Each participant experienced two conditions that were arranged in separate laboratory visits. In the CRF condition, points were delivered for participant's target-button pressing according to a fixed-ratio (FR) 1 schedule. In the PRF condition, target-button pressing produced reinforcement according to a VI 10-s schedule. The order of condition presentation was counterbalanced across participants because previous research has demonstrated that resistance to extinction tends to decrease across successive exposures to extinction contingencies (e.g., Anger & Anger, 1967; Davenport, 1969; Clark, 1964; Craig et al., 2019).

METHOD

Participants, Apparatus, and Setting

Five adult participants (three female) were recruited to participate in the study through word of mouth. Their ages ranged from 20 to 36 years old. The following inclusion and exclusion criteria were used to screen participants. Participants needed to be able to perform the essential gross motor skill required for the task (i.e., pressing a button) and would have been excluded if they reported colorblindness. Based on these criteria, no participants were excluded.

Sessions were conducted in a quiet room equipped with a table, chairs, MotivAider timer, laptop computer, and three BIGmack response buttons that produced a tone that lasted approximately 1 s when pressed. The tone produced by the response buttons functioned as a change-over delay (see below). The participant and the experimenter were present in the room. The sessions were video recorded for data-collection purposes. Data were collected from videotaped sessions by trained observers using the BdataPro program (Bullock et al., 2017) equipped on laptop computers. All procedures reported below were approved by SUNY Upstate Medical University's Institutional Review Board.

Response Definition and Interobserver Agreement

A correct response was defined as a participant pressing a response button and waiting for the button's tone to end to emit another response. If a participant emitted a button press while the tone from an earlier button press was playing, the response was considered incorrect. Corrective feedback was provided when incorrect responses occurred (which was infrequent).

Condition	Variable	P1	P2	P3	P4	P5
PRF	Target Presses	92.38	96.94	93.30	92.88	98.49
	Inactive 1 Presses	95.57	94.86	90.58	93.84	98.02
	Inactive 2 Presses	96.80	98.33	87.24	90.80	98.13
	Reinforcers	97.07	100	94.13	81.74	95.09
CRF	Target Presses	96.51	98.02	98.92	92.15	98.20
	Inactive 1 Presses	95.17	100	99.52	92.15	98.74
	Inactive 2 Presses	98.13	99.58	98.28	92.15	98.29
	Reinforcers	98.62	100	99.75	87.09	98.21

Table 1. Interobserver agreement. Note: Values show percentages of agreement.

Two observers independently collected data on participants' button presses and reinforcer deliveries. Interobserver agreement (IOA) was calculated for each of these variables for each participant by dividing the smaller number of recorded occurrences by the larger number and multiplying by 100 to convert the quotient to a percentage. IOA was calculated for every session for target, Inactive 1, and Inactive 2 button presses, and it was calculated only during baseline sessions for reinforcer deliveries. A summary of IOA outcomes may be found in Table 1.

Experimental Design

All participants attended two laboratory appointments. We used an AB (counterbalanced BA) within-subjects design to conduct the experiment. The A condition was the PRF condition, and the B condition was the CRF condition. Each condition consisted of a baseline phase followed by an extinction test. The purpose of incorporating a counterbalanced design was to control for any effects on extinction performance produced by repeated testing.

Procedure

During the initial laboratory visit, the last author met with each participant to obtain informed consent. Each laboratory visit lasted approximately 90 min and consisted of 30 sessions: 10 baseline and 20 extinction. Sessions were 2 min in duration. Before starting the experiment, participants were presented with a standardized script stating the rules. The experimenter read the following rules to the participant:

> "Welcome to our study of reward learning. Your task today will be completed using circle BIGmack buttons. BIGmack buttons will be presented to you on the table and equidistant from one another. The game will require you to press the different colored buttons. You will use your pointer finger to respond by pressing any of the three BIGmack buttons. Pressing the buttons will sometimes result in point gain. In between every press of the colored buttons, you need to wait until the tone turns off. Your responses to the colored buttons will not count if you press another button or the same button while the tone is still playing. Your goal is to earn as many points as possible. How you respond is completely up to you, and you can stop responding at any time during the experiment. In the event of an emergency or if you wish to withdraw from the experiment, you may notify the experimenter and can exit the room at any time. Watches and cellular devices are to be stored away. Do you have any questions?"

The participants were presented with three BIGmack buttons, and one button was covertly selected to function as the target-response button by the experimenter. The buttons were positioned in an arc in the middle of the table, equidistant from each other and the participant. As mentioned previously, each button press produced a tone that lasted approximately 1 s. The purpose of incorporating the tone was to serve as a change-over delay to reduce the likelihood of adventitious reinforcement of switching (e.g., Shahan & Lattal, 1998) and to prevent rapid responding. A MotivAider timer was used to time the sessions. During baseline, pressing the target-response button sometimes resulted in point delivery. Points were accumulated on a scoreboard and increased in increments of 15 points per delivery. The experimenter oversaw the delivery of the points and sat in front and to the right of the participant.

If a participant emitted an incorrect response, the experimenter said, "Remember, you need to wait for this tone to end for your responses to count." If a participant moved the buttons from their original place, the experimenter said, "The buttons will need to remain in the same place for the duration of the session," before resetting their locations. Between sessions, the buttons' positions were randomized. After a participant completed their second laboratory visit, the experimenter completed an informal interview with them. The interview consisted of questions about what the participant thought the game was about, why they responded as they did, and their thoughts while completing the game.

Two participants were recruited to participate in the CRF condition first and then the PRF condition in the next appointment while the other three participants experienced conditions in the reversed order. The participants' two laboratory appointments were at least five days apart and no more than 14 days apart.

PRF Condition

During the baseline phase of the PRF condition, participants were presented with blue, yellow, and orange BIGmack buttons. During the phase and for every participant, pressing the orange button was reinforced on a VI 10-s schedule. That is, for every participant, pressing the orange BIGmack button resulted in point gain following a variable period of time since the last reinforcer delivery, the average of which was 10 s. All VI schedules were constructed using Fleshler and Hoffman's (1962) method. Expiration of a variable interval was signaled to the experimenter by a PowerPoint ® slide deck that automatically advanced after prespecified periods of time. The PowerPoint played on a laptop computer, and the screen of the laptop was out of the participant's view. Using the MotivAider, the experimenter timed the 2-min sessions. After each session was finished, the participant was notified that the session was over, and the experimenter set up for the next session (i.e., point cards were collected, and button positions were randomized). The inter-session interval was roughly 10 s.

During the extinction phase of the PRF condition, target responses were no longer reinforced. Using the MotivAider, the experimenter timed the 2-min sessions. After each session was finished, the participant was notified, and the experimenter set up for the next session.

CRF Condition

During the baseline phase for the CRF condition, participants were presented with red, brown, and purple BIGmack buttons. During the phase and for every participant, pressing the purple button was reinforced on an FR 1 schedule. That is, the participants received 15 points each time they pressed the purple BIGmack button (provided the button press did not occur during a tone presentation). The laptop computer that was used in the PRF condition to signal reinforcer availability to the experimenter was positioned identically in the room during the CRF condition, but it was not used to signal reinforcer availability. Using the MotivAider, the experimenter timed the 2-min sessions. After each session was finished, the participant was notified that the session was over, and the experimenter set up for the next session (i.e., point cards were collected, and button positions were randomized). The inter-session interval was roughly 10 s.

During the extinction phase of the CRF condition, target responses were no longer reinforced. Using the MotivAider, the experimenter timed the 2-min sessions. After each session was finished, the participant was notified, and the experimenter set up for the next session.

RESULTS

Reinforcer Rates

Table 2 shows the mean and standard deviation (SD) of the rate of reinforcement for all five participants during baseline phases. The left side shows the mean and SD from the PRF condition, and the right side shows these data from the CRF condition. Participant 4 showed the largest difference in reinforcement rates between conditions, and Participant 2 showed the smallest difference between conditions. Each

	Condition			
	PRF		CRF	
Participants	*M*	*SD*	*M*	*SD*
P1	4.24	0.78	41.93	0.79
P2	2.81	1.26	9.04	4.33
P3	3.81	0.66	28.58	8.86
P4	4.43	0.60	43.54	5.07
P5	4.88	0.48	24.88	2.47

Table 2. Baseline reinforcer rates.

participant earned a higher rate of reinforcement in the CRF condition than in the PRF condition.

Overall Performance

Figure 1 shows button presses per minute during the PRF and the CRF conditions for each participant. The left panels show response rates during the PRF condition, and the right panels show these data from the CRF condition. The black circle data paths represent target-button presses, and the white square and white triangle data paths represent inactive-button presses.

The top panels show data from Participant 1. During the PRF condition, the participant pressed all three buttons throughout most of the baseline phase. Target-button pressing occurred at a higher rate than inactive-button pressing after the first three sessions. Presses to either of the inactive buttons were undifferentiated across baseline. When the extinction phase was introduced, Participant 1 pressed all three buttons with no clear overall decrease in response rates across sessions. During the CRF condition, Participant 1 allocated nearly all their button presses toward the target button in all sessions of baseline. When the extinction phase was introduced, Participant 1 allocated nearly all their button presses toward the Inactive 2 button. Target-button presses decreased and remained at a lower level, along with presses to the Inactive 1 button, for the remainder of the extinction phase.

The second-from-top panel of Figure 1 shows outcomes for Participant 2. During the PRF condition, Participant 2 pressed the target button more frequently than the inactive buttons across most sessions in the baseline phase. They pressed the inactive buttons in Sessions 2, 3, 4, 5, and 8. When the extinction phase was introduced, Participant 2 pressed all three buttons, and overall rates of button pressing tended to decrease across sessions of the phase. During the CRF condition, Participant 2 nearly exclusively allocated button presses to the target button. When the extinction phase was introduced, target-button pressing decreased across sessions but persisted to some degree throughout the phase. As in baseline, Participant 2 allocated nearly all their presses to the target button during extinction.

The middle panels in Figure 1 show outcomes for Participant 3. During the PRF condition, the participant allocated a roughly equal number of presses to each of the buttons across sessions. When the extinction phase was introduced, pressing remained undifferentiated across buttons. The rate at which Participant 3 engaged in button pressing, however, decreased across sessions of the phase. During the baseline phase in the CRF condition, Participant 3 allocated nearly all their button presses toward the target button, with the exception of the first few sessions of the phase. When the extinction phase was introduced, the participant allocated their presses roughly equally between buttons. Overall rates of button pressing tended to decrease across sessions of the phase.

The second-from-bottom panel in Figure 1 shows outcomes from Participant 4. During the PRF condition, Participant 4 pressed the target button more frequently than the inactive buttons in most sessions of the baseline phase. During the extinction phase, Participant 4 continued to allocate more presses to the target button, but the response-rate difference between buttons decreased over sessions, as did the overall rate of button pressing. During the CRF condition, Participant 4 allocated nearly all their button presses toward the target button following the first session of the baseline phase. When the extinction phase was introduced, Participant 4 initially engaged in higher rates of target-button pressing than inactive-button pressing. After Session 20 of the condition, the participant allocated presses roughly equally between buttons. Overall, response rates decreased across sessions of the phase, though session-to-session changes in rates of button pressing were nonsystematic.

The bottom panel of Figure 1 shows outcomes for Participant 5. During the PRF condition, Participant 5 tended to allocate more button presses toward the target button than toward the inactive buttons, but this difference was modest. When the extinction phase was introduced, Participant 5 continued to equally allocate presses between buttons. Rates of target-button pressing slightly decreased by the end of the extinction phase, but overall response rates

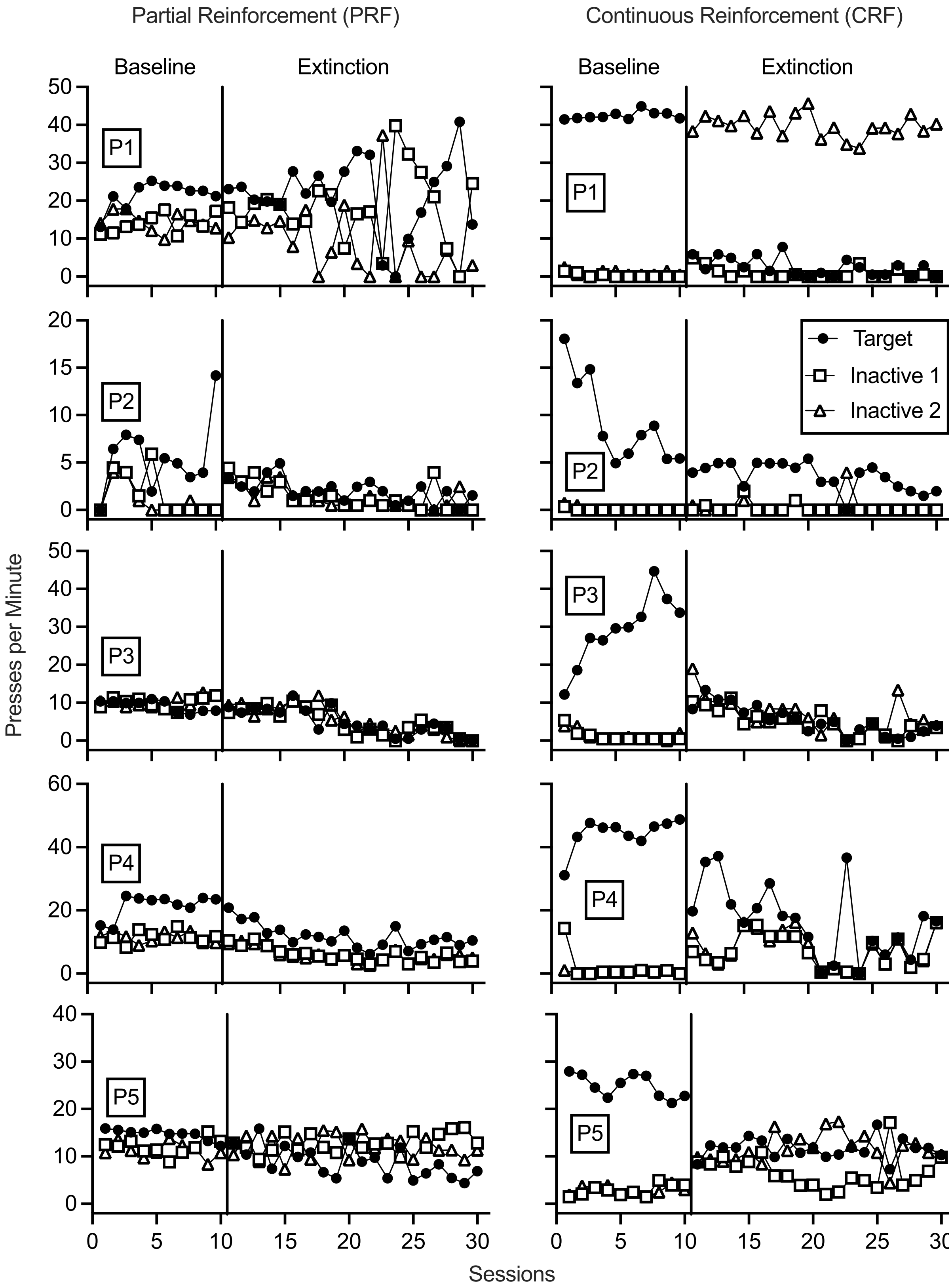

Figure 1. Presses per minute across sessions of the PRF and CRF conditions.

remained comparable to those observed during baseline. During the CRF condition, Participant 5 allocated more presses toward the target button than toward the inactive buttons, and rates of inactive button pressing were low and variable across sessions. When the extinction phase was introduced, target button pressing decreased to a lower level compared to the baseline phase and thereafter continued at a moderate level for the rest of the extinction phase. Responses allocated toward the inactive buttons increased during the extinction phase and were variable throughout. Participant 5 allocated more presses toward the Inactive 2 button than toward the Inactive 1 button during most sessions.

Inactive-button Pressing Within and Between Conditions

Figure 2 shows the mean (plus SD) rate of button presses allocated toward the inactive buttons during the baseline and extinction phases of the PRF and the CRF conditions. The top panel shows outcomes for Participant 1. During the PRF condition, Participant 1's mean rate of inactive-button pressing was similar between the baseline and the extinction phase. During the CRF condition, the rate of inactive pressing increased from the baseline phase to the extinction phase. Inactive-button pressing tended to be higher during baseline in the PRF than in the CRF condition, and it was lower during extinction in the PRF condition relative to the CRF condition.

The second-from-top panel of Figure 2 shows inactive-button pressing for Participant 2. During the PRF condition, Participant 2 pressed the inactive buttons at roughly equal rates in the baseline and extinction phases. During the CRF condition, Participant 2 pressed the inactive buttons at low rates in both the baseline and extinction phases, but rates of inactive-button pressing were higher during extinction than during baseline. Rates of inactive-button pressing were higher in the PRF condition than in the CRF condition during both baseline and extinction phases.

The middle panel of Figure 2 shows inactive-button pressing for Participant 3. During the PRF condition, Participant 3 pressed the inactive buttons more frequently in the baseline phase than in the extinction phase. During the CRF condition, Participant 3 pressed the inactive buttons less frequently in the baseline phase than

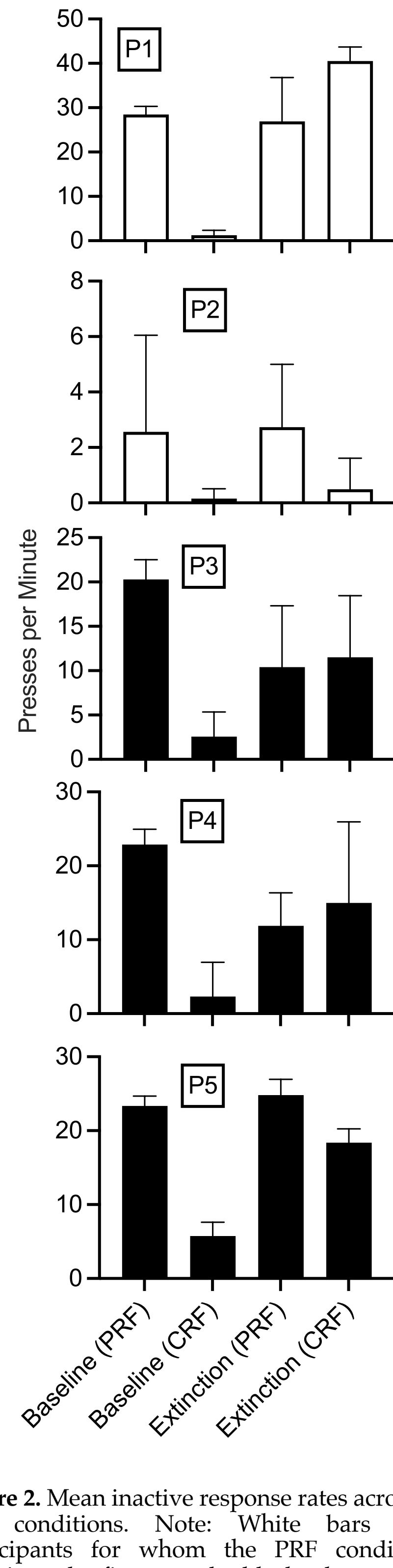

Figure 2. Mean inactive response rates across phases and conditions. Note: White bars represent participants for whom the PRF condition was experienced first, and black bars represent participants for whom the CRF condition was first. Error bars represent SD.

in the extinction phase. Participant 3 engaged in more inactive-button presses in the PRF condition than in the CRF condition during baseline phases. The participant engaged in comparable rates of inactive button pressing during extinction phases with slightly higher rates in the CRF condition than in the PRF condition.

The second-from-bottom panel of Figure 2 shows inactive-button pressing for Participant 4. During the PRF condition, Participant 4 pressed the inactive buttons more frequently in baseline than in extinction. During the CRF condition, Participant 4 pressed the inactive buttons less frequently in baseline than in extinction. They showed higher rates of inactive-button pressing during baseline in the PRF condition than in the CRF condition. Moreover, they showed similar rates of inactive-button pressing across conditions during extinction with slightly more inactive-button pressing in the CRF condition than in the PRF condition.

Finally, the bottom panel of Figure 2 shows inactive-button pressing for Participant 5. During the PRF condition, Participant 5 pressed the inactive buttons at roughly equal rates in the baseline and extinction phases. During the CRF condition, Participant 5 pressed the inactive buttons less frequently in baseline than in extinction. Across conditions, Participant 5 pressed the inactive buttons more frequently in the PRF condition than in the CRF condition during baseline phases. They pressed the inactive buttons more frequently in the PRF condition than in the CRF condition during extinction phases.

Relative Resistance to Extinction

Relative resistance to extinction (Grace & Nevin, 1997) was used to evaluate between-condition differences in rates of extinction. To calculate this measure, proportion-of-baseline rates of button pressing were calculated by dividing rates of button pressing in each session of extinction by the mean rate at which it occurred during the preceding baseline phase. Next, average proportion of baseline across sessions of extinction was calculated separately for each condition. Then, those means were log transformed, and the value from the CRF condition was subtracted from the value from the PRF condition. Relative resistance to extinction was calculated using both rates of target-button pressing and rates aggregated across buttons.

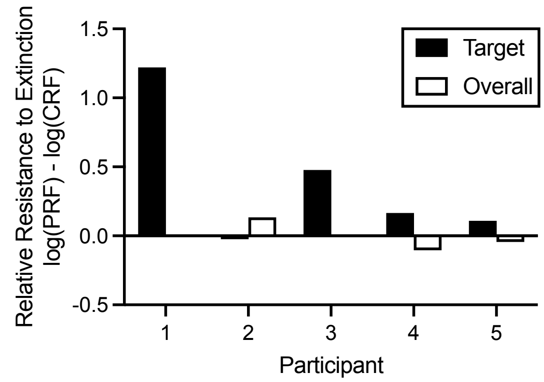

Figure 3. Relative resistance to extinction.

The outcomes from this analysis are shown in Figure 3. Black bars represent the analysis using rates of target-button pressing, and white bars represent the analysis using overall rates of button pressing. Positive values indicate greater resistance to extinction in the PRF condition than in the CRF condition, and negative values indicate greater resistance to extinction in the CRF condition than in the PRF condition.

For the analysis using rates of target-button pressing, relative resistance to extinction was positive for all participants except Participant 2. For Participant 2, this measure was near zero. For the analysis using overall rates of button pressing, relative resistance to extinction was positive for Participant 2, negative for Participant 4, and near zero for Participants 1, 3, and 5. Recall that Participants 1 and 2 experienced the PRF condition first and the CRF condition second, and Participants 3, 4, and 5 experienced conditions in the opposite order. Relative resistance to extinction did not appear to depend on condition order whether based on rates of target or overall button pressing.

DISCUSSION

Recent laboratory analyses of extinction performance in humans have generated outcomes that are inconsistent with extinction analyses from laboratory and applied settings. Specifically, the targeted operant responses of adult humans in these experiments tended to persist, even though they no longer produced reinforcers. This experiment aimed to systematically replicate the procedures used by Saini et al. (2021) to evaluate whether the rate at which reinforcers were delivered during baseline may be associated with the persistent responding observed in these experiments. Participants completed both CRF (FR 1) and PRF (VI 10 s) baseline phases during which their target-button pressing produced point reinforcers, and after both of which extinction performance was assessed. Several outcomes from this experiment are noteworthy.

During baseline phases, participants tended to allocate a larger proportion of their presses toward the target button in the CRF condition than in the PRF condition. Relative to the PRF condition, a larger proportion of target-button presses were reinforced in the CRF condition. Thus, the operant response-reinforcer contingency may have been more salient during baseline in the CRF condition than in the PRF condition, resulting in proportionally more target button presses in the CRF condition (see Nevin, 2009). This outcome may also be described from the perspective of the matching law. Herrnstein (1970) argued that the rate at which a behavior occurs is proportional to the rate of reinforcement for that behavior relative to other competing sources of reinforcement in the environment. Presumably, extraneous sources of reinforcement in participants' environments were equivalent between CRF and PRF conditions in the present experiment. Therefore, one would expect higher rates of target-button presses in the CRF condition than in the PRF condition because the CRF condition was always associated with a higher rate of reinforcement (see Table 2). Because all behavior takes time (Baum, 2004), one may reasonably expect increased rates of target-button pressing in the current experiment to be associated with decreased rates of other behaviors, including inactive-button pressing.

Differences in the way that participants allocated their button presses during the CRF and PRF baselines may also point to differences in the extent to which the contingencies on target-button pressing were sufficient to exert control over behavior. On the one hand, CRF resulted in clear and immediate differentiation in rates of target- and inactive-button pressing, with target-button pressing occurring at high rates and inactive-button pressing occurring at near-zero rates. PRF, on the other hand, resulted in smaller and less consistent differences in rates of button pressing. It is important to note, however, that all participants except Participant 3 pressed the target button more frequently than either of the inactive buttons during most baseline sessions in the PRF condition, thus demonstrating a reinforcement effect. Nevertheless, these data suggest that the rate of reinforcement for an operant response in human-laboratory arrangements may affect the researcher's ability to demonstrate experimental control.

When extinction was introduced in the CRF condition, rates of inactive button pressing increased for every participant. In the PRF condition, rates of inactive button pressing did not change as systematically between baseline and extinction phases. Moreover, during extinction phases, rates of inactive-button pressing did not differ between conditions. In the absence of reinforcement contingencies in both the CRF and PRF conditions, participants may have adopted a strategy of sampling available responses. Similar findings have been reported by others (Bolívar et al., 2017; Bolívar & Dallery, 2020; Cox et al., 2019; Saini et al., 2021; Sweeney & Shahan, 2016; Thrailkill & Alcalá, 2022), suggesting that whatever process gave rise to inactive-button pressing in the current experiment may be general to other human-laboratory preparations.

Participants in the current experiment continued to press buttons across sessions of extinction to degrees that varied between participants and conditions. Nevertheless, for most participants, overall response rates tended to decrease during extinction. This finding may usefully be compared to those reported by Saini et al. (2021) because the current procedure was a systematic replication of the procedure they used. When Saini et al. arranged extinction for all responses, the rate at which participants pushed buttons was consistent across sessions of extinction. We made three major changes to the Saini et al. procedure that may account for these differences.

First, the COD in the present experiment entailed a 1-s tone sounding after each response during which time participants were instructed not to press any other buttons. Following each response, Saini et al. physically blocked participants from pressing other buttons by covering the buttons with a piece of construction paper. It is unclear why these different COD modalities would differentially impact performance, but such effects may exist. Second, in the current experiment, a single experimenter was present in the room with participants while they performed the laboratory task, whereas four experimenters (one to deliver points, one to track reinforcer availability, and two data collectors) were present in the room with participants in Saini et al. (2021). To the extent that the presence of additional observers may increase reactivity or exacerbate perceived experimenter expectations, it may be the case that the larger number of research personnel monitoring participant behavior in Saini et al. contributed to increased response persistence. Finally, participant responses in the current experiment contacted reinforcement for pressing only one button per condition, whereas participants in the Saini et al. study contacted reinforcement for pressing target and alternative buttons across phases before they introduced extinction. As described earlier, serial-response training may set the occasion for participants to develop self-imposed rules that enhance persistence relative to single-response training. That is, following serial-response training, participants might develop a rule such as, "When one response stops producing reinforcement, I should continue to explore other responses because that was a recently productive strategy." These possibilities present areas for future methodological human-laboratory research.

Relative resistance-to-extinction measures suggested that target-button pressing tended to decrease more completely in extinction phases that followed the CRF baseline than those that followed the PRF baseline. This outcome is consistent with the broader literature on reinforcer-rate effects on resistance to extinction. They are also consistent with outcomes from other human-laboratory analyses of the partial-reinforcement extinction effect. For a recent example, Thrailkill (2023) evaluated the effects of presenting edible reinforcers during every trial (CRF) or only on some trials (PRF) of a discrete-trial procedure on resistance to extinction of key pressing in humans. Thrailkill's experiment included manipulations of both the conditioning context (the background color on a computer screen) across phases and the probability of reinforcement per trial (CRF vs. PRF) across experiments and groups, but the most relevant group comparisons for present purposes were between his CRF-B and PRF-B groups in Experiment 2. These groups experienced reinforcement and extinction for key pressing in the same context. Key pressing was more resistant to extinction for participants in the PRF-B group relative to participants in the CRF-B group. Thus, the effects of reinforcer rates on resistance to extinction identified in the current experiment appear to be general across human-laboratory preparations.

Even though button pressing appeared to decrease across sessions of extinction, it still occurred at elevated rates for most participants by the end of most extinction phases. Moreover, relative resistance to extinction of aggregated button pressing varied non-systematically around zero across participants (see Figure 3), suggesting no differential tendency for button pressing to decrease on the whole between conditions. It may be the case that factors that were not directly explored in the current experiment, like demand characteristics, rule-governance, or participant reactivity, resulted in participants continuing to press buttons across sessions of extinction testing. Future research may aim to explore these possible determinants of extinction performance in the human laboratory systematically.

Idiosyncratic factors may also affect human behavior in laboratory settings. For example, during the informal interview following completion of participants' second laboratory visit, Participant 1 indicated that they pressed a specific inactive response during extinction in the CRF condition because they liked the color of the button. Moreover, Participant 2 indicated that they responded slowly during baseline in the PRF condition because the task was boring. The remaining participants reported self-imposed rule such as following a specific sequence to receive reinforcement. Collection and analysis of qualitative data may help to illuminate the effects of such variables in human-laboratory analyses.

Not every recent human-laboratory analysis of extinction has produced persistent responding across response alternatives regardless of the reinforcement histories associated with those alternatives. For example, Podlesnik and his colleagues (Podlesnik et al., 2022; Ritchey et al., 2023) often obtain reasonable suppression of participants' behavior during extinction testing using a procedure delivered over Amazon Mechanical Turk, as do St. Peter and colleagues (e.g., Diaz-Salvat et al., 2020; Kestner et al., 2018; Romano & St. Peter, 2017) using a computer-based laboratory assessment. In general, the specific procedures used in human-laboratory analyses of extinction and related phenomena tend to vary widely across laboratories. Thus, the specific reasons some laboratories fail to produce expected outcomes while other laboratories consistently produce those outcomes are uncertain. Exploring the effects of relevant between-laboratory methodological differences on resistance to extinction is an important area for future research.

Conclusions

Outcomes from the present study suggest that delivering high rates of reinforcement for human behavior in the laboratory may facilitate subsequent extinction of that behavior. Nevertheless, factors such as demand characteristics, rule governance, participant reactivity to observation, and idiosyncratic variables may also influence these outcomes. Gaining a complete understanding of extinction performance in the human laboratory will require research on each of these potential sources of behavior control.

REFERENCES

Adair, J. G. (1984). The Hawthorne effect: A reconsideration of the methodological artifact. *Journal of Applied Psychology*, *69*, 334-345. https://doi.org/10.1037/0021.9010.69.2.334

Anger, D., & Anger, K. (1967). Behavior change during repeated eight-day extinction. *Journal of the Experimental Analysis of Behavior*, *26*, 181-190. https://doi.org/10.1901/jeab.1976.26-181

Baron, A., & Galizio, M. (1983). Instructional control of human operant behavior. *The Psychological Record*, *33*, 495-520.

Baron, A., & Perone, M. (1982). The place of the human subject in the operant laboratory. *The Behavior Analyst*, *5*, 143-158. https://doi.org/10.1007/BF03392383

Baum, W. M. (2004). Molar and molecular views of choice. *Behavioural Processes*, *30*, 349-359. https://doi.org/10.1016/j.beproc.2004.03.013

Baum, W. M. (2012). Extinction as discrimination: The molar view. *Behavioural Processes*, *90*, 101-110. https://doi.org/10.1016/j.beproc.2012.02.011

Bolívar, H. A., Cox. D. J., Barlow, M. A., & Dallery, J. (2017). Evaluating resurgence procedures in a human operant laboratory. *Behavioural Processes*, *140*, 150-160. https://doi.org/10.1016/j.beproc.2017.05.004

Bolívar, H. A., & Dallery, J. (2020). Effects of response cost magnitude on resurgence of human operant behavior. *Behavioural Processes*, *178*, 104187. https://doi.org/10.1016/j.beproc.2020.104187

Bullock, C. E., Fisher, W. W., & Hagopian, L. P. (2017). Description and validation of a computerized behavioral data program: "BDataPro". *The Behavior Analyst*, *40*, 275-285. https://doi.org/10.1007/s40614-016-0079-0

Clark, F. C. (1964). Effects of repeated VI reinforcement and extinction upon operant behavior. *Psychological Repots*, *15*, 943-955. https://doi.org/10.2466/pr0.1964.15.3.943

Cohen, S. L. (1998). Behavioral momentum: The effects of the temporal separation of rates of reinforcement. *Journal of the Experimental Analysis of Behavior*, *69*, 29-47. https://doi.org/10.1901/jeab.199869-29

Cox, D. J., Bolívar, H. A., & Barlow, M. A. (2019). Multiple control responses and resurgence of human behavior. *Behavioural Processes*, *159*, 93-99. https://doi.org/10.1016/j.beproc.2018.12.003

Craig, A. R., Cunningham, P. J., & Shahan, T. A. (2015). Behavioral momentum and accumulation of mass in multiple schedules. *Journal of the Experimental Analysis of Behavior*, *103*, 437-449. https://doi.org/10.1002/jeab.145

Craig, A. R., & Shahan, T. A. (2016a). Behavioral momentum theory fails to account for the effects of reinforcement rate on resurgence. *Journal of the Experimental Analysis of Behavior*, *105*, 375-392. https://doi.org/10.1002/jeab.207

Craig, A. R., & Shahan, T. A. (2016b). Experience with dynamic reinforcement rates decreases resistance to extinction. *Journal of the Experimental Analysis of Behavior*, *105*, 291-306. https://doi.org/10.1002/jeab.196

Craig, A. R., & Shahan, T. A. (2018). Multiple schedules, off-baseline reinforcement shifts, and resistance to extinction. *Journal of the Experimental Analysis of Behavior*, *109*, 148-163. https://doi.org/10.1002/jeab.300

Craig, A. R., Sweeney, M. M., & Shahan, T. A. (2019). Behavioral momentum and resistance to extinction across repeated extinction tests. *Journal of the Experimental Analysis of Behavior*, *112*, 290-309. https://doi.org/10.1002/jeab.557

Davenport, J. W. (1969). Successive acquisitions and extinctions of discrete bar-pressing in monkeys and rats. *Psychonomic Science*, *16*, 242-244. https://doi.org/10.3758/BF03332665

Diaz-Salvat, C. C., St. Peter, C. C., & Shuler, N. J. (2020). Increased number of responses may account for reduced resurgence following serial training. *Journal of Applied Behavior Analysis*, *53*, 1542-1558. https://doi.org/10.1002/jaba.686

Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, *5*, 529-530. https://doi.org/10.1901/jeab.1962.5-529

Galizio, M. (1979). Contingency-shaped and rule-governed behavior: Instructional control of human loss avoidance. *Journal of the Experimental Analysis of Behavior, 31*, 53-70. https://doi.org/10.1901/jeab.1979.31-53

Gallistel, C. R. (2012). Extinction from a rationalist perspective. *Behavioural Processes, 90*, 66-80. https://doi.org/10.1016/j.beproc.2012.02.008

Grace, R., & Nevin, J. (1997). On the relation between preference and resistance to change. *Journal of the Experimental Analysis of Behavior, 67*, 43-65. https://doi.org/10.1901/jeab.1997.67-43

Gray, N. S., Pickering, A. D., Snowden, R. J., Hemsley, D. R., & Gray, J. A. (2002). The partial reinforcement extinction effect in humans: Effects of schizophrenia, schizotypy and low doses of amphetamine. *Behavioural Brain Research, 18*, 333-342. https://doi.org/10.1016/s0166-4328(02)00019-0

Greer, B. D., Fisher, W. W., Saini, V., Owen, T. M., & Jones, J. K. (2016). Functional communication training during reinforcement schedule thinning: An analysis of 25 applications. *Journal of Applied Behavior Analysis*, *49*, 105-121. https://doi.org/10.1002/jaba.265

Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior*, *13*, 243-266. https://doi.org/10.1901/jeab.1970.13-243

Kestner, K. M., Diaz-Salvat, C. C., St. Peter, C. C., & Peterson, S. M. (2018). Assessing the repeatability of resurgence in humans: Implications for the use of within-subjects designs. *Journal of the Experimental Analysis of Behavior*, *110*, 545-552. https://doi.org/10.1002/jeab.477

Lattal, K. M., & Lattal, K. A. (2012). Facets of Pavlovian and operant extinction. *Behavioural Processes*, *90*, 1-8. https://doi.org/10.1016/j.beproc.2012.03.009

Lerman, D. C., & Iwata, B. A. (1996). Developing a technology for the use of operant extinction in clinical settings: An examination of basic and applied research. *Journal of Applied Behavior Analysis*, *29*, 345-382. https://doi.org/10.1901/jaba.1996.29-345

Miyao, G., & Meyers, L. S. (1973). A sequential analysis of the partial reinforcement extinction effect in children. *Memory & Cognition, 1*, 143-148. https://doi.org/10.3758/BF03198085

Nevin, J. A. (2012). Resistance to extinction and behavioral momentum. *Behavioural Processes, 90*, 89-97. https://doi.org/10.1016/j.beproc.2012.02.006

Nevin, J. A. (2005). Resistance to extinction in the steady state and in transition. *Journal of Experimental Psychology: Animal Behavior Processes, 31*, 199-212. https://doi.org/10.1037/0097-7403.31.2.199

Nevin, J. A. (2009). Stimuli, reinforcers, and the persistence of behavior. *The Behavior Analyst*, *32*, 285-291. https://doi.org/10.1007/BF03392191

Petscher, E. S., Rey, C., & Bailey, J. S. (2009). A review of empirical support for differential reinforcement of alternative behavior. *Research in Developmental Disabilities, 30*, 409-425. https://doi.org/10.1016/j.ridd.2008.08.008

Podlesnik, C. A., Ritchey, C. M., Kuroda, T., & Cowie, S. (2022). A quantitative analysis of the effects of alternative reinforcement rate and magnitude on resurgence. *Behavioural Processes, 104641*. https://doi.org/10.1016/j.beproc.2022.104641

Ritchey, C. M., Kuroda, T., & Podlesnik, C. A. (2023). A quantitative analysis of resurgence following downshifts in alternative-reinforcer magnitude. *Journal of the Experimental Analysis of Behavior, 119*, 501-512. https://doi.org/10.1002/jeab.843

Romano, L. M., & St. Peter, C. C. (2017). Omission training results in more resurgence than alternative reinforcement. *The Psychological Record, 67*, 315-324. https://doi.org/10.1007/s40732-016-0214-z

Saini, V., Sullivan, W. E., Craig, A. R., DeRosa, N. M., Rimal, A., Derrenbacker, K., & Roane, H. S. (2021). Responding fails to extinguish during human-laboratory experiments of resurgence. The *Psychological Record*, *71*, 499. https://doi.org/10.1007/s40732-021-00473-y

Shull, R. L., & Grimes, J. A. (2006). Resistance to extinction following variable-interval reinforcement: Reinforcer rate and amount. *Journal of the Experimental Analysis of Behavior*, *85*, 23-39. https://doi.org/10/1901/jeab.2006.119-04

Sullivan, W. E., Saini, V., DeRosa, N. M., Craig, A. R., Ringdahl, J. E., & Roane, H. S. (2020). Measurement of nontargeted problem behavior during investigations of resurgence. *Journal of Applied Behavior Analysis, 53*, 249-264. https://doi.org/10.1002/jaba.589

Svartdal, F. (2000). Persistence during extinction: Conventional and reversed PREE under multiple schedules. *Learning and Motivation, 31*, 21-40. https://doi.org/10.1006/lmot.1999.1037

Sweeney, M. M., & Shahan, T. A. (2016). Resurgence of target responding does not exceed increases in inactive responding in a forced-choice alternative reinforcement procedure in humans. *Behavioural Processes, 124*, 80-92. https://doi.org/10.1016/j.beproc.2015.12.007

Thrailkill, E. A. (2023). Partial reinforcement extinction and omission effects in the elimination and recovery of discriminated operant behavior. *Journal of Experimental Psychology: Animal Learning and Cognition*, *49*, 194-207. https://doi.org/10.1037/xan0000354

Thrailkill, E. A., & Alcalá, J. A. (2022). Relapse after incentivized choice treatment in humans: A laboratory model for studying behavior change. *Experimental and Clinical Psychopharmacology*, *30*, 220-234. https://doi.org/10.1037/pha000043

Weiner, H. (1970). Instructional control of human operant behavior during extinction following fixed-ratio conditioning. *Journal of the Experimental Analysis of Behavior*, *13*, 391-394. https://doi.org/10.1901/jeab.1970.13-139