An investigation of resurgence of reinforced behavioral variability in humans

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Abstract

The present study examined resurgence of reinforced variability in college students, who completed a 3-phase computer-based variability task. In the first phase, *baseline*, points were delivered for drawing rectangles that sufficiently differed from previous rectangles in terms of a target dimension (size or location, counterbalanced) but were sufficiently similar in terms of the alternative dimension. In the second phase, *alternative*, points were only delivered for rectangles that were sufficiently different in terms of the alternative dimension, but repetitive in terms of the target dimension. In the third phase, *extinction*, no points were delivered. In baseline, participants made rectangles that were highly varied in terms of the target dimension and less varied in terms of the alternative dimension, and vice versa in the alternative phase. During extinction, levels of variability increased for the target dimension, providing evidence for resurgence of reinforced variability of a specific dimension of behavior. However, levels of variability also remained high for the alternative dimension, indicating that extinction-induced response variability may also have impacted the results. Although future research is needed to explore other explanations, the results of this study replicate prior research with pigeons and provide some support for the notion of variability as an operant.

Keywords

operant variability; reinforced behavioral variability; resurgence; human

Behavioral variability is generally considered to be adaptive and may be an operant, in that it can be maintained by reinforcement and brought under discriminative stimulus control (see Neuringer, 2002, 2004, for reviews). There are several reinforcement contingencies that can be used to increase behavioral variability. For example, a lag schedule, in which the current response must differ from a certain number of previous responses to produce reinforcement,

generates high behavioral variability. Additionally, the degree of behavioral variability depends on the stringency of the variability schedule in place (e.g., higher levels of variability with a lag 10 than a lag 5; Page & Neuringer, 1985). Further, organisms can learn to behave variably in one context and repetitively in another (e.g., Denney & Neuringer, 1998; Ward et al., 2008). Reinforced behavioral variability may play an important role in processes such as problem solving and creativity (Grunow & Neuringer, 2002) and has been demonstrated across a number of species, including pigeons (e.g., Doughty & Galizio, 2015; Machado, 1997; Odum et al., 2006; Page & Neuringer, 1985), rats (e.g., Cohen et al., 1990; Neuringer, 1991), typically developing adults (e.g., Neuringer, 1986; Ross & Neuringer, 2002), and individuals with autism (e.g., Galizio et al., 2020), indicating that it is a general behavioral phenomenon.

An important feature of operant behavior is that it arises, and is maintained by, reinforcement contingencies. Ross and Neuringer (2002) showed that behavioral variability could be precisely reinforced in humans, indicating that variability may be an operant dimension of behavior. In this study, college students earned points for drawing rectangles of various sizes, locations, and shapes on a computer screen. A control group earned points for any type of rectangle produced; variability was not required. One experimental group earned points when they produced rectangles that were sufficiently variable on all three dimensions —size, location, and shape. An additional experimental group earned points for rectangles that were sufficiently repetitive on one dimension and sufficiently variable on the other two dimensions. Across all three groups, the different dimensions of rectangles were only variable when variability was required for that dimension. The results of this study demonstrated that differential reinforcement selectively controlled levels of behavioral variability. Further, Kong et al. (2019) recently validated this paradigm for studying reinforced behavioral variability by showing generalization of reinforced variability across dimensions of rectangles.

Although substantial evidence indicates that variability is an operant dimension of behavior, because it can be maintained using reinforcement, there is also evidence that appears to contradict this view. Learned behaviors are typically disrupted by environmental changes, such as extinction, delay to reinforcement, presession exposure to the reinforcer, or various drugs (e.g., Nevin & Grace, 2000). However, the evidence of disruption of reinforced behavioral variability is mixed. For example, although certain drugs have been shown to disrupt overall response rates, they do not affect behavioral variability. This finding has been demonstrated with ethanol (Cohen et al., 1990; Ward et al., 2006), *d*-amphetamine (Pesek-Cotton et al., 2011; Ward et al., 2006), and other drugs (e.g., midazolam [benzodiazepine] and pentylenetetrazole [stimulant]; Abreu-Rodrigues et al., 2004). Reinforced behavioral variability is also not readily disrupted by delay of reinforcement (Odum et al., 2006; Wagner & Neuringer, 2006), presession exposure to the reinforcer, or response-independent reinforcer presentations (Doughty & Lattal, 2001). However, in support of the idea of variability as an operant, extinction (i.e., removal of reinforcement) does selectively decrease levels of behavioral variability (Galizio et al., 2018; Neuringer et al., 2001), as would be expected for operant behavior.

When operant behavior is disrupted, certain circumstances can cause relapse of the original behavior. One type of relapse, resurgence, is particularly relevant, because it is a common, and usually unwanted, side effect of behavioral treatments used to reduce undesirable behavior (e.g., differential reinforcement of alternative behavior; DRA; e.g., Smith et al., 2017). Resurgence is defined as the reoccurrence of a previously extinguished target behavior after an alternative source of reinforcement is suspended (e.g., Craig et al., 2017; Epstein, 1985; Greer & Shahan, 2019; Shahan et al., 2020; Shahan & Craig, 2017). Resurgence is typically studied using three experimental phases. In the first phase, *baseline*, a target response is reinforced. In the second phase, *alternative*, the target response is extinguished, and an alternative response is reinforced instead. In the final phase, *extinction*, all reinforcement is suspended. In this phase, resurgence is said to have occurred when the frequency of the target behavior increases from the alternative phase. It is important to note that resurgence is defined by an increase in the target behavior during the extinction phase, even though the alternative behavior typically persists for some time, often with higher response rates than the target behavior (e.g., Craig et al., 2017; Sweeney & Shahan, 2013a, b).

Because relapse is a phenomenon characteristic of operant behavior, relapse of behavioral variability may provide further evidence that it is an operant. However, such evidence is sparse (Galizio et al., 2018). Galizio et al. (2018) studied several different relapse phenomena in the context of reinforced behavioral variability in pigeons, including resurgence (Experiment 3). In the first phase of the experiment, pigeons earned food for sequences of keypecks according to a lag schedule, and levels of behavioral variability were high. In the second phase, the target response, variability, was extinguished, and an alternative response, repetition, was reinforced. This alternative response was then extinguished in the third phase, and levels of variability subsequently increased (i.e., resurgence). One important consideration from the study is that it is difficult to distinguish between resurgence of reinforced variability and variability arising from other sources (e.g., extinction-induced response variability; Antonitis, 1951). Despite this difficulty, there was some evidence that behavioral variability is susceptible to resurgence, providing additional, albeit limited, support for variability as an operant.

Although resurgence is usually considered an adverse side effect of DRA and similar behavioral interventions, resurgence could actually be beneficial for adaptive behaviors. For example, children with autism spectrum disorder (ASD) tend to behave overly repetitively, even when it would be beneficial to respond variably (American Psychological Association [APA], 2013). Because variability is adaptive in many contexts, increasing behavioral variability is often a treatment goal for individuals with ASD (see Galizio et al., 2020). Therefore, it would be useful to know whether reinforced behavioral variability would reoccur in the face of treatment infidelity or other challenges. Investigating resurgence of variability could ultimately inform clinical research, in addition to providing further evidence for variability as an operant.

The purpose of the present study was to investigate the extent to which reinforced behavioral variability is susceptible to relapse in a resurgence paradigm in humans. College students completed a computer-based task in which points were delivered for rectangles that satisfied

a variability contingency (Kong et al., 2019; Ross & Neuringer, 2002). Resurgence was assessed in three phases. In the first phase, *baseline*, points were delivered only when rectangles varied in terms of one target dimension (i.e., size or location) but were repetitive in terms of the alternative dimension. In the second phase, *alternative*, the contingencies were reversed: points were delivered only when rectangles varied in terms of the alternative dimension but were repetitive in terms of the target dimension. In the third phase, *extinction*, no points were delivered for any rectangles. An increase in variability of the target dimension during extinction would be indicative of resurgence of reinforced variability of the target dimension of behavior.

Method

Participants

Undergraduate students ($n = 51$) recruited from Introductory Psychology classes at Utah State University received course credit for participating in the study. All participants gave informed consent before the experiment and completed a demographic survey after the experiment. Data were not obtained for four participants due to equipment malfunction; thus, the total obtained number of participants was 47. The mean age of participants who completed the experiment was 20.77 years ($SD = 4.56$). Thirty-one participants (65.96%) identified as female and 15 (31.91%) identified as male. Forty-four participants (93.62%) identified as white/Caucasian, two participants (4.26%) identified as Hispanic/Latino, and one participant (2.13%) identified as African American. The demographic survey included a section where the participant could enter comments about the study (e.g., hypothesized purpose of the study), and these responses are categorized in Table 1. In addition to the variability task described below, participants completed two other tasks for another study. The data from these tasks are not shown. All procedures were approved by the Utah State University Institutional Review Board prior to conducting the experiment.

Procedure

Participants completed a task similar to that of Ross and Neuringer (2002) in a small room with no distractions. Experimental events were controlled by a computer program written in Visual Basic. Participants were asked to sit in front of the computer screen and received the following instructions:

> To play, simply click the mouse and drag on any diagonal to create a rectangle. Release the mouse button when you are satisfied with your rectangle. The object of this game is to get the most points. You have received points for your actions whenever you hear a tone. There will be three versions of this game. The game will notify you when you are starting a new version. Press "Start" when you are ready to begin.

Participants were able to draw rectangles in a large white space in the center of the screen (640×480 pixels); the outer border of the screen was black, and the cursor was restricted to the white center area (see Fig. 1). There were no guides or tick marks to indicate any spatial dimensions within the area in which the rectangles could be drawn. To draw a rectangle, a participant moved the cursor to their desired start location, depressed the left mouse button,

dragged the cursor to a point that served as the opposite corner of the rectangle, and released the left mouse button. When the mouse button was depressed, the shape of the current rectangle was displayed on the screen and disappeared after the mouse button was released. If the created rectangle met the current contingencies for reinforcement, then a tone was emitted, and a point counter displayed in the outer black border on the screen was incremented immediately. If the rectangle did not meet the current contingencies (or when extinction was in place), there were no programmed consequences after releasing the mouse button. There was a 1-s intertrial interval (ITI) between each rectangle in which the screen was blank and mouse clicks were ineffective. After a rectangle was created, the computer program categorized the rectangle based on both size and location.

Sixteen discrete categories of the two rectangle dimensions, size and location, were defined so that there would be an equal likeli-hood for a randomly generated rectangle to occur in any category (for full details, see Ross & Neuringer, 2002). The rectangle size was defined as the area of the rectangle. The location of the rectangle was defined as the center of the rectangle. The categories used in this study to classify the size and location of a rectangle were identical to those used by Ross and Neuringer.

Participants completed three phases of the same task, consistent with a resurgence preparation. In the first phase, baseline, participants constructed 300 rectangles and earned points when a rectangle was sufficiently variable in terms of the target dimension of behavior (size or location; counterbalanced across participants) and sufficiently repetitive in terms of the alternative dimension. In the second phase, alternative, participants constructed 300 rectangles and earned points when a rectangle was sufficiently variable in terms of the alternative dimension and sufficiently repetitive in terms of the target dimension. In the third phase, extinction, participants completed 100 rectangles but could not earn any points. Separating each phase, a screen displayed the following instructions:

> You are about to play a new version of the same game. Press "Start" when you are ready to begin.

The entire task took less than 30 min to complete.

In the baseline and alternative phases, the schedule of reinforcement was a weighted relative-frequency threshold contingency (e.g., Denney & Neuringer, 1998; Ross & Neuringer, 2002) based on the size or location of the rectangle (counterbalanced, see above). After each rectangle was drawn, the relative frequencies for each possible category of both dimensions were calculated. The relative frequencies of the size and location categories containing the current rectangle were then compared to a fixed threshold value, 0.15. For a point to be delivered, two requirements must have been met. First, the rectangle must have been in a category of the target dimension (or alternative dimension, in the alternative phase) in which 15% or fewer of the rectangles had occurred so far (i.e., threshold contingency). Second, the rectangle must have been in a category of the alternative dimension (or target dimension, in the alternative phase) in which more than 15% of the rectangles had occurred so far (i.e., reverse threshold contingency). This second criterion was added to ensure that target and alternative responding were sufficiently different from each other (cf. Ross & Neuringer, 2002). Using these two criteria, we differentially reinforced rectangles that were

selectively varied along one dimension but not on the other. If either criterion was not met, no points were delivered. During the ITI, all relative frequencies were multiplied by a weighting coefficient, 0.95, in order to preferentially weight more recent responses.

Data Analysis

To assess overall levels of variability, the primary dependent measure was U-value (e.g., Page & Neuringer, 1985). U-value is a common measure used to assess behavioral variability and ranges from 0 to 1. A U-value of 0 would indicate absolute repetition (i.e., all rectangles produced fell into the same category) and a U-value of 1 would indicate each possible category of rectangle occurred an equal number of times. U-value is calculated using Equation 1,

$$U = -\sum_{i=1}^{n} \frac{Rf_i * log_2(Rf_i)}{log_2(n)},$$ (1)

where Rf_i is the relative frequency of a particular response and n is the total number of possible response categories, in this case 16. U-value was separately calculated for size and location in each phase.

To determine if there were differences in U-value across phases or dimensions, a repeated-measures analysis of variance (ANOVA) was conducted using the Greenhouse–Geisser correction. Planned comparisons were conducted for differences in main effects (U-value by phase, U-value by dimension), pairwise comparisons in U-value across dimension within each phase, and pairwise comparisons in U-value across successive phases for each dimension (e.g., target in baseline compared to target in alternative, target in alternative compared to target in extinction, etc.). A Holm-Bonferroni correction was used to ensure a Type I familywise error rate of 0.05. The full results of the ANOVA are available in Table 2, and relevant pairwise comparisons are reported in the Results.

Results

Overall levels of variability were generally sensitive to the contingencies in place throughout the experiment and provided some evidence for resurgence of variability of the target dimension, as shown in Figure 2. In the first phase, baseline, points were delivered for varying on the target dimension and repeating on the alternative. As expected, target U-values were significantly higher than alternative U-values, $t(46) = 6.89$, $p < .0001$, indicating that participants generally behaved more variably on the target dimension than on the alternative dimension; that is, the rectangles produced were more evenly distributed across response categories for the target dimension than the alternative dimension. In the second phase, alternative, points were delivered for varying on the alternative dimension and repeating on the target dimension. U-values for the target dimension decreased significantly from baseline to alternative, $t(46) = 6.95$, $p < .0001$, and conversely, U-values for the alternative dimension increased significantly from baseline to alternative, $t(46) = 6.77$, $p < .0001$. Consistent with these results, U-values were significantly higher for the alternative dimension than for the target dimension during the alternative phase, $t(46) = 4.777$, $p < .0001$, indicating that the rectangles produced were more evenly distributed across

response categories for the alternative dimension than the target dimension. In the third phase, extinction, all points were withheld, and there was evidence for resurgence of reinforced variability of the target dimension. Specifically, U-values for the target dimension increased significantly from alternative to extinction, $t(46) = 6.44$, $p < .0001$.

The majority of participants responded in a manner consistent with resurgence of reinforced variability of the target dimension. Figure 3 shows individual subject U-values for the target dimension across phases. Participants' data were considered to be consistent with resurgence if target U-values decreased from baseline to alternative and increased from alternative to extinction. As shown in Figure 3A, data for 33 of 47 participants (70.2%) demonstrated resurgence according to this definition (Target Pattern A). A second pattern of responding (Target Pattern B), shown in Figure 3B, involved a decrease in target U-values across phases. This pattern was evident for 7 of 47 participants (14.9%) and points to extinction of variability on the target dimension with no resurgence after alternative reinforcement was removed. All other patterns of responding (Target Pattern C) observed in the remaining 7 of 47 participants (14.9%) were considered to be nonsystematic (see Fig. 3C).

There were substantial individual differences in patterns of responding for the alternative dimension. In typical resurgence preparations, alternative responding is not usually a criterion for determining whether resurgence has occurred (e.g., Craig et al., 2017; Sweeney & Shahan, 2013a, b). However, because the target and alternative responses were different dimensions of the same behavior in the current study, it is necessary to analyze responding on the alternative dimension to fully understand the results. Even though target U-values increased from alternative to extinction, indicating resurgence (Fig. 3A), the data for alternative U-values were less clear. Overall, U-values for the alterative dimension did not change significantly from alternative to extinction, $t(46) = 1.85$, $p = 1.0$, and U-values for the target and alternative dimensions were not significantly different during extinction, $t(46) = 0.30$, $p = 1.0$.

Individual differences in patterns of responding on the alternative dimension are shown in Figure 4. The first pattern of responding (Alternative Pattern A) included data from 14 of 47 participants (29.8%) and is displayed in Figure 4A. For these participants, alternative U-values increased from baseline to alternative and decreased from alternative to extinction. This response pattern supports the finding of resurgence of target variability, because behavior was sensitive to the contingencies in the first two phases and because we only observed an increase in variability for the target dimension in the final phase (i.e., resurgence). A second pattern of responding (Alternative Pattern B) is apparent in the data from 25 of 47 participants (53.2%), shown in Figure 4B. For these participants, alternative U-values increased from baseline to alternative and alternative U-values increased or remained constant from alternative to extinction. Behavior of these participants was sensitive to the contingencies, but U-values for the target and alternative dimensions were both high in the final phase. This outcome is not inconsistent with resurgence, but is at the same time consistent with other explanations for the high alternative U-values (e.g., extinction-induced response variability; see Discussion). Nonsystematic alternative responding (Alternative Pattern C) are shown in Figure 4C; alternative U-values from the remaining 8 of 47

participants (17.0%) were not sensitive to the different contingencies in the first two phases, which precludes resurgence.

In considering individual patterns of responding on both dimensions together, Table 3 shows the number of participants displaying each combination of target and alternative response patterns. Of the 33 participants who demonstrated resurgence of variability on the target dimension (Target Pattern A; see Fig. 3A), 30 of those participants (90.9%) also responded on the alternative dimension in a manner supporting resurgence (i.e., Alternative Patterns A or B; see Figs. 4A and 4B). In other words, data for the majority of participants (30 out of 47; 64.3%) were consistent with resurgence of variability on the target dimension and systematic responding on the alternative dimension.

Discussion

In the present study, participants earned points for creating rectangles on a computer screen across three experimental phases. In the first phase, baseline, participants earned points for emitting rectangles that varied along a target dimension, size or location (counterbalanced), but were repetitive on the alternative dimension. In the second phase, alternative, participants earned points for emitting rectangles that varied along the alternative dimension but were repetitive on the target dimension. In the third phase, extinction, all reinforcement was suspended. Overall, in baseline, levels of variability for the target dimension were high and levels of variability for the alternative dimension were lower. In the alternative phase, levels of variability decreased for the target dimension and increased for the alternative dimension. The findings from the first two phases replicate the existing literature showing that variability of specific dimensions of a response could be precisely controlled by differential reinforcement contingencies (Ross & Neuringer, 2002). In the final phase of the current experiment, extinction, levels of variability of the target dimension increased for the majority of participants, consistent with resurgence of reinforced variability of the target dimension of behavior. The demonstration of resurgence of reinforced variability of a specific target dimension of behavior in humans is novel, and replicates resurgence of reinforced variability in pigeons (Galizio et al., 2018).

The present findings are consistent with resurgence; that is, the removal of alternative reinforcement during extinction resulted in the reoccurrence of previously extinguished target responding (e.g., Epstein, 1985). Specifically, in baseline, when only variability along the target dimension was reinforced, participants produced rectangles that were relatively variable along the target dimension but relatively repetitive along the alternative dimension. When the contingencies were reversed in the alternative phase, participants' behavior adapted accordingly (i.e., more variability on the alternative dimension than the target dimension). During extinction, participants tended to return to baseline responding (i.e., increased variability of the target dimension), a resurgence effect. These data provide some evidence for resurgence of reinforced behavioral variability and may support the idea that variability is an operant dimension of behavior.

Even though some of the present findings are consistent with resurgence of reinforced variability of a target dimension of behavior, the results from the final phase of the

experiment are mixed. Target U-values increased from the alternative phase to the extinction phase, indicative of resurgence. For some participants, alternative U-values decreased in the extinction phase, a finding clearly in line with selective resurgence of reinforced variability of the target dimension only. However, levels of variability on the alternative dimension remained high for most participants in the final phase. This outcome is not inconsistent with resurgence; in typical resurgence studies, absolute alternative response rates are frequently higher than target response rates (e.g., Craig et al., 2017; Sweeney & Shahan, 2013a, b). However, there are other potential explanations that could account for the high alternative U-values observed for most participants, such as extinction-induced response variability.

This study is a systematic replication and extension of previous research on resurgence of reinforced behavioral variability in pigeons (Galizio et al., 2018). Although there were several procedural differences between the two experiments, such as the subjects (humans versus pigeons), responses (rectangles on a computer screen versus sequences of keypecks in an operant chamber), and variability contingency (relative-frequency threshold versus lag schedule), the results were similar. In both experiments, levels of variability were high in the baseline phase, low in the alternative phase, and high in the extinction phase (i.e., resurgence). However, in both experiments, levels of variability also increased for the alternative response in the extinction phase. Although this result does not preclude a resurgence explanation, it also does not rule out other explanations, such as extinction-induced response variability.

A major drawback of using the traditional resurgence preparation to study relapse of reinforced behavioral variability is the reliance on extinction in the procedure. Behavioral variability may be induced by the removal of reinforcement (i.e., extinction; e.g., Antonitis, 1951). Therefore, the distinction between behavioral variability arising from reinforcement and behavioral variability induced by extinction is important to consider. Extinction can result in high levels of behavioral variability even with no history of reinforcement for specifically behaving variably (e.g., Antonitis, 1951; Eckerman & Lanson, 1969; Jensen et al., 2014; Mechner, 1958; Mechner et al., 1997; Mintz & Notterman, 1965). U-values alone cannot distinguish between reinforced and extinction-induced variability. There are a number of ways that this issue could be addressed in future research. Procedural changes could include the addition of an inactive response (e.g., Craig et al., 2017). If the behavioral variability observed in extinction has been induced by the removal of reinforcement, the subject's behavior may vary indiscriminately across all responses. If the behavioral variability observed is directed towards the target response and not towards the inactive response, we would have stronger evidence that variability is an operant. There are also potential analytic strategies that could be used in future research to attempt to distinguish between reinforced and extinction-induced variability (e.g., relative frequency distributions; Neuringer et al., 2001). More research is needed to fully address this issue and more effectively differentiate between the contributions of reinforced behavioral variability and extinction-induced response variability.

A possible explanation for the data from participants whose behavior was inconsistent with resurgence on the target (Fig. 3b) and/or alternative dimension (Fig. 4c) is rule-governed behavior. For many participants, U-values changed very little across phases, which indicates

that participants may have behaved in accordance with the contingencies or self-imposed rules during baseline but did not adjust their behavior when the contingencies were altered. Research has shown that instructions can significantly impact behavior on variability tasks (e.g., Souza et al., 2012), so we deliberately provided minimal instructions. Our instructions included how to construct a rectangle, that the goal was to earn as many points as possible, and, between tasks, that they would be playing a different version of the same game. Nevertheless, it is possible that the wording of these instructions may have prompted participants to create their own rules, which could have impacted their behavior. This finding is corroborated by self-report measures collected in the demographic questionnaire. As shown in Table 1, most participants reported that they thought the purpose of the variability task was to make a particular "correct" rectangle at any given time, and many reported that they were responding according to particular patterns. Only one participant reported that the task was about responding variably. Even though accurate description of the programmed contingencies is not necessary to satisfy those contingencies (Hefferline et al., 1959), these results indicate that at least some of the participants may have ultimately been primarily responding to self-imposed rules that incidentally satisfied the experimental contingencies, rather than responding to the contingencies themselves (Baron & Galizio, 1983; Galizio, 1979).

One limitation of the present study is that our primary dependent measure was U-value, which has shortcomings when applied to the study of reinforced behavioral variability. U-value measures variability on a global level and cannot account for the specific responses emitted. The utility of U-value as a measure of variability has recently been questioned, but adequate alternatives have not yet been well established (Kong et al., 2017). Future research should be aimed at investigating more molecular methods of analyzing behavioral variability, and especially methods to quantify how variability changes across conditions.

Given that we used a resurgence preparation to examine relapse of reinforced behavioral variability, there are other issues to consider. For example, a key difference between our preparation and the typical resurgence paradigm is the available response options throughout each phase (for an over-view, see Shahan & Sweeney, 2011). For example, in a typical resurgence experiment with rats, a single response option, the target, is made available during baseline (e.g., lever press). In the alternative phase, the alternative response option is made available for the first time (e.g., chain pull). Importantly, the target and alternative responses are mutually exclusive. That is, the rat cannot press the lever and pull the chain at the same time.

Conversely, in the present study, a single rectangle could be categorized by its size and its location, meaning that the target and alternative responses were available simultaneously throughout the study, and thus never mutually exclusive. We attempted to control for this important procedural difference by altering the contingencies to make the target and alternative responses more distinct. As stated in the Method, a rectangle resulted in a point only if it satisfied a threshold contingency for the dimension currently producing points *and* a reverse threshold contingency on the other dimension. For example, in baseline, points were only delivered for rectangles that were sufficiently variable on the target dimension (e.g., size) and also were sufficiently repetitive on the alternative dimension (e.g., location).

Points were never delivered for high levels of variability on both dimensions simultaneously. That said, a limitation of the present study is that the two response dimensions were not truly mutually exclusive, as they are in most resurgence studies, and could co-occur during extinction.

Despite these limitations, the finding in the present study of evidence for resurgence of reinforced behavioral variability in humans has important theoretical and practical implications. At a theoretical level, demonstrating relapse of reinforced behavioral variability provides further evidence that variability is an operant dimension of behavior. Resurgence of reinforced behavioral variability has been demonstrated in pigeons (Galizio et al., 2018), but the present experiment will be the first published study[1] to directly examine and demonstrate resurgence of variability in humans. However, the results also elucidate the difficulty in studying reinforced behavioral variability in a relapse preparation, especially due to the difficulties of parsing extinction-induced variability from relapse of reinforced behavioral variability.

On a practical level, these findings may also inform clinical interventions in applied settings. For example, individuals diagnosed with ASD experience a number of behavioral deficits, including the tendency to behave repetitively (APA, 2013). Even when it would be more beneficial to vary their responses, individuals with ASD often engage in stereotypy. For example, when playing with blocks, a peer may make many variable structures, but the child with ASD may construct the same arrangement of blocks repeatedly. Such behavior may limit the degree to which the two children will engage in social interaction. Variability training has been shown to be beneficial to individuals with ASD in facilitating social interactions and allowing individuals to more effectively contact reinforcement in various settings (e.g., Brodhead et al., 2016; Contreras & Betz, 2016; Goetz & Baer, 1973; Lee & Sturmey, 2006, 2014). Unfortunately, such training is likely to be subject to lapses in treatment fidelity, which makes the investigation of resurgence useful. The finding that reinforced behavioral variability is susceptible to relapse may inform both theoretical interpretations and treatment strategies in clinical settings.

Acknowledgments

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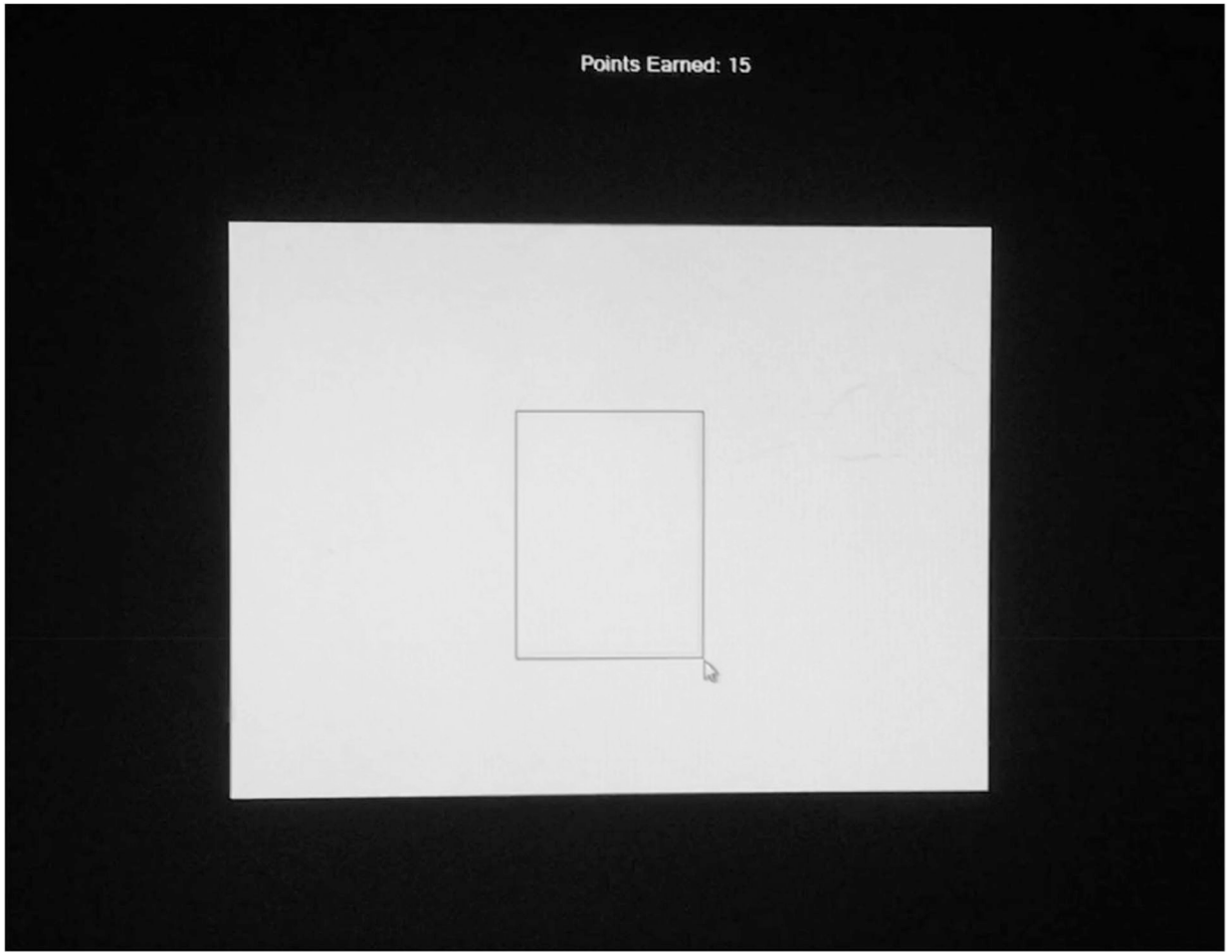
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Figure 1.
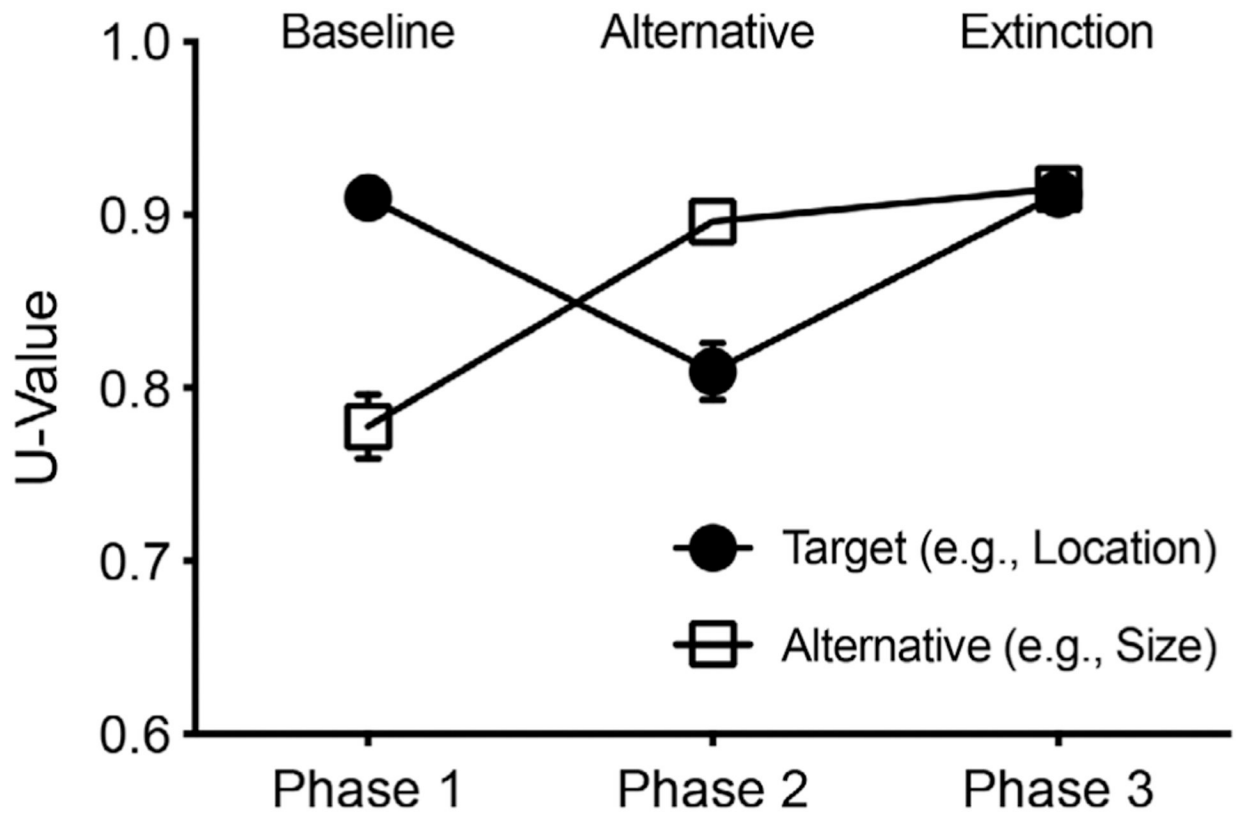Example Screenshot During the Task

Figure 2. Mean U-Values

Note. U-value (y-axis) as a function of Phases 1 (baseline), 2 (alternative), and 3 (extinction), for the target dimension (filled circles) and alternative dimension (open squares). Symbols represent means and error bars represent standard error of the mean. In most cases the variability around a point is encompassed by the point.
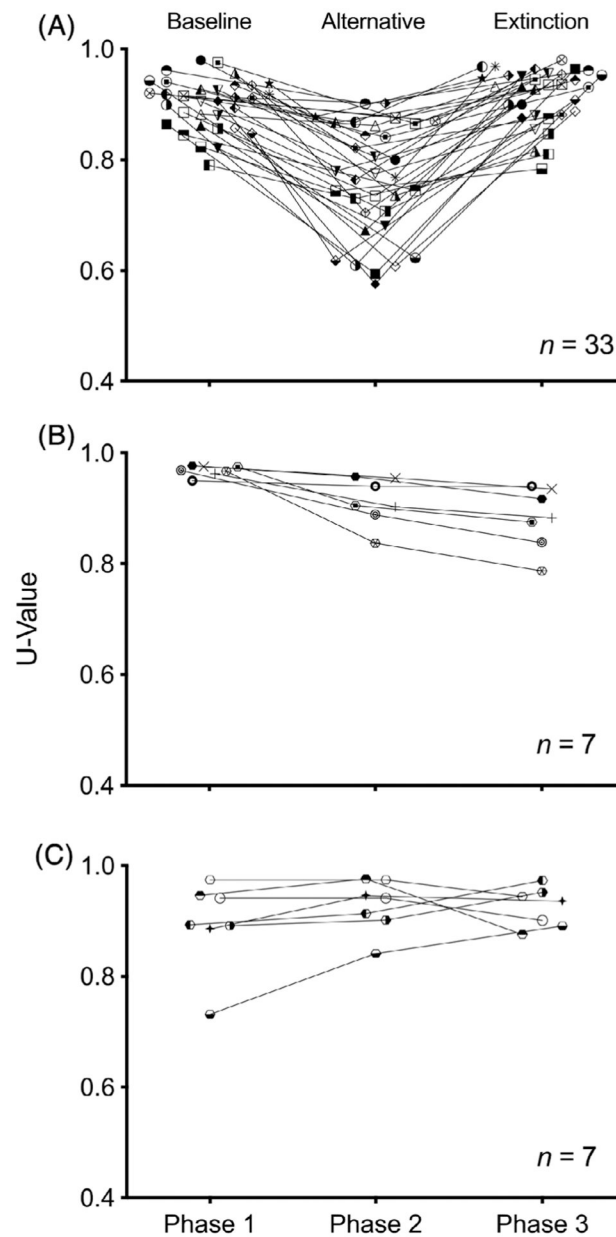
Figure 3. Target U-Values for Individual Participants

Note. U-values for the target dimension (y-axis) as a function of Phases 1 (baseline), 2 (alternative), and 3 (extinction) for individual participants. Data for each participant are represented by a unique symbol, which is consistent across Figures 3 and 4. Panel A shows responding consistent with resurgence, Panel B shows responding consistent with extinction and no resurgence, and Panel C shows nonsystematic responding (see text for full descriptions). The number of subjects showing each response pattern is indicated in each panel.
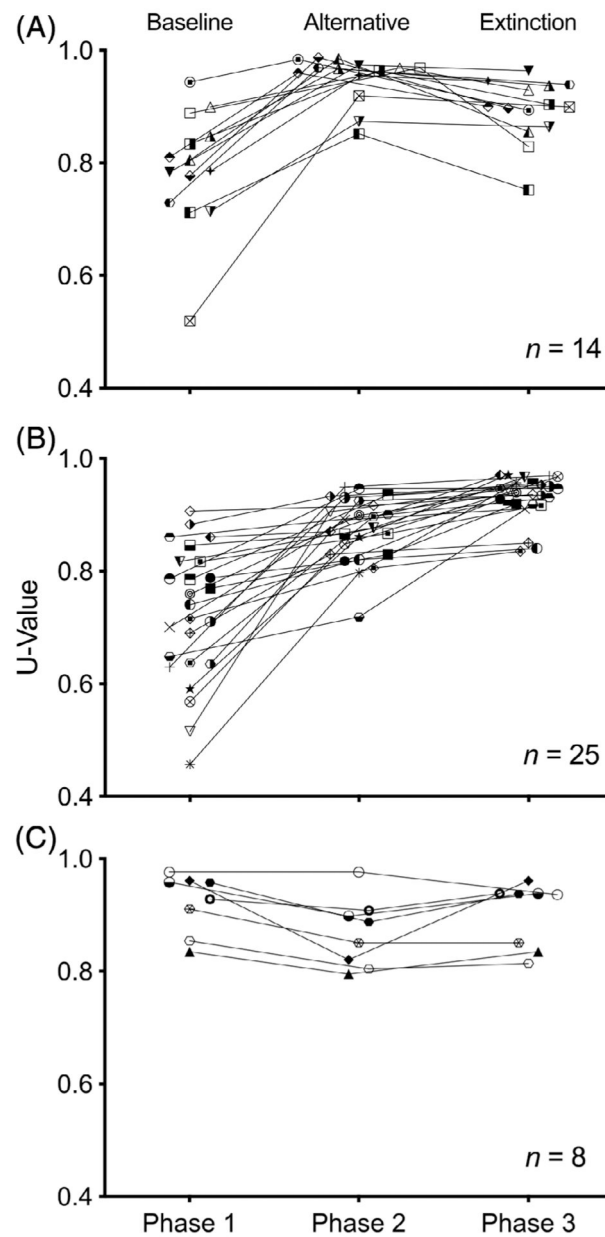
Figure 4. Alternative U-Values for Individual Participants

Note. U-values for the alternative dimension (y-axis) as a function of Phases 1 (baseline), 2 (alternative), and 3 (extinction) for individual participants. Data for each participant are represented by a unique symbol, which is consistent across Figures 3 and 4. Panel A shows responding consistent with resurgence, Panel B shows responding consistent with resurgence or extinction-induced response variability, and Panel C shows responding inconsistent with resurgence (see text for full descriptions). The number of subjects showing each response pattern is indicated in each panel.

Table 1

Participant Responses to Hypothesized Purpose of Experiment

Hypothesized Purpose of Experiment	Number of Participants	Percentage of Participants
"Correct" responding	17	36.17%
Idiosyncratic "patterns" of responding	9	19.15%
"Reinforcement" learning	9	19.15%
"Recalling" past responses	6	12.77%
Behavioral "persistence"	2	4.26%
"Motivation" to respond	1	2.13%
Behaving "randomly"	1	2.13%
No response	2	4.26%

Note. These categories were based on participant responses. If the participant used the word in quotations or a synonym of that word in their response, they were included in that category.

Table 2

Repeated-Measures ANOVA for U-Value

Repeated-Measures ANOVA for U-Value						
Source	SS	DF	MSE	F	GES	Adjusted p
Phase	0.027	1.89	0.593	21.00	0.127	<.0001
Dimension	0.014	1	0.397	1.65	0.008	1.0
Phase × Dimension	0.573	1.96	0.449	58.60	0.235	<.0001

Note. Greenhouse–Geisser and Holm-Bonferroni corrections applied. Effect size is shown as generalized eta squared (GES).

Table 3

The Number of Participants Displaying Each Combination of Target and Alternative Response Patterns

	Alternative Pattern A	Alternative Pattern B	Alternative Pattern C
Target Pattern A	**12**	**18**	3
Target Pattern B	2	3	2
Target Pattern C	0	4	3

Note. The bolded patterns and numbers show data supporting the finding of resurgence of variable target responding.