8-2020

A Translational Investigation of Reinforced Behavioral Variability: Implications for Promoting Behavioral Variability in Individuals with Autism Spectrum Disorder

Ann Galizio
Utah State University

A TRANSLATIONAL INVESTIGATION OF REINFORCED BEHAVIORAL VARIABILITY: IMPLICATIONS FOR PROMOTING BEHAVIORAL VARIABILITY IN INDIVIDUALS WITH AUTISM SPECTRUM DISORDER

by

Ann Galizio

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Psychology

Approved:

Amy L. Odum, PhD Major Professor	Thomas S. Higbee, PhD, BCBA-D Committee Member
Gregory J. Madden, PhD Committee Member	Timothy A. Shahan, PhD Committee Member
Maryellen McClain Verdoes, PhD Committee Member	Janis L. Boettinger, PhD Acting Vice Provost of Graduate Studies

UTAH STATE UNIVERSITY

Logan, Utah

2020

ABSTRACT

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by

Ann Galizio, Doctor of Philosophy

Utah State University, 2020

Major Professor: Dr. Amy L. Odum
Department: Psychology

Behavioral variability is sometimes adaptive and can be maintained by the delivery of reinforcement. Individuals with autism spectrum disorder (ASD) often show restricted and repetitive behaviors. Therefore, interventions to promote behavioral variability in individuals with ASD are needed. The present line of research was designed to inform such interventions by investigating reinforced behavioral variability from basic, applied, and translational perspectives. Each of these laboratory studies involved participants making sequences of well-defined responses, which were compared to previous responses. Responses that meet a variability contingency (i.e., were sufficiently different from previous responses) produced rewards. Study 1 consisted of several basic experiments conducted with pigeons, and the results showed that behavioral variability could be maintained using reinforcement, extinguished through removal of reinforcement, and recovered under relapse-inducing conditions (i.e., reacquisition, reinstatement, and resurgence). In Study 2, we again demonstrated relapse, specifically resurgence, of reinforced behavioral variability, this time with college students

completing a computer-based task. Study 3 was an applied experiment in children with ASD; our results indicated that children with ASD do not necessarily behave repetitively because they prefer repetition, but because they would require additional teaching to behave variably. After learning to play variably, two of three participants preferred to engage in variable play as opposed to repetitive play. Study 4 was a translational experiment which examined reinforced behavioral variability in a drug-induced (i.e., valproate; VPA) rat model of ASD, and our findings were mixed. If VPA-exposed rats were truly a model for the overly repetitive responding that is characteristic of ASD, we would have expected to see impairment in a reinforced behavioral variability task. Although VPA rats behaved more repetitively than controls on some assessments of repetition, this finding was not observed in the reinforced behavioral variability task, which limits the validity of the VPA model of ASD. This translational line of research should be continued to better understand reinforced behavioral variability and its implications for ASD.

(344 pages)

PUBLIC ABSTRACT

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Behavioral variability is sometimes adaptive and can be maintained by the delivery of reinforcement. Individuals with autism spectrum disorder (ASD) often show restricted and repetitive behaviors. Therefore, interventions to promote behavioral variability in individuals with ASD are needed. The present line of research was designed to inform such interventions by investigating reinforced behavioral variability from basic, applied, and translational perspectives. Each of these laboratory studies involved participants making sequences of well-defined responses, which were compared to previous responses. Responses that meet a variability contingency (i.e., were sufficiently different from previous responses) produced rewards. Studies 1 and 2 were basic experiments, in which we demonstrated a recurrence of reinforced behavioral variability in pigeons and college students, respectively. Study 3 was an applied experiment designed to assess choice for variability in children with ASD. Study 4 was a translational experiment investigating the viability of a rat model of ASD. This translational line of research should be continued to better understand reinforced behavioral variability and its implications for ASD.

ACKNOWLEDGMENTS

I would like to thank the following people for their helpful contributions, without whom I never would have completed this project:

My mentor, Amy Odum, for her unwavering support and patience throughout my time in graduate school, for always going above and beyond to help me succeed, and for believing in me, even when I felt lost. Thank you for shaping me into a better scientist, writer, teacher, and human being.

My mentor, Tom Higbee, for welcoming me into his lab and treating me as one of his own. Thank you for providing me with countless opportunities to develop my skills in the practice, research, and teaching of applied behavior analysis.

My entire committee, including Amy Odum, Tom Higbee, Greg Madden, Tim Shahan, and Maryellen McClain Verdoes, for their helpful feedback.

My friends and colleagues who helped to conduct these experiments, especially Lorraine Becerra, Jon Friedel, Casey Frye, Jeremy Haynes, Jay Hinnenkamp, Kailey Morrissey, Lyndsay Nix, Sara Peck, D Perez, Kassidy Reinert, and Caroline Towse.

My parents, Mark Galizio and Kate Bruce, for their continual encouragement and advice. Thank you for your unconditional support and for always being there for me.

My partner, Jay Hinnenkamp, for sharing this past year with me and for tolerating me during stressful times. Thank you for your constant kindness and for doing your part to maintain the set of interlocking contingencies that is our relationship.

My cats, Menace and Ruckus, for always being fuzzy, adorable, and cuddly.

Annie Galizio

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Variability in behavior is generally considered to be adaptive. Although there are certainly circumstances in which behaving repetitively is more appropriate (e.g., a surgeon implementing a series of precise techniques to successfully perform an operation), behavioral variability can be beneficial in many contexts (e.g., a comedian telling a joke in a unique way to amuse the audience). From an evolutionary perspective, the ability to behave variably has historically been critical for survival. For example, squirrels foraging for nuts are more likely to find enough food if they check in a variety of places. Similarly, a lioness hunting prey will be most successful by using a variety of attack maneuvers. For the antelope to have any chance of escaping predation by the lioness, it must engage in a variety of evasive strategies. Animals, of course, need not behave variably at all times; however, only those who are able to behave variably when the situation calls for it will survive to see another day. For humans especially, behavioral variability plays a critical role in creativity, learning, and problem solving. As a society, we tend to place value on original works of art, science, literature, and music; and on a daily basis, we are faced with unexpected situations that require us to adapt. The individuals who thrive in our society are those who are able to behave variably as needed. In fact, behaving stereotypically is diagnostic of a variety of mental and behavioral disorders (e.g., autism spectrum disorder [ASD]). Therefore, understanding how behavioral variability arises and is maintained is imperative to improving the lives of individuals who struggle to vary their behavior appropriately.

Defining Behavioral Variability

For the purposes of this discussion, *behavioral variability* will be defined as the distribution of responses across a subset of behaviors within an organism's repertoire. In other words, behavioral variability refers to the degree to which behavior differs or changes across time or space (Rodríguez & Hunziker, 2008). The distribution of responses or degree of difference between responses can be assessed in several ways (see Measuring Reinforced Behavioral Variability below), but importantly, behavioral variability can only be defined by comparing multiple responses (e.g., Holth, 2012). Behavioral variability also has been described as a spectrum, ranging from complete repetition, or stereotypy, at one end of the continuum to complete randomness, or stochasticity, on the other (Neuringer, 2002). However, it should be recognized that *variability* and *randomness* are not necessarily equivalent. True randomness is unpredictable by definition; yet behavioral variability can sometimes be predicted, given a sufficient understanding of the sources of that variability and the factors that may influence it.

To begin to study behavioral variability, one must define the responses of interest. Not only must the researcher describe a single behavioral unit, they must also identify the universe of all possible variations of that behavioral unit. In the natural environment, phylogenetic and ontogenetic pressures help to establish the set of possibly functional responses which can be emitted variably or repetitively (Jensen et al., 2006). In the laboratory, one of the most commonly studied behavioral units is a sequence of responses across two or more manipulanda. For example, a pigeon may be trained emit four-peck sequences across a left (L) and a right (R) key (e.g., Page & Neuringer, 1985). If the

pigeon pecked left four times in a row, then the current response would be denoted as LLLL. The universe of all possible sequences would include every combination of four left and right keypecks, in this case 16 possible sequences (e.g., LRLR, RLRL, etc.). Therefore, behavioral variability, in this case, would be defined as the distribution of responding across all possible sequences. Other behavioral units sometimes studied in variability research are inter-response time (IRT), or the time between two responses (e.g., Blough, 1966), response location (e.g., Antonitis, 1951), and response duration (e.g., Cruvinel & Sério, 2008). To clearly define the realm of possible responses, IRTs, response locations, and response durations may be categorized into "bins," and behavioral variability would be the distribution of responses across all of these bins. Some more complex behaviors that have been studied in variability research include block structures built by children (e.g., Goetz & Baer, 1973), rectangles drawn on a computer screen (e.g., Ross & Neuringer, 2002), tricks performed by porpoises (e.g., Pryor et al., 1969), techniques demonstrated by martial artists (e.g., Harding et al., 2004), and even eye movements (i.e., saccades; Paeye & Madelain, 2011).

Sources of Behavioral Variability

An investigation of behavioral variability must begin with locating its potential sources. There are at least three environmental, as opposed to genetic or physiological, sources of behavioral variability: novelty, extinction, and reinforcement. In humans, random events (e.g., tossing a coin) also sometimes serve as a source of behavioral variability (see Neuringer, 2002). However, we will be focusing on behavioral variability generated through novelty, extinction, and reinforcement.

Novelty-Induced Behavioral Variability

Novelty-induced behavioral variability occurs when an organism is in an unfamiliar environment or faced with unfamiliar stimuli (e.g., Montgomery, 1951; Pisula & Siegel, 2005). The adaptive response to an unknown environment is to explore it. If the organism does not engage in exploratory behavior, they are unlikely to locate important reinforcers, such as food, mates, shelter, etc., or to identify any potential threats. This exploratory behavior seems to be induced, in that it results from a change in stimulus conditions (i.e., novelty) and does not directly depend on consequences (Neuringer, 2012).

Extinction-Induced Behavioral Variability

Extinction-induced behavioral variability occurs when reinforcement is withheld for a response that previously produced reinforcement. Many organisms begin to behave variably when the reinforcer is removed (i.e., extinction; e.g., Antonitis, 1951; Kinloch et al., 2009; Morgan & Lee, 1996), when reinforcers are delivered intermittently (e.g., Eckerman & Lanson, 1969; Ferraro & Branch, 1968), or when the rate or magnitude of reinforcement is reduced (e.g., Jensen et al., 2014). Again, this reaction is potentially adaptive; even though reinforcement has been suspended or reduced for one response, it may be available for other responses. The variability that emerges seems to be induced by the transition to extinction conditions, independent of consequences, similar to variability induced by novel stimuli (Neuringer, 2012).

Reinforced Behavioral Variability

Finally, reinforced behavioral variability occurs when an organism only earns a desired stimulus, or reinforcer, by behaving sufficiently variably (e.g., Page & Neuringer,

1985). There is clear evidence, discussed throughout this dissertation, that behavioral variability can be maintained by reinforcement contingencies and controlled by discriminative stimuli, which are characteristics of operant behavior (Skinner, 1953). From a traditional behavior-analytic perspective, however, this notion is counterintuitive. In behavior analysis, *reinforcement* is said to have occurred when a stimulus has been presented following a response, resulting in a subsequent increase in the probability, or "strengthening," of that response (Cooper et al., 2007, p. 258). If reinforcement increases the behavior it follows, then it should, and typically does, engender repetition. Reinforcers have also been conceptualized as discriminative stimuli that guide behavior; when a reinforcer is delivered, the previous response is not necessarily strengthened or increased, but the reinforcer may instead serve as a signal to indicate what kind of responding is likely to produce the next reinforcer (e.g., Cowie & Davison, 2016; Cowie et al., 2011), an approach which may more readily explain reinforced behavioral variability. The question of how reinforcement can be used to maintain variable behavior has garnered much curiosity over the years (see Potential Mechanisms of Reinforced Behavioral Variability below).

Because of the controversy surrounding this issue, we will use the term *reinforced behavioral variability* throughout this dissertation to describe the increase in behavioral variability observed as a result of implementing a variability contingency (see Methods of Reinforcing Variability below). We will attempt to avoid the assumption of variability as an operant (Neuringer, 2002), given that there are a number of other viable explanations. We will also attempt to avoid any assumption of the processes involved in reinforcement (i.e., reinforcement as strengthening or reinforcers as discriminative stimuli). There is a

need for more precise terminology, which, unfortunately, cannot occur until the mechanisms underlying reinforced behavioral variability are better understood.

Methods of Reinforcing Behavioral Variability

There are several reinforcement contingencies that have been used to increase variable responding. These schedules all operate by differentially providing reinforcement only for behavior that is sufficiently variable. A "sufficient" level of variability can be determined by relative response novelty, relative response recency, and relative response frequency.

Differential Reinforcement of Novelty

One procedure used to increase and maintain variable behavior is differential reinforcement of novel behaviors[1]. In one of the first demonstrations of reinforced behavioral variability, Pryor et al. (1969) studied captive porpoises engaging in a variety of behaviors, such as swimming, leaping, and turning. Trainers delivered food only when the porpoise emitted a response it had not yet made. By differentially reinforcing only novel behaviors, researchers obtained high levels of variability. The porpoises even began to engage in complex behaviors that had never before been observed in the species. This technique has also been utilized in humans. Goetz and Baer (1973) analyzed blockbuilding in preschoolers and provided social praise only when a new structure was made (i.e., differential reinforcement of novel structures). Unlike the procedure used by Pryor et al., which required porpoises to emit responses they had never made, Goetz and

[1] Differential reinforcement of novelty is sometimes described in the literature as "extinction," because after the first occurrence of the behavior, reinforcement is withheld for that particular response (e.g., Betz et al., 2011). However, we will use the terminology of differential reinforcement of novelty throughout this dissertation to avoid any confusion with extinction-induced response variability, which is theoretically a separate concept.

Baer reinforced the first occurrence of a block structure within a single session. If the same block structure was built in the next session, it would still be followed by praise the first time. Thus, differential reinforcement of novelty may require responses to be unique either within or across sessions.

As a demonstration of the application of differential reinforcement of novelty, Table 1-1 shows a series of trials from a hypothetical experiment. Hypothetical response sequences (e.g., LRLR) are displayed for 20 trials. The table indicates whether each sequence would have met a differential reinforcement of novelty contingency or lag contingency (see Differential Reinforcement of Non-Recency below). The sequence on a given trial would meet a differential reinforcement of novelty contingency only if it had never occurred in a previous trial.

There are some advantages and disadvantages to using differential reinforcement of novelty. Because actions cannot be repeated after they are reinforced, extremely high levels of variability are needed to sustain reinforcement. This procedure might be most useful in situations where repetition is especially problematic, because organisms responding on this contingency will likely learn to inhibit any repetitive behavior. This procedure may also give rise to behaviors the organism has never before emitted, which may be particularly useful in contexts that encourage creative responding. However, if the number of response options available to the organism is limited, this procedure is less than ideal. Each time the organism emits a response, there are fewer possible response options available that could be eligible for reinforcement, which could suppress overall responding. If an organism's behavioral repertoire is restricted, it could be beneficial to teach additional response options before implementing differential reinforcement of

Table 1-1.
Hypothetical Sequences and Contingency Satisfaction: Differential Reinforcement of Novelty and Lag Schedules.

Trial	Sequence	Novel	Lag 5	Lag 8
1	LLLL	Yes	Yes	Yes
2	RRLL	Yes	Yes	Yes
3	LRLR	Yes	Yes	Yes
4	RLLR	Yes	Yes	Yes
5	RRLL	No	No	No
6	RLRL	Yes	Yes	Yes
7	RLRL	No	No	No
8	RLLR	No	No	No
9	LRLR	No	Yes	No
10	LLLL	No	Yes	Yes
11	RRLL	No	Yes	No
12	LLLR	Yes	Yes	Yes
13	LLLL	No	No	No
14	RLRL	No	Yes	No
15	RRLR	Yes	Yes	Yes
16	LLLR	No	No	No
17	RLLR	No	Yes	Yes
18	LRLR	No	Yes	Yes
19	RRRL	Yes	Yes	Yes
20	LLLL	No	Yes	No

Note. This table displays a sample series of sequences emitted in Trials 1-20 by a single subject in a hypothetical variability experiment. The first column contains the trial number, and the second column contains the hypothetical sequence emitted on that trial. The third column indicates whether the sequence emitted on each trial would satisfy a differential reinforcement of novelty contingency. The fourth and fifth columns indicate whether the sequence emitted on each trial would satisfy a lenient or stringent lag schedule, respectively.

novelty. Another potential drawback of this procedure is that every behavior must be tracked throughout the study to determine whether a reinforcer should be delivered for a given response. For a human experimenter (typical for many applied studies), comparing the current response to all previous responses can take a substantial amount of time, potentially delaying the reinforcer. If a computer is used (typical for many basic studies), there are constraints on what possible responses can be made, due to either mechanical or programming limitations. Undetectable novel responses could never be reinforced in this

situation. Exploring ways to automate the procedure, while still allowing a plethora of response options, would be a valuable direction for future research.

Differential Reinforcement of Non-Recency [2]

The most common variability contingency used in the literature is the lag schedule of reinforcement, which provides reinforcement differentially for responses that have not been produced recently. In a lag *x* schedule, a response is reinforced only if it differs from the previous *x* responses. Page and Neuringer (1985) used lag schedules to promote behavioral variability in pigeons. Pigeons repeatedly emitted sequences of keypecks across two keys (e.g., LRLR). With a lag 5 schedule in place, the current sequence only produced food if it differed from the sequences emitted on each of the previous five trials. In a series of experiments, Page and Neuringer demonstrated that lag schedules reliably increased behavioral variability. Levels of variability also seemed to track the lag criterion; levels of variability tended to increase as the lag requirement increased (see also Morris, 1989). Since then, lag schedules have been successfully used in many experiments with pigeons (e.g., Cherot et al., 1996; Galizio et al., 2018; Odum et al., 2006), rats (e.g., Cherot et al., 1996; Neuringer & Huntley, 1992; van Hest et al., 1989), humans (e.g., Contreras & Betz, 2016; Galizio et al., 2020; Falcomata et al., 2018), and even budgerigars (Manabe, 2008).

In addition to indicating response novelty, Table 1-1 also shows whether a series of hypothetical sequences would have satisfied a lag contingency. This table identifies which sequences would have produced reinforcement according to a relatively lenient lag contingency (lag 5) and a relatively stringent lag contingency (lag 8). A sequence would

[2] Lag schedules were utilized in Study 1 (Chapter 2) and Study 3 (Chapter 4) of this dissertation.

have met a lag 5 schedule only if it differed from the previous 5 trials, and a sequence would have met a lag 8 schedule only if it differed from the previous 8 trials.

Lag schedules are relatively straightforward to implement; however, there is a question of whether they are the most effective procedure to promote truly variable behavior. Lag schedules are relatively simple to program in basic studies, because of the possibility of automation. Implementing lag schedules in clinical settings is more challenging, because a human experimenter must track a moving window of behaviors and determine whether the current response has met the criterion. Because of this difficulty, only requirements of lag 1 or lag 2 are typically used, which is more practical for the experimenter (e.g., Esch et al., 2009). However, with such low lag requirements, there is also a risk of the subject engaging in higher order stereotypy (e.g., Machado, 1992; Schwartz, 1982). For example, if the subject cycled through two responses, a reinforcer would be delivered for every response under a lag 1, even though cycling between only two responses would more likely be considered as repetitive than variable. In addition, the lag schedule is restrictive in that it never reinforces repetition. If the organism is responding randomly, as has been hypothesized (e.g., Neuringer, 2002; see Potential Mechanisms of Reinforced Behavioral Variability below), repetitions will sometimes occur due to chance. Therefore, a lag schedule would not always accommodate truly random responding, which is problematic for a variability procedure.

Differential Reinforcement of Infrequency [3]

A variety of procedures have been used to differentially reinforce only responses emitted relatively infrequently. In one of the first demonstrations of this type of contingency, Blough (1966) measured interresponse time (IRT) in pigeons pecking keys. Sixteen IRT bins of systematically increasing durations were created, such that a randomly generated IRT would fall into any of the bins with equal probability. Each time the pigeon pecked the key, the IRT was categorized into one of these bins. A response was only followed by food if the current IRT fell into the bin that contained the fewest IRTs at that moment (i.e., the bin of IRTs represented least frequently). Pigeons' behavior was sensitive to this contingency, which resulted in high levels of IRT variability.

Another method of differentially reinforcing infrequently emitted responses is the relative-frequency threshold contingency. In a relative-frequency threshold procedure, the relative frequencies of all possible responses are calculated after every response. A reinforcer is delivered only if the relative frequency of the current response is below a threshold value predetermined by the experimenter. Often, these relative frequencies are multiplied by a weighting coefficient, also predefined by the experimenter, to more heavily weight recent responses. For example, Denney and Neuringer (1998) applied a weighted relative-frequency threshold contingency in rats emitting sequences of four-response lever presses across two levers (e.g., LRLR), using a threshold value of $t = 0.09$ and a weighting coefficient of $w = 0.95$. After each sequence, the relative frequency of all sixteen possible four-response sequences was calculated by dividing the number of

[3] Relative-frequency threshold contingencies were used in Study 2 (Chapter 3) and Study 4 (Chapter 5) of this dissertation.

instances of each sequence by the total number of sequences completed. After each food delivery, these relative frequencies were multiplied by 0.95, which resulted in an exponentially decreasing contribution of recent sequences. Using these calculations, a sequence was only followed by food if its weighted relative frequency was 0.09 or less; in other words, the sequence must have been emitted less than approximately 9% of the time in the past. Denney and Neuringer found that the presence of the threshold contingency resulted in increased levels of behavioral variability. Similar to lag schedules, behavioral variably has also been shown to be sensitive to the specific threshold value. For example, Doughty et al. (2013) observed higher levels of variability in pigeons responding on a weighted relative-frequency threshold contingency with a strict threshold value of $t = 0.05$ (i.e., only sequences emitted less than approximately 5% in the past would produce food) and lower levels of variability with a threshold value of $t = 0.30$, a much more lenient criterion (i.e., only sequences emitted less than approximately 30% in the past would produce food). Thus, levels of variability tended to increase as the threshold value decreased. Threshold schedules have been used successfully, not only in rats and pigeons, but also in mice (e.g., Arnold & Newland, 2018) and humans (e.g., Galizio et al., under review; Hansson & Neuringer, 2018; Ross & Neuringer, 2002). To illustrate the use of the relative-frequency threshold contingency, Table 1-2 shows a series of trials from a hypothetical experiment including response sequences (e.g., LRLR), as well as relative frequencies of those sequences, across 30 trials. Sequences with asterisks would have satisfied a relative-frequency threshold contingency with a threshold value of 0.05 (e.g., Doughty et al., 2013), because the relative frequencies of those sequences were at or below 0.05.

Table 1-2.
Hypothetical Sequences and Contingency Satisfaction: Relative-Frequency Threshold and Percentile Schedules.

Trial	Sequence	Count	Relative Frequency	Rank	Trial	Sequence	Count	Relative Frequency	Rank
71	RLLL	4	0.056	8	81	RRRR	5	**0.062**	**11**
72	LLLL	22	0.306	16	82	LLRR	5	0.061	10
73	LRRR*	3	0.041	3	83	LLLR*	3	0.036	3
74	LLLL	23	0.311	17	84	LLRL*	3	0.036	2
75	LRRL	4	0.053	7	85	RLRR*	4	0.047	6
76	LLLL	24	0.316	19	86	RRLL*	4	0.047	5
77	LRRL	5	0.065	13	87	LLLL	26	0.299	15
78	RLLL	5	0.064	12	88	RLLR	5	0.057	9
79	LLLL	25	0.316	20	89	LLLL	27	0.303	16
80	LRLL*	4	0.050	6	90	LLLL	28	0.311	17
81	RRRR	5	**0.062**	**11**	91	LLRL*	4	0.044	4
82	LLRR	5	0.061	10	92	LLLL	29	0.315	18
83	LLLR*	3	0.036	2	93	RLLR	6	0.065	14
84	LLRL*	3	0.036	1	94	LLLL	30	0.319	19
85	RLRR*	4	0.047	5	95	RLRL	6	0.063	13
86	RRLL*	4	0.047	4	96	LLLL	31	0.323	20
87	LLLL	26	0.299	14	97	LLRR	6	0.062	12
88	RLLR	5	0.057	9	98	LRLL	5	0.051	8
89	LLLL	27	0.303	15	99	RRLR	3	0.030	1
90	LLLL	28	0.311	18	100	LLRL*	5	0.050	7
Percentile criterion = 0.062				No	Percentile criterion = 0.062				Yes

Note. This table displays a sample series of sequences emitted in Trials 71-90 (left panel) and Trials 81-100 (right panel) by a single subject in a hypothetical variability experiment. In each panel, the first column contains the trial number, and the second column contains the hypothetical sequence emitted on that trial. The third column shows the cumulative frequency of that sequence since Trial 1, and the fourth column shows the relative frequency of that sequence (count / current trial number). The fifth column rank orders relative frequencies for Trials 71-90 (left panel) and 81-100 (right panel). The bottom row indicates whether Trials 90 or 100 would have satisfied a percentile schedule; relative frequency less than the percentile criterion (i.e., the eleventh-lowest relative frequency; see Miller & Neuringer, 2000). The percentile criterion for each set of 20 trials is bolded. Asterisks denote sequences that meet a relative-frequency threshold contingency (relative frequency less than the threshold value = 0.05; see Doughty et al., 2013).

Another procedure used to reinforced behavioral variability is the percentile reinforcement schedule (see Galbicka, 1988), which is similar to both a relative-frequency threshold schedule, in that it also reinforces only infrequently performed

responses, and a lag schedule, in that the criterion for reinforcement also considers response recency. Percentile schedules have been used to promote behavioral variability in pigeons (e.g., Machado, 1989) and humans (e.g., Miller & Neuringer, 2000). For example, Miller and Neuringer implemented a percentile reinforcement schedule to increase behavioral variability in adolescents, with and without ASD, emitting four-response sequences across two buttons (e.g., LRLR). Each time a sequence occurred, its weighted relative frequency was calculated, similar to a weighted relative-frequency threshold contingency, and added to a list of the most recent twenty trials. The list of relative frequencies was then rank ordered, and the eleventh lowest value in the list was set as the criterion for reinforcement (the stringency of the contingency could be increased by decreasing the rank set as the criterion). If the current sequence had a weighted relative frequency of less than the criterion, points were delivered. In this way, the same percentage of sequences was always reinforced, and the participants' responding was gradually "pushed" to be more and more variable over time.

To exemplify the application of a percentile schedules Table 1-2 shows hypothetical response sequences (e.g., LRLR) emitted across 30 trials. The left panel displays Trials 71-90 and the right panel displays Trials 81-100 (trials overlap to illustrate the moving window of 20 trials used for comparison in the percentile schedule). According to a percentile schedule, a sequence is reinforced only if its relative frequency is less than the current percentile criterion. On every trial, the percentile criterion is determined by rank ordering the relative frequencies for most recent 20 trials. The eleventh-lowest relative frequency is set as the percentile criterion (Miller & Neuringer, 2000), and a reinforcer is delivered if the relative frequency on the current trial is below

the criterion. Because the rank order of the most recent 20 trials, and therefore the percentile criterion, are updated on every trial, Table 1-2 only shows whether Trials 90 and 100 would have satisfied a percentile schedule based on the ranks of the previous 20 relative frequencies.

Relative-frequency threshold and percentile schedules are advantageous, because they discourage higher order stereotypy more so than a lag schedule. Additionally, these schedules permit the reinforcement of occasional repetitions, as long as the sequences being repeated have been emitted relatively infrequently compared to other sequences, which allows truly random responding. However, these schedules are difficult to implement without automation (e.g., Duker & van Lent, 1991). It may be useful for future research to develop feasible methods of introducing relative-frequency threshold and percentile schedules into applied settings.

Control Procedures

Regardless of what methods are used to reinforce behavioral variability, the role of the contingency in producing behavioral variability cannot be isolated without using some sort of control procedure (which may be implemented as a control condition for within-subjects comparison or for a control group of subjects for between-subjects comparison). A number of control procedures have been utilized in variability research. These include yoked control schedules (e.g., trial-by-trial, variable-interval, and probabilistic reinforcement schedules), as well as repetition schedules (e.g., target sequence and lag repetition schedules).

Yoked control schedules aim to equate reinforcer rates for a variability (vary) condition or group and a yoked control (yoked) condition or group. Importantly, whereas

variability is required for vary subjects, variability is permitted but not required for yoked subjects. One way to yoke reinforcer rates is by using a *trial-by-trial* [4] procedure, in which reinforcers are delivered for a yoked subject on the exact same trials as the matched vary subject (e.g., Page & Neuringer, 1985). For example, if a vary pigeon satisfied a lag schedule on the first, fourth, and tenth trials, then the matching yoked pigeon would also receive food on the first, fourth, and tenth trials, independent of response variability. Another form of yoking involves the use of *variable-interval (VI) schedules* (e.g., Neuringer et al., 2001). For example, if a VI 1-min schedule were in place, then food would be available following a set interval of time; time intervals would be unpredictable, but they would average to 60 s. Each time an interval elapsed, a vary rat would receive food for the next sequence satisfying the variability contingency, whereas a yoked rat would receive food on the next trial regardless of which sequence occurred. Yoking may also be accomplished using *probabilistic reinforcement* [5] (e.g., Doughty & Galizio, 2015). In this procedure, the yoked condition or group would earn reinforcers for any sequence with a set probability, regardless of which sequence occurred. The probability of reinforcement would be based on the proportion of sequences reinforced for vary subjects in similar conditions. For example, if a vary pigeon satisfied a lag schedule on one-third of trials, sequences made by a yoked pigeon would be followed by food with a probability of 0.33, regardless of sequence variability.

Whereas yoked control schedules permit, but do not require, behavioral variability, *repetition* schedules only reinforce extremely low levels of variability. One

[4] A variation of the trial-by-trial yoked control schedule was used as a control in Study 4 (Chapter 5) of this dissertation.
[5] Probabilistic reinforcement was used as a control in Study 1 (Chapter 2) and Study 4 (Chapter 5) of this dissertation.

type of repetition schedule involves reinforcement of only a single *target* response sequence (e.g., RRLL; Odum et al., 2006). A similar procedure, which also reinforces repetitive responding, is the *lag repetition* [6] schedule. In this procedure, no particular sequence is required. However, in a lag repetition condition or group, a sequence is only reinforced if it is identical to one of a certain number of previous sequences (e.g., Neuringer, 1992). It is essentially the opposite of a typical lag schedule, in which sequences are only reinforced if they differ from a certain number of previous sequences. Even though no specific target sequence is required, the organism must repeat itself to earn reinforcement.

Measuring Behavioral Variability

After any of the above procedures is used to reinforce behavioral variability, the next question researchers are faced with is how to measure the results. Like in any other aspect of learning, one must first define the behavioral unit in question. In the case of variability, the behavioral unit may be defined as a sequence of responses across multiple operanda (e.g., four-peck sequence across two keys, such as LRLR), the time between responses (IRT), or a more complex response (e.g., a completed block structure). Even after defining a clear behavioral unit to use as a response, however, measuring behavioral variability is challenging, because the degree of variability cannot be determined based on a single response. The current response must be systematically compared to previous responses to determine the extent of the difference. However, there is some variance in the techniques and levels of analysis used to compare these responses.

[6] A lag repetition schedule was used as a control in Study 3 (Chapter 4) of this dissertation.

U-Value [7]

The most commonly used measure of behavioral variability, especially in basic research, is U-value. U-value is a global measure that analyzes the distribution of responses across all possible responses, typically within a session (Attneave, 1959; Miller & Frick, 1949; Page & Neuringer, 1985). U-value ranges from 0 to 1, where 0 would indicate that only one of the possible responses was emitted throughout the session (i.e., absolute repetition) and 1 would indicate that every possible response was emitted an equal number of times throughout the session (i.e., absolute variability). U-value is calculated using Equation 1:

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

in which Rf_i is the relative frequency of each response and n is the total number of possible responses. For example, pigeons may emit four-peck sequences across two keys (e.g., LRLR), yielding 16 possible sequences. To calculate U-value, relative frequencies (i.e., Rf_i, or the number of instances of each of the 16 sequences divided by the total number of sequences in that session) and the number of possible sequences (n = 16) would be entered into the equation. Higher and lower U-values would be indicative of higher and lower levels of behavioral variability, respectively.

U-value is a highly useful measure of behavioral variability; however, there are certain limitations. First, U-value requires a finite, specified number of possible responses (n). There are some studies in which the potential number of possible responses is virtually infinite, or at least unspecified (e.g., vocalizations; Esch et al., 2009). Second,

[7] U-value was used as the primary measure of behavioral variability in Study 1 (Chapter 2), Study 2 (Chapter 3), and Study 4 (Chapter 5) of this dissertation.

U-value requires a large number of trials completed per session for an accurate calculation. When response rates are low, U-value is no longer a reliable measure (see Galizio et al., 2018; Chapter 2). One way to correct for this issue is to calculate pooled U-values, by calculating U-values across multiple sessions of the same condition to ensure a sufficient of responses is entered into the calculation (see Galizio et al., 2018; Chapter 2). Third, although U-value quantifies performance over an entire session, which facilitates analysis, researchers using this molar perspective on behavior may overlook important behavioral changes on a more molecular level of analysis (see Kong et al., 2017). U-value is based on the distribution of responses across all possible response options within a session or block of sessions, which does not account for which particular responses occurred or the order in which they occurred. Last, some researchers have noted the lack of correspondence between the variability contingencies used and the primary dependent measure, U-value (Barba, 2012). Although lag and relative-frequency threshold schedules reinforce behavior based on relative recency or frequency, U-value is a summary of the distribution of responses. More accurate measures could be those that directly correspond to the contingency (e.g., proportion of responses satisfying the variability contingency).

Given these advantages and concerns, U-value may be an excellent initial analysis to conduct on reinforced behavioral variability data. U-value could even be sufficient as the sole analysis in certain studies, depending on the research question. However, to improve our theoretical understanding of behavioral variability, a U-value analysis should usually be accompanied by alternative measures.

Proportion of Responses Satisfying the Variability Criteria [8]

Another common measure used to quantify behavioral variability is the proportion of responses satisfying the variability criteria (e.g., Galizio et al., 2018; Galizio et al., 2020; Machado, 1997; Page & Neuringer, 1985). For example, if a lag *x* schedule was in place, one would divide the number of responses that differed from the immediately previous *x* responses (i.e., met the requirement) by the total number of responses made to determine the proportion of responses that satisfied the lag criterion. This measure can be applied regardless of which variability procedure is in place. However, whereas U-value is highly standardized, the proportion of responses meeting the variability criteria should not be compared across different variability requirements, because the variability requirement directly impacts the calculation. This measure is sometimes referred to as the proportion of responses reinforced. However, it is important to note that proportion of responses satisfying the variability criteria and proportion of responses reinforced are only equivalent while the variability contingency in place and when every response satisfying the criteria is reinforced. With a control condition or extinction in place, or when reinforcement is intermittent (e.g., Cherot et al., 1996), one can still calculate the proportion of responses that would have met the variability criteria. This measure is particularly useful because it can be used in virtually any preparation; however, it shares a limitation with U-value in that it is a molar measure, which could obscure any molecular effects.

[8] The proportion of responses satisfying the variability criteria was used as a measure of behavioral variability in Study 1 (Chapter 2), Study 2 (Chapter 3), Study 3 (Chapter 4), and Study 4 (Chapter 5) of this dissertation.

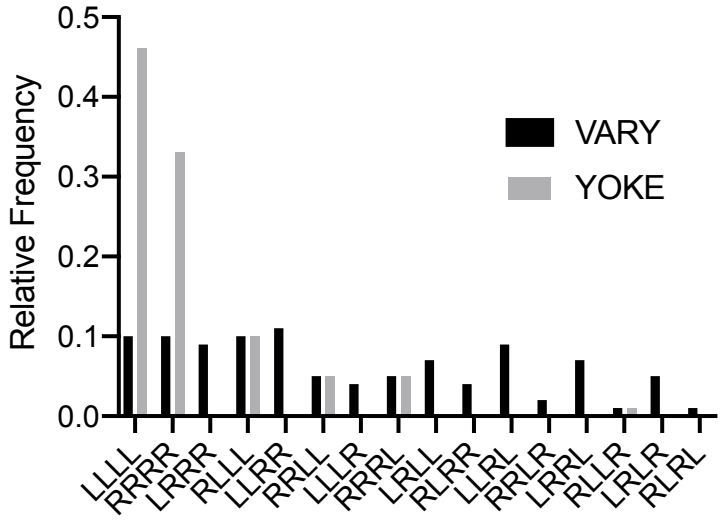
Relative Frequency Distributions [9]

Although the molar measures of U-value and the proportion of responses satisfying the variability criteria are informative in many regards, it is important to note that behavioral variability and randomness are not synonymous. More molecular analyses are called for in many cases to identify any systematic patterns of responding that appear highly variable, but truly show instances of higher order stereotypy. These molecular analyses often begin by creating relative frequency distributions, which can visually represent how evenly responding is distributed across all possible response options and whether there are biases for or against certain responses.[10] Figure 1-1 shows a relative frequency distribution for a hypothetical subject in a preparation involving four-response sequences across two operanda (e.g., LRLR). Black bars represent responding in a hypothetical variability condition, and grey bars represent responding in a hypothetical yoked control condition. All possible response options, in this case sequences, are displayed on the horizontal axis. Because the difference between sequences is categorical, not ordinal, the order in which they are presented on the graph is arbitrary. In Figure 1-1, the possible sequences are arranged from simplest (i.e., fewest changeovers between operanda) on the left to most complex (i.e., most changeovers) on the right. In

[9] Relative frequency distribution analyses were used to measure behavioral variability in Study 1 (Chapter 2) and Study 2 (Chapter 3) of this dissertation.

[10] These graphical representations are most useful when the number of possible response options is relatively small. For example, graphing relative frequency distributions can be useful with four-response sequences across two operanda (16 possible sequences) and even three-response sequences across three operanda (27 possible sequences), but they would likely not be useful with eight-response sequences across two operanda (256 possible sequences). However, subsequent analyses could be performed regardless of the total number of response options.

Figure 1-1.
Hypothetical Relative Frequency Distributions.



this example, the distribution of responding across available responses is relatively even for the vary condition, with a U-value of 0.944, and less evenly distributed for the yoked condition, with a U-value of 0.468, indicating high and low levels of behavioral variability, respectively.

However, additional information can be gleaned from examining relative frequency distributions, beyond the molar measure of U-value. For example, one can evaluate the prevalence of sequences with more or fewer changeovers between operanda, sequences with more or fewer repetitions at the end of the sequence, and sequences beginning with a right or left response, as well as the total number of distinct sequences emitted. Regarding changeovers, the hypothetical data in Figure 1-1 show a bias towards sequences with zero (e.g., LLLL, RRRR) or one changeover (e.g., LLLR, RRLL, etc.) for both conditions, although this bias is much more pronounced for the yoked condition. Sequences with two (e.g., LRRL, RRLR, etc.) or three changeovers (e.g., LRLR, RLRL)

are represented less frequently, especially for the yoked condition, in which these sequences almost never occur. Similar findings have been shown in the laboratory (e.g., Doughty & Galizio, 2015; Machado, 1997). For example, Galizio et al. (2018; Chapter 2) showed that pigeons tended to emit sequences with fewer changeovers more frequently than sequences with more changeovers. However, sequence complexity, in terms of number of changeovers, increased as behavioral variability also increased.

Another sequence characteristic to consider is the number of repetitions at the end of each sequence. As shown in the hypothetical relative frequency distribution in Figure 1-1, the most frequently emitted sequences are those with more end repetitions in both the vary and yoked conditions, but sequences with fewer end repetitions are still represented for the vary condition. The results depicted by the hypothetical data in Figure 1-1 are also evident in the current literature. As demonstrated by Doughty et al. (2013) and Doughty and Galizio (2015), pigeons tended to show a bias to emitting sequences with more end repetitions (e.g., RRRR [3 end repetitions], LRRR [2 end repetitions]), as opposed to fewer end repetitions (e.g., LLRR [1 end repetition], LLLR [0 end repetitions]). However, with a variability contingency in place, the number of end repetitions tended to decrease, and responding became more diverse.

It may also be helpful to examine which particular sequences are emitted more than others and how many total distinct sequences are represented. The hypothetical data in Figure 1-1 show that the most frequently emitted sequence in the vary condition was LLRR, followed closely by LLLL, RRRR, and RLLL. As the sequences become more complex, sequences beginning with a left become more probable. Further, all of the 16 possible sequences were emitted at least once. For the yoked condition, only six of the 16

possible sequences were emitted at least once, sequences beginning with a right were more probable, and the most frequently emitted sequences were the simplest ones, LLLL and RRRR. As an example from the available literature, Galizio et al. (2018; Chapter 2) reported the sequences that were most and least frequently emitted, as well as the percentage of sequences beginning with left and right keypecks. Although there were substantial individual differences, each individual pigeon tended to favor sequences beginning on one side over the other. As would be expected, sequences with fewer changeovers and more end repetitions (i.e., less complex sequences) were typically those emitted most often, but there were individual differences in which particular sequences were most dominant.[11] Additionally, out of the 16 possible sequences, the majority were represented when there was a variability contingency in place. However, during control conditions, when variability was not required, very few of the possible sequences occurred. Thus, although biases for specific sequences tend to be idiosyncratic across individuals, both sequence complexity and the number of distinct sequences emitted per session tended to increase with behavioral variability.

One final consideration related to relative frequency distributions is how to quantify and compare them. One can analyze these sequence characteristics (e.g., changeovers, end repetitions, biases for individual sequences, etc.); however, comparing overall relative frequency distributions across conditions is challenging because of all the factors that must be accounted for. Neuringer et al. (2001) attempted to address this concern by calculating the ratio of the relative frequencies of each sequence across

[11] The precise causes of such tendencies are unclear, but they are likely the result of individual experimental histories or physical characteristics of the responses themselves. For example, subject may show a bias for the responses farthest away from the door of the chamber or for responses closest to the food source (e.g., Neuringer et al., 2001).

conditions (reinforcement and extinction). A ratio of 1 would indicate no change across conditions, whereas a ratio above or below 1 would indicate that the relative frequency of that sequence increased or decreased in extinction, respectively. Neuringer et al. found that those sequences emitted most frequently during reinforcement tended to decrease in extinction, and vice versa, raising an interesting question about the nature of the variability observed during extinction (i.e., extinction of reinforced variability versus extinction-induced response variability).

Another method of comparing relative frequency distributions across conditions is explored in Chapter 3 of this dissertation (Galizio et al., under review). In this study, participants created rectangles on a computer screen and earned points based on variability in the location or size of the rectangles. To evaluate the degree of difference in relative frequency distributions across conditions, we calculated the absolute mean difference in relative frequencies across conditions for location and size. A greater difference across conditions indicated a more substantial change in performance. Using a cluster analysis, several distinct patterns of behavior were identified by categorizing changes in participants' performance across conditions. Theoretical interpretations were developed for the patterns of behavior observed in each class, including resurgence of reinforced behavioral variability, rule-governed behavior, and extinction-induced response variability. Additional strategies for quantifiably comparing relative frequency distributions should also be explored.

Sequential Dependency

Although relative frequency distributions can help clarify U-value and other global measures of behavioral variability, these distributions do not account for any

sequential dependencies that may be present. Sequential dependency refers to the degree of independence between events (Rodríguez & Hunziker, 2008). For example, a subject may emit all possible responses, resulting in a U-value of 1. If they emitted those sequences stochastically, then sequential dependency would be low. However, if they emitted those sequences in a specific order, repeatedly cycling through all possibilities (i.e., higher order stereotypy), then sequential dependency would be high. There are several analyses that can be used to test for these kinds of dependencies. For example, Machado (1992, 1997) used lag analyses and Markov chains to determine whether the current response (or pair of responses, or triplet of responses, and so on) could be predicted based on previous responses. Similarly, Mechner (1958) measured run lengths, or how many of a particular response occurred consecutively, and whether the current run length could be predicted based on previous run lengths. Using these and other techniques, higher order stereotypies may be detected.

Potential Mechanisms of Reinforced Behavioral Variability

Despite the diversity of procedures used to increase and maintain variability and the various techniques used to measure variability, it is clear that behavioral variability can be promoted using reinforcement. As discussed previously, this notion is counterintuitive from a traditional behavior-analytic perspective, which describes reinforcement as an increase in the probability of the same response occurring again in the future. Numerous theories have been proposed to account for the fact that, in a reinforced behavioral variability paradigm, a reinforcer delivery results in response variation, as opposed to repetition. Each of these explanations may account for reinforced

behavioral variability in some circumstances, but there is not currently enough evidence to prove any one of these theories correct.

Variability due to Remembering

The term *remembering* describes behavior under the control of past stimuli. One potential explanation for reinforced behavioral variability is that an organism satisfies the variability criterion by remembering its previous actions and emitting a behavior it has not done recently. This strategy is certainly the most efficient way of satisfying a lag schedule. If a lag 2 schedule is in place, it would be most effective for the subject to cycle through three different responses, earning every possible reinforcer. There are some circumstances in which this kind of behavior is observed in the literature. For example, rats responding on a lag 1 schedule for IRTs came to alternate between long and short IRTs (Schoenfeld et al., 1966). Additionally, pigeons emitting two-response sequences across two keys (LL, LR, RR, RL) eventually began to alternate responses in order to maximize food deliveries (Machado, 1993). However, remembering seems to govern responding only in situations in which the variability criterion is extremely lenient (e.g., lag 1) or the response unit is extremely simple (e.g., LR, RL). Based on the discussion above of variability versus higher-order stereotypy evidenced by sequential dependencies, it could be argued that these cases are not true examples of reinforcing variability but are instead examples of reinforcing the remembering of repeated response patterns. Performance under more strict variability requirements, however, (e.g., lag 50; Page & Neuringer, 1985) cannot be explained through remembering.

When the variability or response requirements are strict or complex, remembering seems to no longer play a major role. For example, Page and Neuringer (1985)

systematically manipulated the number of responses per sequence (e.g., four-peck versus eight-peck sequences). As the number of responses per sequence increased, levels of variability changed only minimally. Assuming that longer sequences are more difficult to remember than shorter sequences, this result indicates that the pigeons were most likely not relying on remembering to vary their responding. Neuringer (1991) introduced long interresponse intervals (IRIs) for rats completing four-response sequences across two levers (e.g., LRLR). As the time between responses was increased, levels of variability also increased. An increased IRI duration was hypothesized to hinder remembering of the previous response; this finding was interpreted as evidence that remembering was not only unnecessary, but it could also reduce variability. If organisms have an innate tendency to repeat, then remembering their previous response could bias their next response in the direction of repetition, which would hinder performance in a reinforced behavioral variability task. In addition, several studies have been conducted to test the effects of memory-impairing drugs, such as ethanol, on variability. In each of these studies, exposure to ethanol adversely impacted performance on a repetition task but did not affect performance on a variability task (e.g., Cohen et al., 1990; Crow, 1988; McElroy & Neuringer, 1990; Ward et al., 2006). Because ethanol is known to impair memorial processes, it was concluded that reinforced behavioral variability did not require remembering.

As further evidence that remembering is not necessary for reinforced behavioral variability, Doughty and Galizio (2015) showed that embedding a remembering contingency within a variability contingency did not alter levels of behavioral variability. In this experiment, pigeons completed four-peck sequences (e.g., LRLR) and earned

reinforcers according to a relative-frequency threshold schedule; as a result, pigeons engaged in high levels of behavioral variability. In another condition, pigeons continued to complete four-peck sequences. However, those sequences were periodically interrupted at any point in the sequence. When the sequence was interrupted, one key turned red and the other turned green (sides counterbalanced across trials). Through previous training, pigeons learned to respond to one color if their most recent peck was on the left and respond to the other color if their most recent peck was on the right. Although pigeons completed this task with high accuracy, the level of variability on the noninterrupted sequences was unchanged. If the pigeons had been using remembering to satisfy the variability contingency, then training and promoting remembering would have enhanced performance. The evidence seems to point to the fact that remembering is not needed for subjects to perform well on reinforced behavioral variability tasks, limiting the explanatory power of remembering processes.

Variability as a Byproduct

Given that remembering cannot fully explain reinforced behavioral variability in many cases, other explanations have also been proposed. One school of thought is that "reinforced" behavioral variability is not a result of direct reinforcement. Instead, the behavioral variability observed when variability schedules are implemented may be a byproduct of these schedules. One interpretation is that variability schedules inadvertently reinforce some other aspect of behavior directly (e.g., changeovers; Machado, 1997). When that aspect of behavior increases, overall behavioral variability may also increase. This point of view is more consistent with the traditional behavior-analytic perspective that reinforcement increases the behavior it follows. If behavioral

variability arises as the result of reinforcement of a different aspect of behavior, then there is no need to explain how a reinforcer following one response can increase the likelihood of a different response.

The notion that "reinforced" variability emerges as a byproduct of accidental reinforcement of some other aspect of behavior has been explored. For example, Machado (1997) proposed that, although variability contingencies are intended to reinforce behaving variably, those contingencies inadvertently reinforce another aspect of behavior – switching, or changing over, between keys. Machado tested this hypothesis by studying pigeons emitting eight-peck sequences (e.g., LLRRLLRR), with one of two schedules in place. Pigeons responded either on a lag schedule or on a schedule that delivered food only for sequences with a certain number of changeovers. If 1 changeover was required, then every possible sequence containing one changeover would be followed by food (e.g., LLLLRRRR, RRRRRRRL, etc.). Machado systematically varied the number of changeovers required to produce food. Even though pigeons could satisfy the changeover contingency by repeating a single sequence with the correct number of changeovers (e.g., RRRRRRRL), high levels of variability were observed, nearly equivalent to levels of variability obtained using a lag schedule, which indicates that the lag schedule may not be reinforcing variability per se but may instead be reinforcing changeovers. Machado hypothesized that pigeons did not behave repetitively on the changeover contingency due to limitations of stimulus control (i.e., imperfect remembering and replication of previous sequences) and generalization (i.e., strengthening of similar sequences, not only the sequence that produced the reinforcer).

Although this explanation of behavioral variability is plausible, subsequent evidence has indicated that it is likely not a complete explanation. Doughty and Galizio (2015) attempted to replicate Machado's (1997) results, but using four-peck sequences (e.g., LRLR) as opposed to eight-peck sequences (e.g., LLRRLLRR). Reinforcing sequences with at least one changeover did not result in high levels of behavioral variability in four-peck sequences. There are a number of possible reasons for these discrepant findings. Machado proposed limitations of stimulus control, or imperfect remembering, as a reason for the increased behavioral variability. However, remembering a four-peck sequence is much easier than remembering an eight-peck sequence, meaning the pigeons in the experiment by Doughty and Galizio may have been more accurately remembering and replicating past sequences that met the changeover requirement. Therefore, inadvertently reinforcing changeovers may account for behavioral variability under specific conditions (e.g., long sequences) but not others, limiting its applicability. Although variability schedules seem to be doing more than just reinforcing switching, it is possible that there is some other aspect of behavior that is being inadvertently reinforced, rather than variability per se. More research is needed to rule out this hypothesis.

Another interpretation is that variability schedules do not directly reinforce any aspect of behavior. Instead, the variability we observe is induced by occasionally withholding reinforcement, which is a natural result of all variability contingencies. If so, the concept of reinforced variability is superfluous, and all behavioral variability observed is inadvertently induced by cycles of reinforcement and nonreinforcement (e.g., Holth, 2012). Variability contingencies typically involve intermittent reinforcement,

although contingent on the occurrence of a non-recent or infrequent response. Thus, it is possible that the observed behavioral variability from these procedures has been induced by periods of nonreinforcement (i.e., extinction-induced response variability), rather than directly reinforced (see Holth, 2012). For example, after a food delivery, the pigeon may be more likely to repeat the sequence again, a predictable outcome of reinforcement. However, under a variability schedule, the same sequence would not likely produce food again. After contacting extinction, behavioral variability could be induced, resulting in the pigeon emitting a new sequence, which would be more likely to be followed by food. This periodic exposure to extinction could result in high levels of behavioral variability without directly reinforcing variability. One major issue with this theory is that intermittent reinforcement, alone, is not sufficient to account for the levels of variability observed with lag or threshold schedules in place, evidenced by the low levels of variability observed in yoked control groups and conditions that also involve intermittent reinforcement (e.g., Page & Neuringer, 1985). Therefore, it is unlikely that our procedures are resulting in extinction-induced behavioral variability as an artifact of the alternating periods of reinforcement and nonreinforcement inherent in every schedule, though more research is needed to completely rule out this hypothesis.

Variability as an Operant

Although remembering, inadvertent reinforcement of an unrelated response, and induction by extinction may explain the behavioral variability observed in some specific cases, there is also overwhelming evidence to suggest that behavioral variability can be reinforced directly. These data have led Neuringer to propose that behavioral variability may be an *operant*, similar to response rate, force, duration, location, or topography (see

Neuringer, 2002, 2004, 2009, 2014, 2016; Neuringer & Jensen, 2012, 2013, for reviews). An operant is a class of responses that are affected similarly by a consequence (Skinner, 1953). For example, a rat may earn food contingent on pressing a lever. If food delivery were made contingent on pressing the lever rapidly, with great force, for a specified duration, in a particular location, or with a certain body part, then that specific dimension of behavior would be selected and would occur more frequently. Neuringer has argued that variability is another one of those operant dimensions, in that specific levels of response variability can be differentially reinforced.

For a dimension of behavior to be considered operant, it must be sensitive to consequences (i.e., reinforcement) and controllable by antecedents (i.e., discriminative stimuli). In the first major demonstration of variability as an operant, Page and Neuringer (1985) studied pigeons emitting sequences of keypecks of varying lengths across two keys (e.g., LRLR, LLRRLLRR). Food was delivered when the pigeon made a sequence that differed from a certain number of previous sequences (i.e., lag schedule). This procedure produced high levels of behavioral variability only when the lag schedule was in place (i.e., not with a yoked control contingency in place). Levels of variability seemed also to be sensitive, not only to the presence of a reinforcement contingency requiring variability, but also to the stringency of the variability criterion. Page and Neuringer (1985) implemented lag schedules with various requirements. Levels of variability observed under a lag 50 schedule, a very strict requirement, were higher than those observed under a lag 5 schedule, a much more lenient requirement.

Further, if behavioral variability is an operant, then it should not only be sensitive to reinforcement contingencies, but also controllable by discriminative stimuli. In other

words, organisms must be able to learn the situations in which variability is and is not required. To test this idea, Page and Neuringer (1985) implemented a multiple variability-stereotypy schedule, in which two components, signaled by discriminative stimuli (i.e., colors), alternated periodically. During the variability component, the keys were one color (e.g., blue), and a lag schedule was in place, meaning that high levels of variability were required to produce food. During the stereotypy component, the keys were another color (e.g., green), and only a single, experimenter-determined target sequence was followed by food. After exposure to this procedure, pigeons began to behave highly variably when the keys were blue and highly repetitively when the keys were green. Pigeons also tracked the contingencies when the components were reversed. These data provide clear evidence that levels of behavioral variability are controllable by discriminative stimuli. Combined with the evidence that behavioral variability is sensitive to reinforcement contingencies, these data support the idea of variability as an operant.

It has further been hypothesized that behavioral variability may be a *generalized operant* (Barba, 2015; Neuringer, 2012). A similar example of a generalized operant is imitation, in which an organism receives a reinforcer, not for a behavior of a certain topography, but when the behavior matches a model. Through such training, a relational property (e.g., similarity between model and behavior), as opposed to a particular response property (e.g., topography), is made more likely through reinforcement. In other words, the higher order "rule," *to imitate*, is learned. Under a variability contingency, no specific response is reinforced; instead, responses are only reinforced if they have not been emitted too recently or too frequently. Under these conditions, it has been suggested that organisms learn the higher order "rule," *to vary*, similar to imitation. More

specifically, Neuringer (2012) has suggested that organisms may sometimes learn *to behave randomly*, resulting in unpredictable, stochastic responses that meet the variability criteria.

To explain the apparent randomness in the behavior of animals responding on a variability contingency, Neuringer (2002) has proposed the theory that behavioral variability is produced by an endogenous stochastic generator. According to this theory, organisms are innately equipped with a sort of random response generator. As discussed by Jensen et al. (2006), it is theoretically possible that animals could have biological structures akin to "roulette wheels in their heads" (Smith, 1982, p. 76). Jensen et al. argue that some sort of "operant randomizing device" (p. 459) has evolved, allowing animals to behave in a random-like manner. Therefore, when an organism encounters a variability contingency, it has been hypothesized that this "device" is activated, and responses begin to "emerge stochastically" (Neuringer, 2002, p. 697). If variability is an operant, then there exists a class of responses, consisting of all possible behaviors (e.g., 16 possible sequences of four L or R responses). When the organism makes a response, it is thought that one of the behaviors in the class is selected randomly, and the organism does the selected behavior. If an organism responds according to a random generator, then its behavior would satisfy a variability contingency relatively frequently.

There is a great deal of evidence that is consistent, or at least not inconsistent, with endogenous stochastic generation. First, the finding that remembering is not necessary for the production of variable behavior is taken as evidence to support an endogenous stochastic generator (Neuringer, 2002). As described above, available evidence suggests that variability is not impacted by an additional remembering

contingency (Doughty & Galizio, 2015) and is increased or unaffected by manipulations that hamper remembering (Cohen et al., 1990; Neuringer, 1991). Because each response produced by a random generator should theoretically be completely independent of other responses, it follows that remembering would either have no effect or even have a detrimental effect on random performance, by biasing the endogenous random generator, detracting from its stochasticity, and reducing behavioral variability (Neuringer, 1991).

Perhaps the most compelling piece of evidence in support of the endogenous random generator is the similarity in response distributions between an organism and a random number generator responding on a variability contingency. For example, Neuringer (1986) tested for random responding in high school and college students producing sequences of two numbers on a keyboard. The participants were initially instructed to behave randomly, and their responses differed significantly from all stochastic models. However, when the participants were provided feedback according to a variety of statistical tests of randomness, they eventually generated response distributions that closely approximated the stochastic models. This result led Neuringer to conclude that, although responding prior to feedback was clearly nonrandom, the feedback seemed to activate an endogenous stochastic generator, allowing participants to behave randomly. This finding has been further demonstrated in pigeons responding on a lag schedule. Page and Neuringer (1985) systematically increased the number of responses required per sequence. The probability of satisfying the lag criterion increased as the number of responses per sequence increased; the same pattern was shown by a random number generator.

Despite the evidence that is consistent with an endogenous stochastic generator as an explanation of reinforced variability, there are limitations as well. For example, Neuringer (2002) has acknowledged the major concern that this theory is currently unfalsifiable. Because randomness is, by definition, unpredictable, there is no way to prove that a response distribution could not be the result of a random generator. Additionally, Jensen et al. (2006) have suggested that the endogenous stochastic generator is physically manifested within the organism, but where in the brain such a generator might exist is unclear. Even if there were a brain structure that functioned as a random generator, there are other remaining questions, such as how this brain structure would be activated and inactivated (Holth, 2012). One potential explanation is that organisms discriminate situations in which repetition or variability is more advantageous through contact with the reinforcement contingencies (Page & Neuringer, 1985). However, even if we accept that organisms constantly discriminate whether or not a variability contingency is in place to determine when to activate their endogenous stochastic generator, the question remains of how the device may be "tuned." Page and Neuringer (1985) have shown that levels of behavioral variability are sensitive to the specific level of variability required (e.g., variability is higher for a lag 50 than a lag 10). Therefore, the generator must have been adjusted in some way across these schedules, but it is unclear how or when these adjustments would occur. Although the available evidence is not inconsistent with this theory, there are no data to suggest that an endogenous stochastic generator exists in an organism's body. Therefore, we should not appeal to this theory until it has been formalized and been made falsifiable, and not until other explanations have been definitively ruled out.

The Balance Hypothesis of Variability [12]

One of the most recent theories proposed to explain reinforced behavioral variability is known as the balance hypothesis. First suggested by Machado and Tonneau (2012) and later formalized by Barba (2015), the balance hypothesis posits that variability is not necessarily an operant but is reinforced through negative frequency-dependent selection, implemented by variability procedures. According to this theory, variability contingencies work by differentially reinforcing the least frequently emitted responses. For example, when a pigeon produces a particular sequence of keypecks, the frequency of that sequence compared to all other possible sequences increases. As the frequency of a sequence increases, the chances of a food delivery following that sequence are diminished. As the pigeon continues to make sequences, non-emitted sequences decrease in frequency compared with other possible responses, increasing the likelihood that they will produce food when they eventually occur. This perspective has been primarily conceptualized from a reinforcer-strengthening approach; as one "sequence becomes weaker (less frequent), it is more likely to produce reinforcement, and as an alternative sequence becomes stronger (more frequent), it is less likely to produce reinforcement" (Barba, 2015; p. 99). In this way, no one sequence is reliably selected because the likelihood of each possible sequence occurring is balanced over time, resulting in high levels of behavioral variability.

[12] The balance hypothesis (Barba, 2015; Machado & Tonneau 2012) shares some similarities with the hypothesis of variability as a byproduct of cycles of reinforcement and nonreinforcement (Holth, 2012). However, Holth's theory explains the presence of behavioral variability as a result of extinction-induced response variability, whereas the balance hypothesis explains behavioral variability through negative frequency-dependent selection, or differential reinforcement of infrequently occurring behaviors.

However, the balance hypothesis can also be approached using the perspective of reinforcers as discriminative stimuli. This theory would suggest that a reinforcer delivery serves as a discriminative stimulus, signaling that the most recent sequence is unlikely to produce another reinforcer, and any sequence that has occurred relatively infrequently has a greater chance of producing a reinforcer. As an illustration of this concept, Olton and Samuelson (1976) studied rats in a radial arm maze, in which food was only available once per arm. Rats quickly learned not to reenter an arm where they had just received food, a finding which indicated that reinforcers could serve as discriminative stimuli, as opposed to strengtheners. Instead of increasing the probability of the most recent response, food deliveries signaled that subsequent food deliveries would occur elsewhere. Similarly, Cowie et al. (2011) arranged conditions in which a pigeon would be more or less likely to receive food for pecking the key that was most recently productive (i.e., had most recently produced food). When food was less likely to follow keypecking to the most recently productive location, pigeons learned to switch locations after a food delivery. In a reinforced variability preparation, a food delivery serves as a signal that the same sequence is unlikely to produce food again. Subjects therefore learn to emit a different sequence after receiving food, resulting in high levels of behavioral variability.

The balance hypothesis can account for all of the same phenomena as the theory of variability as an operant (i.e., endogenous stochastic generator). The theory directly predicts the increase and maintenance of behavioral variability under frequency-based procedures (e.g., relative-frequency threshold contingencies; e.g., Denney & Neuringer, 1998), because the logic behind the theory and these procedures is essentially the same. Only relatively infrequently emitted responses are eligible for reinforcement. Results

from lag schedules (e.g., Page & Neuringer, 1985) can also be explained by the balance hypothesis, even though lag schedules are recency- instead of frequency-based. On a lag *x* schedule, when a particular sequence is emitted, that sequence will not produce food again until *x* other sequences have occurred. Thus, more frequently occurring sequences are less likely to produce food and less frequently occurring sequences are more likely to produce food, resulting in high levels of variability. The balance hypothesis can also account for increased levels of variability as the variability requirement and the number of responses per sequence increased (e.g., Page & Neuringer, 1985). If the variability requirement is increased, then, according to the balance hypothesis, a sequence must be emitted even less frequently in order to be eligible for food, which results in more sequences being represented and higher levels of behavioral variability. If the number of responses per sequence is increased, then the total number of possible sequences also increases; a balanced distribution of sequences is more widely spread when more possible sequences exist.

The balance hypothesis can also explain higher levels of behavioral variability with a variability contingency in place than a yoked or other control contingency (e.g., Denney & Neuringer, 1998). Because food in the yoked condition is delivered irrespective of which sequences occurred, any sequence may be followed by food, even if it has occurred at a high frequency. In fact, food deliveries are more likely to follow more frequently emitted sequences, simply because those sequences occur more often. When the contingency does not differentially reinforce infrequently emitted responses, negative frequency-dependent selection does not occur. In addition, it makes sense that such behavioral differences could be readily brought under stimulus control. In the presence of

a stimulus signaling a variability contingency, more of the possible sequences have a history of reinforcement and so more different sequences are likely to occur, resulting in high levels of variability. In the presence of another stimulus, signaling a control condition in which variability is not required, fewer sequences have a history of reinforcement, and so those limited sequences are more likely to occur than others, resulting in low levels of variability.

One potential limitation of the balance hypothesis is that it does not predict generalization of variable responding. If, as Neuringer (2012) has proposed, variability is a generalized operant, then organisms should be able to learn the rule, *to vary*, and apply that same strategy in novel contexts, in other tasks, and with new response topographies. The balance hypothesis, however, predicts limited generalization. According to the balance hypothesis, the frequency of each individual response must be shaped using reinforcement (Barba, 2015). The reinforcement history of each response may transfer across contexts, but variability of novel response topographies should require new contact with the contingencies before a balanced distribution can arise. There is some evidence for generalization of variability of the same response topography across contexts in the literature (e.g., Betz et al., 2011; Lee et al., 2002; Sellers et al., 2015). Because generalization was shown across contexts and the specific behaviors did not change, the reinforcement history of each individual response could have easily transferred to the new context. Additionally, a history of reinforcement for interacting with objects variably has been shown to enhance later foraging behavior (e.g., Weiss & Neuringer, 2012). Again, even though the tasks were slightly different (interacting with objects variably versus foraging for food among those objects), the behaviors that the rats engaged in

were similar. Finally, variability training has been shown to facilitate learning of a new, difficult response in rats (e.g., Grunow & Neuringer, 2002; Neuringer, 1993; Neuringer et al., 2000) and humans (Hansson & Neuringer, 2018). It has been assumed that these studies demonstrate facilitation of learning through variability training, which would require variability to be a generalized operant. However, another possible interpretation is that the subjects were simply engaging in a variety of responses due to the negative frequency-dependent selection characteristic of variability contingencies, encountering the difficult target response by chance. None of these explanations is inconsistent with the balance hypothesis.

Although outside the scope of this dissertation, two important future tests of the validity of the balance hypothesis, in comparison to the theory of variability as an operant, would be to assess generalization across response topographies and to examine reinforcement histories more closely. Because the balance hypothesis requires a specific reinforcement history for each response, introducing a novel response topography should require a new reinforcement history to be established, and generalization should not occur. If variability is a generalized operant, however, the rule, *to vary*, should readily generalize across response topographies. Preliminary data from our lab suggest that variability training does *not* generalize across response topographies.[13] More research is required to reach a definitive conclusion, but our initial findings provide some support for the balance hypothesis over variability as an operant. A second important test involves reanalysis of existing data to determine whether organisms reliably engage in the least frequent responses and whether any response biases (e.g., more frequently emitting

[13] Unpublished data (manuscript in preparation).

sequences with more end repetitions; Doughty et al., 2013) can be explained by reinforcement history. These and other future directions for research will help to better evaluate the proposed mechanisms of reinforced behavioral variability.

Reinforced Behavioral Variability in Clinical Populations

Whereas basic, experimental research has been focused on understanding the mechanisms underlying reinforced behavioral variability, a number of clinical applications have also been explored by applied researchers. Despite the value society places on behavioral variability, in terms of novel ideas, conversations, works of art, ways of thinking, etc., there are some individuals who struggle to behave appropriately variably. In defining variability, we often conceptualize it as a continuum from very repetitive to highly variable, or even random (e.g., Neuringer, 2002). The most successful individuals are those who engage in different levels of variability depending on the situation. If there is a discrepancy between behavioral variability and the environmental contingencies, an individual would likely lose many opportunities for reinforcement. Sometimes, these abnormal levels of behavioral variability are indicative of psychopathology.

On one end of the continuum, some individuals behave too variably, even when the environmental contingencies are designed to support repetitive behavior. For example, excessive behavioral variability is a common symptom experienced by individuals with attention deficit hyperactivity disorder (ADHD; e.g., Barkley, 1990). Without intervention, this variability is likely to be disruptive in certain environments (e.g., classrooms, offices, etc.), making it difficult for these individuals to thrive (e.g., Saldana & Neuringer, 1998).

On the other end of the continuum, some individuals tend to engage in overly repetitive behavior, even when it would be beneficial to vary. For example, individuals with clinical depression have trouble behaving variably in a variety of situations (e.g., Horne et al., 1982). An individual with depression may be unwilling to try new experiences or strategies, limiting access to reinforcement and potentially exacerbating other symptoms, such as anhedonia (i.e., lack of pleasure). Research suggests that individuals with clinical depression could benefit from variability training (Hopkinson & Neuringer, 2003). Other clinical conditions characterized by excessive repetition include obsessive compulsive disorder (OCD), as well as ASD (Jiujias et al., 2017). Individuals diagnosed with OCD or ASD could also benefit from variability training. Restricted and repetitive behavior in ASD will be one major point of focus throughout this dissertation.

Reinforced behavioral variability has been most widely researched in relation to ASD. There are three main criteria involved in diagnosing ASD (American Psychological Association [APA], 2013). The first two criteria include deficits in social interaction and impaired communication. The third criterion is presentation of restricted and repetitive behaviors, though the exact topography of the repetitive behaviors is highly individualized. These behaviors can range from motor stereotypy, such as hand flapping, rocking, or even self-injurious behavior; vocal stereotypies (i.e., echolalia); repetition in play, including arranging or engaging with toys atypically; repetition in conversation, such as when an individual asks everyone repeatedly for their name; and even restricted interests, such as a fixation on a certain movie, song, or activity (Goldman & Greene, 2013). The degree to which an individual with ASD engages in stereotypy may impact access to social (e.g., Jordan, 2003; Williams et al., 2001) and other forms of

reinforcement (e.g., Mullins & Rincover, 1985). Limited access to reinforcers may, in turn, impede development (e.g., McConnell, 2002).

Addressing stereotypy is often a primary emphasis of treatment for ASD. A variety of interventions have been studied (e.g., response interruption and redirection; Ahearn et al., 2007). One of the most successful methods used to treat behavioral stereotypy is applying a variability contingency (see DiGennaro Reed et al., 2012; Rodriguez & Thompson, 2015; Wolfe et al., 2014, for reviews). Sensitivity of the behavior of individuals with ASD to variability contingencies has been demonstrated experimentally, using arbitrary responses. For example, Miller and Neuringer (2000) examined variability in children and adults with ASD engaging in sequences of button pressing. Although individuals with ASD initially exhibited lower levels of behavioral variability than controls, variability reliably increased for all participants after implementation of a percentile schedule of variability. Similar findings have also been shown by Murray and Healy (2013), among others, indicating that variability contingencies could be a promising treatment avenue.

Based on years of research on reinforced behavioral variability in the laboratory, variability schedules have been successfully implemented in clinical settings. Researchers have reinforced behavioral variability using variability schedules for numerous behaviors, including vocalizations (Esch et al., 2009), requests (Betz et al., 2011; Brodhead et al., 2016; Sellers et al., 2016), conversations (Contreras & Betz, 2016; Lee et al., 2002; Lee & Sturmey, 2006, 2014), and play (Baruni et al., 2014; Galizio et al., 2020; Goetz & Baer, 1973; Napolitano et al., 2010). These findings suggest that variability contingencies

are effective in increasing adaptive behavioral variability in individuals with ASD in clinical settings.

Currently, it is not clear which variability contingencies are most effective when applied to clinical populations. Lag schedules are most frequently used with individuals with ASD (Baruni et al., 2014; Contreras & Betz, 2016; Brodhead et al., 2016; Esch et al., 2009; Galizio et al., 2020; Lee & Sturmey, 2006, 2014; Napolitano et al., 2010; Sellers et al., 2016). However, as previously discussed, the lag schedule has limitations. First, if behavioral variability is randomly generated (as suggested by Neuringer, 2002, etc.), repetition will occasionally occur due to chance. A lag schedule never reinforces repetition, which indicates that it may not be the most effective schedule of reinforcement for behavioral variability. Second, individuals responding on lag schedules frequently engage in higher order stereotypy (i.e., cycling between responses; Machado, 1992), especially with a lenient lag requirement. Lenient lag requirements (e.g., lag 1; Esch et al., 2009) are often used, either because they are practical to implement in applied settings or because the subject's behavioral repertoire is limited. However, under these conditions, individuals with ASD may learn higher order stereotypies, as opposed to learning to vary their responding, which is the goal.

There are alternatives to lenient lag schedules that can be explored. First, the lag requirement could be increased. However, this option is only feasible if the subject has a sufficient number of appropriate responses in their behavioral repertoire, and if the intervention is implemented in highly controlled settings, ideally with multiple experimenters (with a greater lag requirement, the possibility of treatment infidelity is increased). When a response is multidimensional, there is a way to increase the

variability criterion while maintaining a low lag requirement. Galizio et al. (2020; Chapter 5) implemented a lag 1 schedule for play behavior; however, the play action was required to differ from the previous response in multiple ways – the figurine selected, the movement made, and the location on the playset. In this way, the variability requirement was relatively high, but the burden on the experimenter implementing the lag schedule was manageable. However, there were still some instances of response cycling in this study, indicating that it is not a perfect solution. Another potential direction would be to use a variable lag schedule, in which the lag requirement changes from reinforcer to reinforcer. This procedure would be more reasonable to implement, because treatment fidelity errors would not be very costly. Additionally, a variable lag schedule could reduce the likelihood of higher order stereotypies emerging.

Other variability contingencies could also be considered. For example, differential reinforcement of novel behaviors, typically within-session, has been used in some applied studies (e.g., Betz et al., 2011; Goetz & Baer, 1973). This procedure may be slightly easier to implement than a lag schedule, but it would only be appropriate in situations where the subject has a very large number of responses at their disposal; otherwise, they would quickly run out of new behaviors to do. A percentile schedule, in which increasing levels of behavioral variability are required over time, has been used with clinical populations in the basic laboratory (e.g., Miller & Neuringer, 2000). Also, a procedure akin to an extremely lenient threshold contingency, in which only infrequently occurring responses are reinforced, was used to increase the variability of communicative gestures in an applied setting (Duker & van Lent, 1991). Percentile and threshold schedules more precisely reinforce variable behavior; however, they are burdensome to implement, due

to the calculations involved for every response. Future work should be focused on finding the procedures that most effectively reinforce variability while still being reasonable to implement (e.g., automation of procedures).

Theoretical and Clinical Considerations

A number of factors must be considered with regard to our theoretical understanding and clinical application of reinforced behavioral variability, including persistence, relapse, and choice of reinforced behavioral variability, among others.

Persistence and Relapse of Reinforced Behavioral Variability

The durability and potential recurrence of reinforced behavioral variability is highly relevant from both a theoretical and a clinical perspective. The degree to which behavioral variability is resistant to change and is susceptible to relapse would add to our theoretical understanding of variability as an operant. These findings could also have important implications for treatment.

One characteristic of operant behavior is that it is systematically disrupted by certain environmental changes (see Craig et al., 2014, for a review). For example, when responding is placed on extinction, overall response rates will decrease over time. The degree of persistence in response to these disruptors may be taken as a measure of response strength, and certain responses tend to be stronger than others (e.g., Nevin & Grace, 2000). For instance, responding maintained by higher reinforcer rates, more immediate reinforcement, and a higher magnitude of reinforcement tend to be more resistant to change (e.g., Nevin, 1974). However, behavioral variability tends to be more persistent than behavioral repetition, even when reinforcement conditions (rate,

immediacy, magnitude, etc.) are held constant, which is contrary to the typical conceptualization of response strength.

In fact, behavioral variability in rats and pigeons has been shown to be relatively unaffected by the application of a variety of disruptors, such as delay to the reinforcer (Odum et al., 2006; Wagner & Neuringer, 2006), pre-session exposure to the reinforcer and response-independent reinforcer presentations (Doughty & Lattal, 2001; Morris, 1990), and exposure to drugs, such as ethanol (e.g., Cohen et al., 1990; Crow, 1988; McElroy & Neuringer, 1990; McKinley et al., 1989; Ward et al., 2006), *d*-amphetamine (Pesek-Cotton et al., 2011; Ward et al., 2006), and others (e.g., midazolam [benzodiazepine] and pentylenetetrazole [stimulant]; Abreu-Rodrigues et al., 2004). Even when overall response rates decreased due to these manipulations, responding on variability contingencies remained highly variable, whereas responding on repetition contingencies tended to become more variable. In other words, the likelihood that the subject would make a response that satisfied the repetition requirement was reduced in the face of a disruptor, but the likelihood of making a response that satisfied the variability requirement was unchanged. The finding that reinforced behavioral variability is not readily disrupted by environmental changes, in the way other operant behavior is, complicates the interpretation of variability as an operant.

A related characteristic of operant behavior is a susceptibility to relapse after being eliminated (Craig et al., 2014). In the laboratory, relapse is often studied using reinstatement or resurgence preparations. *Reinstatement* is the reoccurrence of a previously reinforced behavior after extinction as a result of the delivery of response-independent reinforcers (e.g., de Wit & Stewart, 1981, 1983). *Resurgence* is the

reoccurrence of a previously reinforced behavior following extinction of a more recently reinforced behavior (e.g., Epstein, 1985). Relapse of behavioral variability would provide further evidence that it is operant behavior, but such evidence is sparse.

From a clinical perspective, it would be useful to know the extent to which reinforced behavioral variability persists in unfavorable conditions or recurs after elimination. A common behavioral strategy used to increase desirable behavior and decrease undesirable behavior is known as differential reinforcement of alternative behavior (DRA). DRA involves placing a problematic behavior (e.g., excessive stereotypy) on extinction while only reinforcing a socially appropriate replacement behavior (e.g., behavioral variability). For a clinician implementing this kind of intervention with an individual with ASD, it would be helpful to be able to predict the results of various environmental challenges. One important side effect of DRA is resurgence (e.g., Epstein, 1985; Smith et al., 2017). For example, if a therapist fails to reinforce behavioral variability or accidentally reinforces stereotypy (i.e., treatment infidelity), there is a risk of the client reverting to behaving stereotypically. Persistence of behavioral variability could be a particularly useful quality in these cases, because the individual would be more likely to continue to engage in the adaptive alternative, varying, as opposed to returning to the original problem behavior, stereotypy.

Although a great deal of basic research has been conducted on persistence of reinforced behavioral variability, relapse of reinforced behavioral variability has not been fully investigated. Studies 1 and 2 (Chapters 2 and 3) in this dissertation explored these questions in pigeons and humans, respectively. In Study 1 (Galizio et al., 2018), pigeons responded on lag contingencies and were tested according to three relapse phenomena in

three experiments: rapid reacquisition, reinstatement, and resurgence. The results showed persistence, but eventually extinction, of reinforced behavioral variability in each experiment. In addition, reinforced behavioral variability was shown to be susceptible to rapid reacquisition, reinstatement, and resurgence, although there are still some concerns when distinguishing between a recurrence of reinforced behavioral variability and extinction-induced response variability. In Study 2 (Galizio et al., under review), college students completed a computer-based variability task in a resurgence paradigm. We found some evidence for resurgence of reinforced behavioral variability; however, several other patterns of responding emerged, with interpretations including rule-governed behavior and extinction-induced response variability. These studies have added to the existing literature and served to further our understanding of the persistence and relapse of reinforced behavioral variability.

Choice for Reinforced Behavioral Variability

Preference for engaging in reinforced behavioral variability or repetition is relevant both theoretically and clinically. *Choice* is the allocation of responses among available response alternatives (e.g., Fisher & Mazur, 1997). When more behavior is consistently allocated to one option over others, it is termed *preference*.[14] After an individual has been taught to vary and repeat their behavior, it would be helpful to understand the factors that determine whether they will choose to engage in variable or repetitive behavior at any given time and which option they will generally prefer. From a theoretical perspective, it would be important to identify the specific aspects of each

[14] Throughout this dissertation, the terms *choice* and *preference* will refer only to the relative allocation of responding across alternatives. There is no assumption or implication of "free will." It is assumed that the allocation of responding (i.e., choice) is due to identifiable phylogenetic, ontogenetic, and environmental influences, and not originating from the organism itself.

contingency that may produce greater preference, which could potentially lead to a fuller understanding of the mechanisms underlying reinforced behavioral variability. From a clinical perspective, it would be useful to identify methods to increase preference for reinforced behavioral variability in individuals with ASD and other disorders, which would increase the likelihood that these individuals will engage in behavioral variability. Research involving choice and reinforced behavioral variability is critical, yet very little research has so far been conducted on the topic.

A common method of assessing preference is a concurrent chains schedule of reinforcement (e.g., Squires & Fantino, 1971). In a concurrent chains schedule, subjects are first exposed to two response options (i.e., initial links), available concurrently. Responding to one of these initial links will produce one outcome, or terminal link, whereas responding to the other initial link will produce the other terminal link. Responding for each initial link is taken as a measure of preference for the conditions in one terminal link over the other. To assess preference for reinforcement of behavioral variability or repetition, a concurrent chains schedule can be arranged such that one terminal link requires variable responding and the other terminal link requires repetitive responding to produce reinforcement. If a subject responds more to the initial link that leads to the variability terminal link than to the initial link leading to the repetition terminal link, then it can be inferred that the subject would prefer to respond according to the variability contingency than the repetition contingency.

Using a concurrent chains preparation, several studies have been conducted to assess choice between responding on a variability or repetition schedule. Abreu-Rodrigues et al. (2005) arranged a concurrent chains schedule in which pigeons could

choose to enter a terminal link that required variable responding to produce food or a terminal link that required repetitive responding to produce food. In this study, pigeons generally preferred to respond on a lag schedule, as long as the lag schedule was relatively lenient (e.g., lag 1). However, as the lag requirement increased (up to lag 10), preference shifted to the alternative requiring repetitive responding. Similar results were found when the effects of different lag requirements were compared, such that more lenient lag requirements were preferred over stricter requirements (Pontes et al., 2012). Importantly, this effect holds true even when reinforcer rates are equated across the two alternatives, meaning that a preference for one alternative over the other cannot be explained by rate of reinforcement (e.g., Arantes et al., 2012). Data from these studies suggest that, all else being equal, pigeons would prefer to behave variably than repetitively, but only when the variability requirement is lenient. Comparable results have also been found in college students (Abreu-Rodrigues et al., 2007).

The literature on choice for variability is limited. One major gap in the literature on choice for variability is extension to clinical populations. For example, it is unclear whether a preference for variability, given lenient enough requirements, would be present in individuals with ASD. To address this question, Study 3 (Galizio et al., 2020; Chapter 4) in this dissertation assessed choice for variable play in children with ASD. After being taught to play variably with one playset, and to play repetitively with another playset, participants were offered a choice between the two conditions. Two of the three participants selected the variability option more frequently than repetition (the other participant was indifferent). This finding indicates that at least some individuals with

ASD tend to behave repetitively, not necessarily because they prefer repetition, but because they have not yet learned to vary.

Translational Research on Reinforced Behavioral Variability

Reinforced behavioral variability has been and continues to be studied extensively from basic and clinical perspectives, considering both theory and practical application. However, a greater focus on translational research could help to bridge the gap between these two approaches, resulting in a more nuanced understanding of the mechanisms underlying reinforced behavioral variability, as well as the development and refinement of clinical interventions designed to promote variability. A translational research perspective combines a focus on basic experimental approaches and concern for the generality of behavioral principles to applied problems, producing "innovation through synthesis" (Mace & Critchfield, 2010, p. 296).

There are two directions in which translational research can be conducted – from basic to applied, and from applied to basic. Translational research is often bidirectional, containing elements of both of these approaches (McIlvane, 2009). One line of translational research has involved testing established basic findings of reinforced behavioral variability in applied settings. For example, researchers and clinicians have begun using lag schedules in treatment of individuals with ASD, with the goal of directly improving the lives of the participants in the study (e.g., Adami et al., 2017; Silbaugh & Falcomata, 2017). Similarly, variability schedules have been used in more everyday situations, such as in martial arts training (Harding et al., 2004). Another line of research has involved studying reinforced behavioral variability in clinical populations but in highly controlled experimental contexts. For example, researchers have studied

reinforced behavioral variability using arbitrary tasks in the laboratory in individuals with ADHD (Saldana & Neuringer, 1998), clinical depression (Hopkinson & Neuringer, 2003), and ASD (Miller & Neuringer, 2000). In a more everyday example, problem solving and learning have been studied using arbitrary tasks in the laboratory with typically developing individuals (e.g., Hansson & Neuringer, 2018).

Finally, one line of translational research has involved the use of animal models to address everyday situations and approximate clinical conditions. Rats have been used to investigate the role of reinforced behavioral variability on problem solving and learning (e.g., Grunow & Neuringer, 2002; Weiss & Neuringer, 2012). Researchers are just beginning to utilize animal models of clinical conditions to study reinforced behavioral variability as it may relate to those populations. These models have included spontaneously hypertensive rats (SHR), which are a well-established model of ADHD (Hunziker et al. 1996; Mook & Neuringer, 1994) and the BALB/c mouse model of ASD (Arnold & Newland, 2018). These preclinical models combine the social significance of applied research and experimental control of basic research but have not yet been fully leveraged to understand behavioral variability in individuals with ASD and other conditions.

A number of potential animal models of ASD have been proposed (Lewis et al., 2007; Whitehouse & Lewis, 2015), but one promising variation is early exposure to valproate (VPA; a teratogenic drug known to increase the risk of ASD diagnosis) in rats (Mabunga et al., 2015; Schneider & Przewłocki, 2005). Preliminary findings have suggested that VPA exposure in utero may impair social interaction and exacerbate stereotypy in rats. However, this model has yet to be examined in a reinforced behavioral variability task,

which was the primary aim of Study 4 (Chapter 5) in this dissertation. In this study, rats were exposed to VPA in utero and then tested in a variety of tasks. Our results were mixed: VPA rats seemed to exhibit increased stereotypy in some tasks and not in others, namely the reinforced behavioral variability task, raising questions about the validity of the VPA rat model of ASD. Study 4 exemplified bidirectional translational research aimed to begin to bridge the gap between basic and applied research. We used many of the strong experimental methodologies that distinguish basic behavioral research (e.g., nonhuman subjects, steady-state procedures, and elements of single-subject design; Critchfield, 2011*a*, 2011*b*), and we brought an applied perspective into the basic laboratory by using an animal model of ASD.

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CHAPTER 2

STUDY ONE:

PERSISTENCE AND RELAPSE OF REINFORCED BEHAVIORAL VARIABILITY IN PIGEONS [15]

Introduction

Variability may be an operant dimension of behavior (for reviews, see Neuringer, 2002, 2009, 2012, 2016). Like other operant behavior, behavioral variability may be controlled by its antecedents and consequences (e.g., Barba, 2012, 2015). Behavioral variability arises and is maintained as a result of reinforcement. A lag schedule of reinforcement is a variability contingency in which a response produces a reinforcer only if it differs from a certain number of previous responses (Page & Neuringer, 1985). Under a lag 5 schedule, for instance, the current response must be different than the previous five responses for a reinforcer to occur. Page and Neuringer demonstrated that high levels of behavioral variability could be sustained using lag schedules. Additionally, reinforced behavioral variability has been observed in pigeons (e.g., Abreu-Rodrigues et al., 2005; Doughty et al., 2013; Doughty & Galizio, 2015; Machado, 1997; Odum et al., 2006; Ward et al., 2006; Ward et al., 2008), rats (e.g., Cohen et al., 1990; Neuringer, 1991), and humans (e.g., Abreu-Rodrigues et al., 2007; Neuringer, 1986; Paeye & Madelain, 2011; Ross & Neuringer, 2002).

Operant behavior is characterized by control by antecedents and consequences. Behavioral variability is sensitive to reinforcing consequences. Several studies have

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[15] Chapter 2 of this dissertation was adapted from Galizio, A., Frye, C. C. J., Haynes, J. M., Friedel, J. E., Smith, B. M., & Odum, A. L. (2018). Persistence and relapse of reinforced behavioral variability. *Journal of the Experimental Analysis of Behavior, 109*(1), 210-237. https://doi.org/10.1002/jeab.309. See Appendix A for permission letter.

shown that the stringency of the variability contingency determines the degree of behavioral variability (e.g., Doughty et al., 2013; Page & Neuringer, 1985). For example, a lag 10 schedule results in higher levels of behavioral variability than a lag 5 schedule. Behavioral variability can also be brought under discriminative stimulus control. Several studies have shown that organisms may learn to emit variable behavior in the presence of one stimulus and emit repetitive behavior in the presence of another stimulus (e.g., Denney & Neuringer, 1998; Ward et al., 2008). Taken together, these findings support the notion of behavioral variability as an operant, although other theoretical interpretations have been proposed as well (Barba, 2015; Machado, 1997; Machado & Tonneau, 2012; Holth, 2012).

Operant behaviors can also be systematically affected by disruptors, such as extinction (for a review, see Craig et al., 2014). For example, if reinforcers are removed for responding at a high rate, then the overall rate of responding will decrease. Such disruption demonstrates the sensitivity of the behavior to its consequences, or lack thereof. According to behavioral momentum theory, the degree of persistence of responding in the presence of disruptors is an indicator of response strength (e.g., Nevin, 1974).

Although behaviors accompanied by equal reinforcer rates should have equal response strength and therefore be equally resistant to change (e.g., Nevin, 1974), some behaviors are still more persistent than others. For example, behavioral variability tends to be more persistent than behavioral repetition, even with matched reinforcement rates (e.g., Odum et al., 2006). Results from a number of studies have supported this exception to behavioral momentum. Several drugs have been shown to disrupt performance under

repetition contingencies while having little effect on performance under variability contingencies; for example, this effect has been demonstrated with ethanol (Cohen et al., 1990; Ward et al., 2006), *d*-amphetamine (Pesek-Cotton et al., 2011; Ward et al., 2006), other stimulants, and benzodiazepines (Abreu-Rodrigues et al., 2004). Similar results have been found for delay of reinforcement (Odum et al., 2006; Stahlman & Blaisdell, 2011; Wagner & Neuringer, 2006), prefeeding, and other response-independent food presentations (Doughty & Lattal, 2001). Even though other dimensions of behavior, such as rate of responding, are altered by these disruptors, behavioral variability per se does not seem to be affected.

Another prediction of behavioral momentum theory is that more persistent behaviors will be more susceptible to relapse (Craig et al., 2014). In the laboratory, relapse is often studied using reinstatement or resurgence preparations. Reinstatement is the reoccurrence of a previously reinforced behavior after extinction as a result of the delivery of response-independent reinforcers (e.g., de Wit & Stewart, 1981, 1983). Resurgence is the reoccurrence of a previously reinforced behavior following extinction of a more recently reinforced behavior (e.g., Epstein, 1985). Given the clinical implications of behavioral variability, discussed later, it is important to determine whether it is susceptible to relapse. Evidence of the relapse of behavioral variability is sparse, and more research is needed in this area to better test whether behavioral variability has typical operant characteristics.

One difficulty posed by studying relapse of behavioral variability is that relapse procedures frequently rely on extinction as a disruptor (e.g., de Wit & Stewart, 1981, 1983; Epstein, 1985). In the context of behavioral variability, the use of extinction creates

complications because of the difficulty in distinguishing between reinforced behavioral variability and extinction-induced behavioral variability. This distinction is important to consider, given that 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).

Few studies have examined the effects of extinction on behavior under the control of a variability contingency (Arantes et al., 2012; Neuringer et al., 2001). Neuringer and colleagues (2001) studied extinction of variable behavior in rats. Three groups of rats emitted sequences of lever- and keypresses. One group earned food for emitting variable sequences (Experiments 1, 2, & 3), another group received yoked reinforcement rates, matched to other groups, but no specific responses were required to produce reinforcement (Experiment 2), and a final group earned food for repeating a single target sequence (Experiment 3). When responding was extinguished, molar, statistical measures of behavioral variability increased slightly, indicative of extinction-induced behavioral variability. Neuringer and colleagues also conducted molecular, response-specific analyses. In baseline, rats in all groups emitted particular sequences more often than others. In extinction, those specific sequences continued to be emitted more often than others, but the probability of emitting a particular sequence tended to decrease if it had been produced more frequently in baseline and increased if it had been produced less frequently in baseline. Overall, rats behaved similarly in baseline and extinction, but occasionally emitted less frequent sequences when extinction was in place. It is important

to further examine the potentially confounding effects of extinction on behavioral variability, especially in the context of relapse.

The purpose of the present study was to determine the effects of extinction on reinforced behavioral variability and to determine if behavioral variability is susceptible to relapse. Experiment 1 was designed to examine extinction and reacquisition of reinforced behavioral variability in pigeons. Pigeons responded on a lag schedule in both components of a multiple schedule. Reinforcement was removed for behavior in one component to differentiate between reinforced and extinction-induced behavioral variability. In Experiments 2 and 3, we examined whether behavioral variability would relapse under reinstatement and resurgence procedures, respectively.

Experiment 1: Extinction and Reacquisition

The aim of the present experiment was to examine the effects of extinction on reinforced behavioral variability in pigeons using a multiple schedule to directly compare behavioral variability under reinforcement and extinction within subjects. In this experiment, four-peck sequences produced food on a lag schedule. Then, responding in one component was maintained on the same lag schedule, whereas responding in the other component was extinguished. Finally, the lag schedule of food delivery was restored for both components.

Method

Subjects

Twelve adult pigeons with prior experimental histories served as the subjects for this experiment. Although presented first, Experiment 1 was conducted after Experiments 2 and 3. Table 2-1 shows the chronological order of the experiments, as well as recent

Table 2-1.
Recent Behavioral Histories and Identifying Symbols for Each Individual Subject.

Subject	Symbol used	Immediate prior history	Experiment 2	Experiment 3	Experiment 1
55	●○	Relapse of key pecking	X	X	X
220	■□	Relapse of key pecking	X	X	X
223	▲△	Relapse of key pecking	X	X	X
237	▼▽	Relapse of key pecking	X	X	X
373	◆◇	Delay discounting	-	-	X
381		Relapse of key pecking	X	-	-
927		Relapse of key pecking	X	-	-
936		Relapse of key pecking	X	X	X
956	★✳	Relapse of key pecking	X	-	X
957		Relapse of key pecking	X	X	X
966	▶▷	Relapse of key pecking	X	X	X
1158	◀◁	Delay discounting	-	X	X
1499		Delay discounting	-	X	X
17556	♦◊	Delay discounting	-	X	X

Note: An X indicates that the pigeon participated in that experiment, and a - signifies that the pigeon did not. The first column shows the subject number, the second column shows the symbol used in all graphs, the third column shows the immediate behavioral history prior to the three reported experiments, and the next three columns show which pigeons participated in each experiment. Experiments are listed in chronological order from left to right.

experimental histories for each subject. Subjects were maintained at 80% of their ad libitum body weight by supplemental feeding when necessary. Pigeons received Purina pigeon chow in the home cage and also in a food hopper during experimental sessions.

When not in experimental sessions, the subjects were housed in a temperature-controlled vivarium with a 12-h light/dark cycle and had continuous access to water. Sessions were conducted five days per week at approximately the same time each day.

Apparatus

Four experimental chambers were used in this study. Each operant chamber was 29 cm x 26 cm x 29 cm and made of clear plastic and aluminum. Each chamber contained two 2.5-cm diameter response keys, each requiring a force of about 0.1 N to operate. One of the response keys was 6 cm left of center and 16 cm above the floor, and the second response key was 6 cm right of center and 16 cm above the floor. The keys could be illuminated white and blue from behind by 28-V DC bulbs. The chamber included a 28-V DC shielded houselight centered on the wall, 33 cm from the floor of the chamber. A 6-cm x 5-cm aperture, located 5 cm from the chamber floor and directly below the houselight, allowed the pigeon to access chow from a raised solenoid-operated hopper during food deliveries. During food deliveries, the houselight and keylights were extinguished and a 28-V DC bulb in the hopper aperture was illuminated. A ventilation fan was used to mask extraneous sounds. Control of experimental events and data recording were conducted on a computer using Med Associates® interfacing and software.

Procedure

In this and all subsequent experiments, pigeons made sequences of responses across two keys. A response sequence consisted of four keypecks across left and right response keys (e.g., RLRL). With four-peck sequences and two possible responses, there were 16 possible response sequences. Each trial began with the illumination of the

houselight and the left and right keylights. After a response to either key, the keylights were extinguished for a 0.5-s resetting inter-response interval (IRI). After the fourth keypeck, the houselight and keylights were extinguished. Each four-response sequence resulted in either activation of the hopper and hopper light for 1.5 s (reinforcement) or flashing of the houselight for 1.5 s with a 0.25-s on/off cycle (nonreinforcement). The next trial began immediately after reinforcement or nonreinforcement.

A two-component multiple schedule of reinforcement was in place throughout the experiment. Each component of the multiple schedule was active for 5 min and each component was presented three times per session, with the two components alternating and a 30-s inter-component interval (ICI) between each component. One component was designated by blue keylights and the other component was designated by white keylights (colors were counterbalanced across subjects).

Experiment 1 consisted of three phases: Baseline, Extinction, and Reacquisition. In Phase 1, Baseline, both components of the multiple schedule were identical, except for the key colors. A separate lag 8 schedule of reinforcement was in place for each component; i.e., a sequence produced access to pigeon chow if it were different than the previous 8 sequences in that component. The lag was continuous across sessions and component presentations. We used a lag 8 schedule because this requirement is relatively strict, ensuring high levels of behavioral variability, but not so strict that we would not be able to observe either an increase or decrease in behavioral variability. For each phase of each experiment, we used fixed-time stability criteria to determine when to progress from one phase to another (Perone, 1991). Phase 1 was in effect for 20 sessions.

There were two additional phases. Phase 2, Extinction, was similar to Baseline, except that reinforcers were suspended for one of the components (Vary Ext). The other component remained active on a lag 8 schedule (Vary). Phase 2 was in effect for 10 sessions. Phase 3, Reacquisition, was identical to Baseline. Both components were once again active on a lag 8 schedule of food delivery. Phase 3 was in effect for 10 sessions.

Data Analysis

The primary dependent measures used in this study were response rate, reinforcer rate, proportion of sequences meeting the lag schedule, and U-value. Response rates were calculated as trials per minute for each component, with all time in that component included. Reinforcer rates were calculated as reinforcer deliveries per minute, with all component time included. Proportion of sequences meeting the lag schedule was calculated as all sequences that satisfied the lag 8 contingency divided by the total number of sequences emitted for each component. Even if a sequence was not followed by food (i.e., during Extinction), it counted towards this measure if it would have satisfied the lag schedule. A higher proportion of sequences meeting the lag schedule indicates higher levels of behavioral variability.

U-value is a common measure of behavioral variability that ranges from 0 to 1 (Miller & Frick, 1949; Page & Neuringer, 1985). A U-value of 0 would indicate absolute repetition (i.e., only a single sequence occurred throughout the session). A U-value of 1 would indicate an even distribution of response sequences (i.e., every possible sequence occurred an equal number of times throughout the session). U-value is calculated using Equation 1,

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

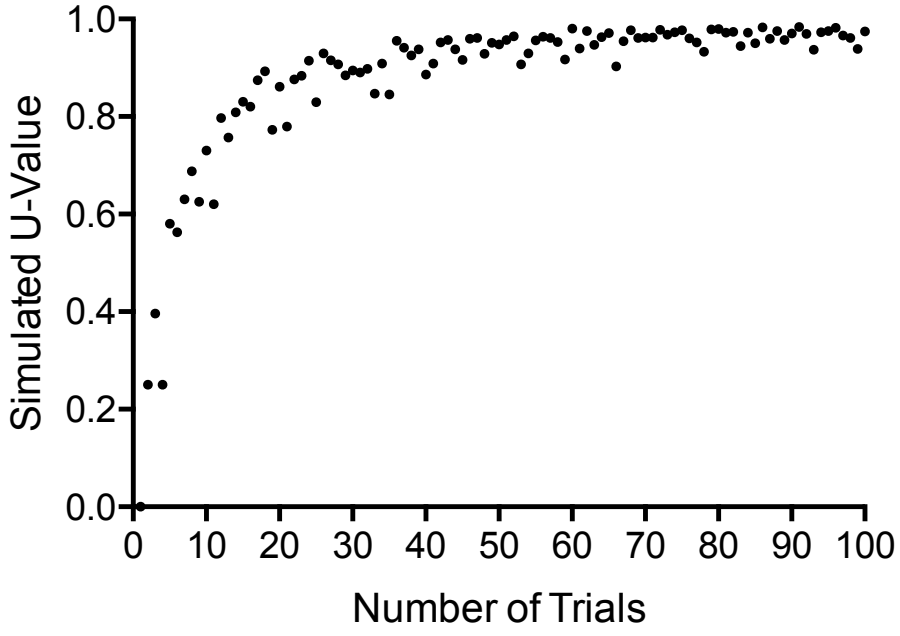
where *Rf* is the relative frequency of a given sequence and *n* is the total number of possible sequences, in this case 16. Higher U-values indicate higher levels of behavioral variability.

Although U-value can be a useful molar measure of behavioral variability, it has limitations (Kong et al., 2017; Neuringer et al., 2001). Namely, U-value is dependent on the number of sequences included in the calculation, i.e., the number of trials completed in a session. We used a random number generator to simulate U-values for hypothetical sessions with 1 to 100 trials completed (see Figure 2-1). Because we used a random number generator, levels of variability should have been high; however, with fewer trials, simulated U-values were low. Only with approximately more than 25 trials were U-values relatively unaffected by the number of trials included. This ceiling effect is especially problematic because we used extinction as a disruptor, which results in greatly reduced response rates.

To minimize the impact of the ceiling effect on U-value, we calculated a pooled U-value for each component using all trials across five sessions instead of a single session. In this way, each data point is based on a greater number of trials, leading to a more accurate measure of behavioral variability (e.g., Neuringer et al., 2001). In the rare event that a five-session block consisted of 25 trials or fewer, those data were excluded.

Group and individual subject data are displayed graphically for response rate, pooled U-value, and proportion of sequences meeting the lag schedule. In each figure, the top two panels show individual subject data, and the bottom panel shows group data. Symbols used in the graphs depicting individual subject data are consistent across

Figure 2-1.
Simulated U-value as a Function of Number of Trials.



experiments, such that the same symbol is used for the same pigeon across all experiments.

Relevant inferential statistical analyses were conducted on all primary dependent measures. All statistical tests were conducted using an alpha level of 0.05. Analyses were conducted using the final five sessions of Phase 1, the first five sessions of Phase 2, the final five sessions of Phase 2, and the first five sessions of Phase 3. A two-way analysis of variance (ANOVA) was conducted, using a Greenhouse-Geisser correction for violations of the sphericity assumption. Planned comparisons were then evaluated with *t*-tests. Corrections for multiple comparisons were not used to reduce the likelihood of a Type II error (Rothman, 1990). Tables depicting the details of these planned pairwise comparisons are shown in the Supplemental Material, accessible through the published

article. Each table contains, for each comparison, descriptive statistics (mean and standard error of the mean) and details of the statistical test (degrees of freedom, obtained *t*-statistic, *p*-value, and effect size, *d*).

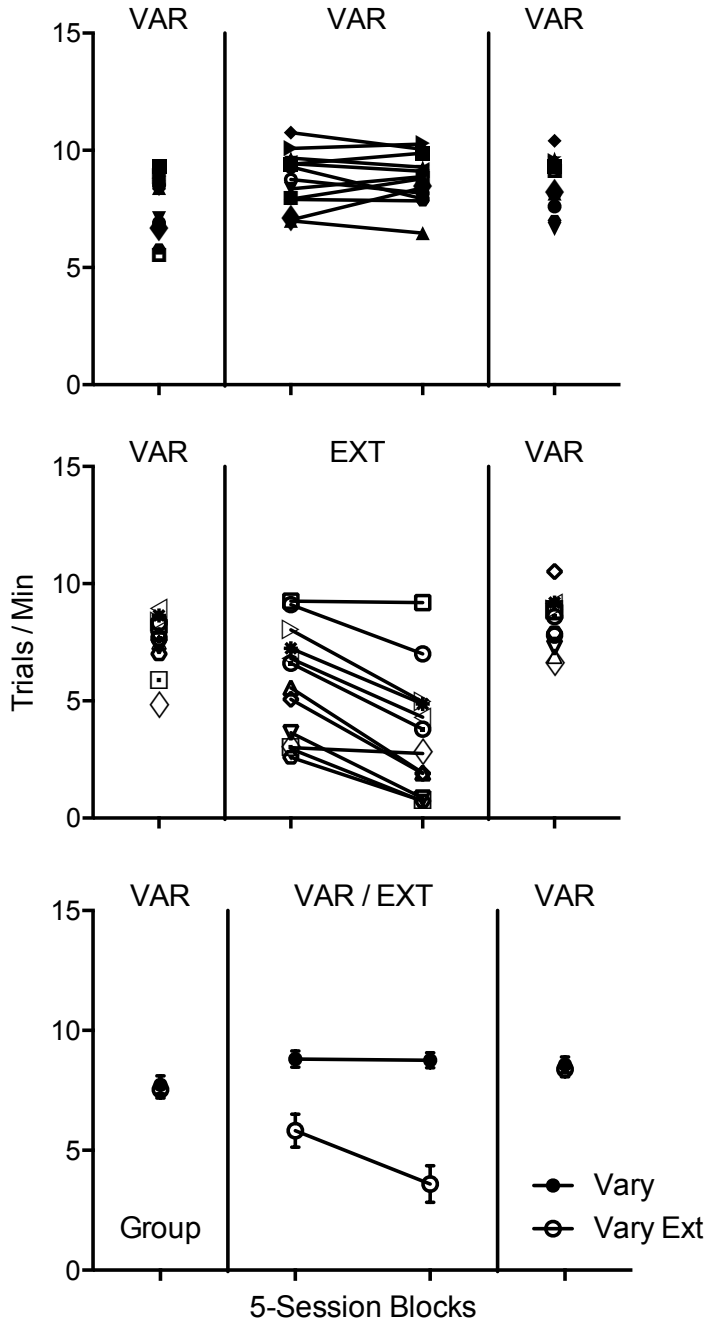
In addition to the molar measures described, we also plotted relative frequency distributions for individual subjects across phases. Graphs showing the relative frequencies for each sequence across phases and subjects are included in the Supplemental Material. Additionally, we analyzed specific aspects of the relative frequency distributions, including the most frequently and least frequently emitted sequences, average number of switches per sequence, the proportion of sequences beginning with the left key, and the total number of distinct sequences emitted. These data are depicted in tables.

Results

Response rates were relatively high when the lag reinforcement schedule was active but decreased when extinction was in place. Figure 2-2 shows that, for some individual subjects, response rates increased from the last five sessions of Baseline to the first five sessions of Extinction, but otherwise did not change across phases in the unchanged Vary component (top panel). Figure 2-2 also shows that response rates decreased during the Extinction phase and increased during Reacquisition for nearly all individual subjects in the Vary Ext component (middle panel).

The bottom panel of Figure 2-2 shows response rates averaged across all subjects across phases and components. Response rates significantly changed across phases [$F(3, 33) = 16.338$, $p < .001$, $\eta^2 = .735$] and components [$F(1, 11) = 49.797$, $p < .001$, $\eta^2 = .819$], with a significant interaction [$F(1.115, 12.265) = 30.487$, $p < .001$, $\eta^2 = .735$]. As

Figure 2-2.
Response Rates in Experiment 1.



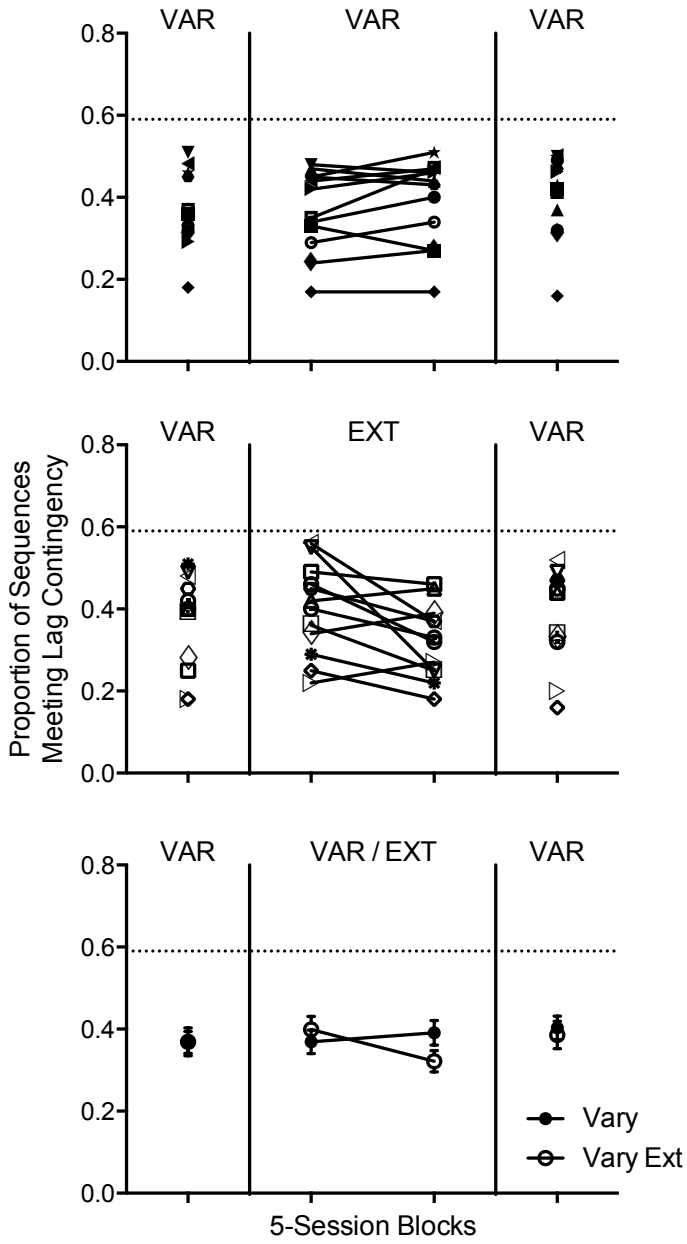
Note. Response rate (trials/min) across phases for both components in Experiment 1. Each point represents a five-session block. The top panel shows individual subject data for the Vary component. The middle panel shows individual subject data for the Vary Ext component. The bottom panel shows group data. Symbols for individual subjects are consistent across components and phases. Filled symbols show response rates for the Vary component, and open symbols show response rates for the Vary Ext component. For all graphs, the first phase is Baseline and is labeled with the contingency in place, the second phase is Extinction and is labeled with the contingency in place, and the third phase is Reacquisition and is labeled with the contingency in place. Error bars in the bottom panel show standard error of the mean.

supported by planned pairwise comparisons (shown in Supplemental Material), in Baseline, response rates were similar across components. In the first five sessions of Extinction, response rates slightly increased from Baseline for the Vary component, and response rates decreased throughout Extinction for the Vary Ext component. Response rates returned to levels similar to Baseline during Reacquisition.

The proportion of sequences meeting the lag contingency did not change systematically across phases in the Vary component but decreased during Extinction and increased during Reacquisition for the Vary Ext component. Figure 2-3 shows no change in the proportion of sequences meeting the lag contingency across phases for individual subjects in the Vary component (top panel). Figure 2-3 also shows a decrease in proportion of sequences meeting the lag contingency from the last five sessions of Baseline to the first five sessions of Extinction and an increase from the last five sessions of Extinction to Reacquisition for individual subjects in the Vary Ext component (middle panel).

Group data for the proportion of sequences meeting the lag contingency across components and phases are shown in the bottom panel of Figure 2-3. There was no significant main effect of phase [$F(3, 33) = 1.928$, $p = .144$, $\eta^2 = .149$] or component [$F(1, 11) = .424$, $p = .528$, $\eta^2 = .037$], but a trend towards a significant interaction [$F(3, 33) = 2.663$, $p = .064$, $\eta^2 = .195$]. As supported by planned pairwise comparisons (shown in the Supplemental Material), the proportion of sequences meeting the lag contingency was similar across components during Baseline and remained similar during Extinction for the Vary component. The proportion of sequences meeting the lag contingency decreased slightly from Baseline and the first five sessions of Extinction to the final five

Figure 2-3.
Proportion of Sequences Meeting the Lag Contingency in Experiment 1.



Note. Proportion of sequences meeting the lag contingency (number of sequences meeting the lag contingency / total sequences) in Experiment 1. Each point represents a five-session block. The top panel shows individual subject data for the Vary component. The middle panel shows individual subject data for the Vary Ext component. The bottom panel shows group data. Symbols for individual subjects are consistent across components and phases. Filled symbols show proportion of sequences meeting the lag contingency for the Vary component, and open symbols show proportion of sequences meeting the lag contingency for the Vary Ext component. For all graphs, the first phase is Baseline and is labeled with the contingency in place, the second phase is Extinction and is labeled with the contingency in place, and the third phase is Reacquisition and is labeled with the contingency in place. Error bars in the bottom panel show standard error of the mean. In all panels, the horizontal dashed line represents the expected proportion of sequences meeting the lag contingency given random responding, determined through simulations.

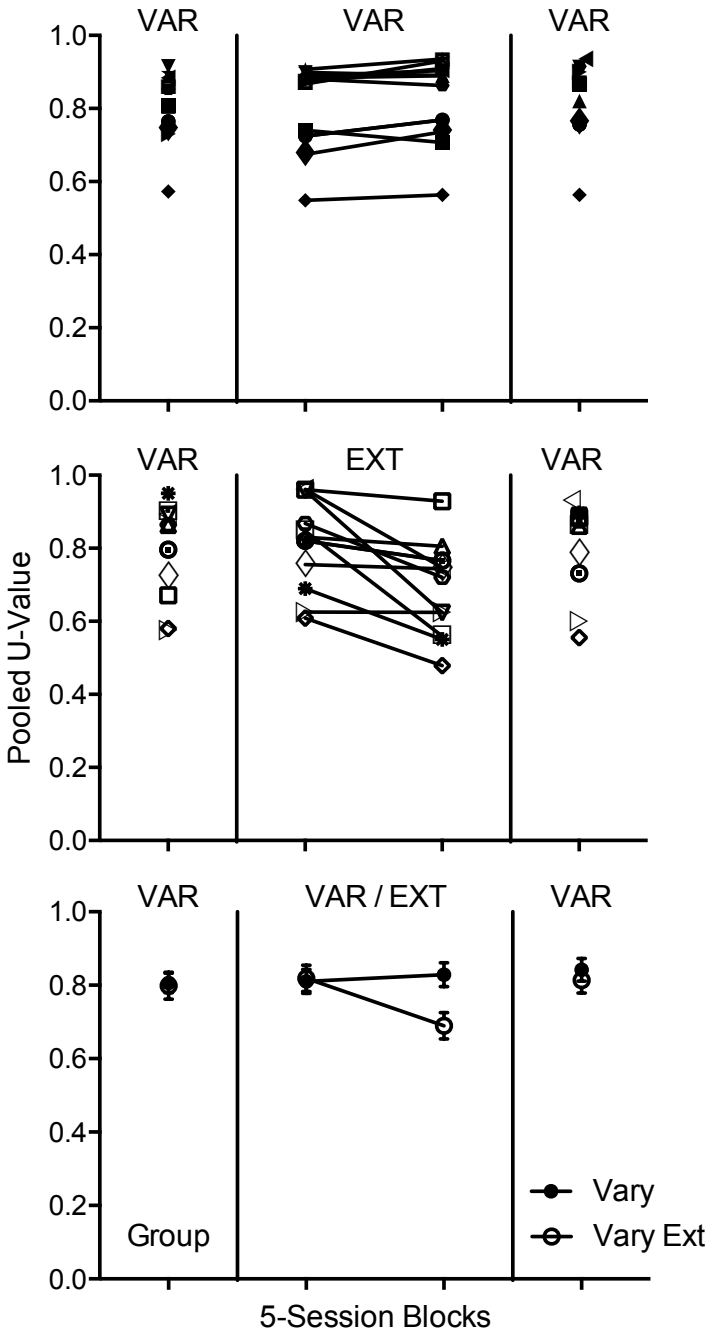
sessions of Extinction. During Reacquisition, the proportion of sequences meeting the lag contingency was similar across components and similar to Baseline levels.

Group data for the proportion of sequences meeting the lag contingency across components and phases are shown in the bottom panel of Figure 2-3. There was no significant main effect of phase [$F(3, 33) = 1.928$, $p = .144$, $\eta^2 = .149$] or component [$F(1, 11) = .424$, $p = .528$, $\eta^2 = .037$], but a trend towards a significant interaction [$F(3, 33) = 2.663$, $p = .064$, $\eta^2 = .195$]. As supported by planned pairwise comparisons (shown in the Supplemental Material), the proportion of sequences meeting the lag contingency was similar across components during Baseline and remained similar during Extinction for the Vary component. The proportion of sequences meeting the lag contingency decreased slightly from Baseline and the first five sessions of Extinction to the final five sessions of Extinction. During Reacquisition, the proportion of sequences meeting the lag contingency was similar across components and similar to Baseline levels.

Pooled U-values, a measure of sequence variability, were high when the lag schedule was in place but decreased with prolonged exposure to extinction. Figure 2-4 shows that pooled U-values did not change systematically for most individual subjects across phases for the Vary component (top panel). Figure 2-4 also shows that pooled U-values decreased for most subjects from the first five sessions of Extinction to the final five sessions of Extinction for the Vary Ext component (middle panel).

The bottom panel of Figure 2-4 shows average pooled U-values across phases for both components. Pooled U-values changed significantly across phases [$F(3, 33) = 5.620$, $p = .003$, $\eta^2 = .338$] but were similar across components [$F(1, 11) = 2.897$, $p = .117$, $\eta^2 = .208$] overall. The interaction between phase and component was significant [$F(1.472,$

Figure 2-4.
Pooled U-Value in Experiment 1.



Note. Pooled U-value across phases for both components in Experiment 1. Each point represents a five-session block. The top panel shows individual subject data for the Vary component. The middle panel shows individual subject data for the Vary Ext component. The bottom panel shows group data. Symbols for individual subjects are consistent across components and phases. Filled symbols show pooled U-values for the Vary component, and open symbols show pooled U-values for the Vary Ext component. For all graphs, the first phase is Baseline and is labeled with the contingency in place, the second phase is Extinction and is labeled with the contingency in place, and the third phase is Reacquisition and is labeled with the contingency in place. Error bars in the bottom panel show standard error of the mean.

16.190) = 5.252, p = .025, η^2 = .323]. As supported by planned pairwise comparisons (shown in the Supplemental Material), in Baseline and the first five sessions of Extinction, pooled U-values were similar across components. From the first five sessions of Extinction to the last five sessions of Extinction, pooled U-values remained high for the Vary component but decreased slightly for the Vary Ext component. Pooled U-values returned to Baseline levels during Reacquisition.

Relative frequency distributions for each subject across components and phases are shown in the Supplemental Material. Table 2-2 shows, for each individual subject across phases and components, the average number of switches and the number of distinct sequences emitted. The average number of switches per sequence was similar across components for all phases except the last five sessions of Extinction, as well as across phases for the Vary component. There was an average of one switch per sequence across phases for the Vary Ext component, except in the last five sessions of Extinction, in which the average number of switches decreased. The number of distinct sequences emitted did not change systematically with component or phase. Table 2-3 shows the sequences emitted most and least frequently, as well as the proportion of sequences emitted beginning with a left keypeck, for each individual subject across phases and components. For most subjects, the dominant sequences in the last five sessions of Baseline were also dominant during other phases. For the Vary Ext component, the proportion of sequences beginning with a left keypeck frequently changed during Extinction. Despite these few general findings, the results of these analyses appear largely idiosyncratic across subjects.

Table 2-2.
Average Switches per Sequence and Number of Distinct Sequences in Experiment 1.

Subject	Average switches per sequence								Number of distinct sequences per five-session block							
	VAR				VAR EXT				VAR				VAR EXT			
	BL	EXT 1	EXT 2	REAC	BL	EXT 1	EXT 2	REAC	BL	EXT 1	EXT 2	REAC	BL	EXT 1	EXT 2	REAC
55	1.05	1.17	1.33	1.37	1.02	1.03	0.63	1.07	16	16	16	16	16	16	16	16
220	1.76	1.61	1.29	1.58	0.99	1.29	1.28	1.63	16	13	13	16	15	16	16	15
223	0.83	0.94	1.00	0.82	0.99	0.96	0.88	0.99	15	16	16	15	15	15	14	15
237	1.14	1.04	1.29	1.20	1.10	1.43	1.06	1.13	16	16	16	16	16	16	13	16
373	1.53	1.39	1.40	1.17	1.57	0.86	0.46	1.24	16	16	16	15	16	16	16	16
936	0.85	0.96	0.92	1.25	0.88	1.01	1.20	1.02	15	16	16	16	16	16	14	16
956	1.24	0.51	0.47	0.55	0.46	0.39	0.23	0.52	16	5	9	5	10	12	10	6
957	0.87	0.73	0.84	0.97	1.09	0.80	0.63	0.95	13	14	13	11	11	15	15	11
966	0.74	1.01	1.15	1.03	0.55	0.52	0.39	0.51	14	16	16	16	7	14	14	14
1158	1.02	1.13	1.20	1.31	1.03	1.48	0.97	1.29	16	16	16	16	16	16	16	16
1499	1.47	1.15	1.18	1.30	1.32	0.91	0.56	1.49	16	16	16	16	16	16	10	15
17556	0.67	0.56	0.69	0.65	0.70	0.75	0.70	0.72	14	13	14	12	14	14	13	15
Mean	1.10	1.02	1.06	1.10	0.98	0.95	0.75	1.05	15.25	14.42	14.75	14.17	14.00	15.17	13.92	14.25
(SEM)	(0.10)	(0.09)	(0.08)	(0.09)	(0.09)	(0.10)	(0.10)	(0.10)	(0.30)	(0.92)	(0.63)	(0.97)	(0.87)	(0.37)	(0.62)	(0.85)

Note: Average switches per sequence and number of distinct sequences emitted per five-session block for individual subjects and on average (with standard error of the mean in parentheses) across phases and components in Experiment 1. VAR represents the Vary component and VAR EXT represents the Vary Ext component. BL represents the last five sessions of the Baseline phase, EXT 1 represents the first five sessions of Extinction, EXT 2 represents the last five sessions of Extinction, and REAC represents the first five sessions of the Reacquisition phase.

Table 2-3.
Specific Sequences for Individual Subjects in Experiment 1.

Subject	Most frequently emitted sequence (proportion) / Least frequently emitted sequence (proportion) / Proportion of sequences starting with a left keypeck							
	VAR				VAR EXT			
	BL	EXT 1	EXT 2	REAC	BL	EXT 1	EXT 2	REAC
55	LLRR (0.19) RLRL (0.00) L 0.77	RLLL (0.18) LLRL (0.00) L 0.32	RLLL (0.19) LLRL (0.00) L 0.38	RLLL (0.13) LLRL (0.01) L 0.39	LLLL (0.21) RLRL (0.00) L 0.70	LLLL (0.20) RLRL (0.01) L 0.57	LLLL (0.43) LRLR (0.00) L 0.68	RRLL (0.18) RLRL (0.00) L 0.41
220	RLRR (0.29) LLRL (0.00) L 0.50	RLRR (0.25) LLLL (0.00) L 0.31	RRRR (0.27) LLLL (0.00) L 0.22	RLRR (0.17) LLRL (0.00) L 0.60	RRRR (0.37) LLLL (0.00) L 0.36	LRLR (0.10) RRRR (0.03) L 0.61	RLRR (0.06) RLRL (0.02) L 0.64	RLRR (0.17) LLRL (0.00) L 0.45
223	RRRR (0.20) LRLR (0.00) L 0.29	RRRR (0.15) LRLR (0.00) L 0.47	LLLL (0.16) LRLR (0.01) L 0.56	RRLL (0.18) RLRL (0.00) L 0.40	LLLL (0.16) LRLR (0.00) L 0.55	RRLL (0.19) LRLR (0.00) L 0.35	RRRR (0.18) RRLR (0.00) L 0.55	LLLL (0.17) LRLR (0.00) L 0.55
237	RRRR (0.14) RLRL (0.00) L 0.56	RRRR (0.19) RLRL (0.00) L 0.55	LLRR (0.17) RLLL (0.00) L 0.62	LLRR (0.13) RLLL (0.00) L 0.62	RRRR (0.17) RLRL (0.00) L 0.53	RRRR (0.08) RLLR (0.04) L 0.51	LLLL (0.39) RRRL (0.00) L 0.82	RRRR (0.17) RLLL (0.01) L 0.56
373	RRRL (0.17) LLLL (0.01) L 0.40	RRRL (0.15) RLLR (0.01) L 0.40	RRRL (0.13) RLLR (0.01) L 0.49	RRRL (0.18) RLLR (0.00) L 0.52	RRRL (0.11) RLLR (0.02) L 0.52	RRRR (0.51) RLRR (0.00) L 0.30	RRRR (0.65) LRLL (0.01) L 0.18	RRRL (0.13) RLLR (0.00) L 0.58
936	LLLL (0.19) LRLR (0.00) L 0.44	LLRR (0.17) RLRL (0.00) L 0.57	RRRR (0.15) LRLR (0.00) L 0.51	LLLL (0.15) RLRL (0.01) L 0.52	LLLL (0.17) RLRL (0.00) L 0.54	LLLL (0.20) LRLR (0.01) L 0.61	RRRR (0.23) RRRL (0.00) L 0.45	RRRR (0.14) LRLR (0.00) L 0.40
956	RRRL (0.13) RLLR (0.00) L 0.58	LRRR (0.28) RLLL (0.00) L 0.78	LLLL (0.32) RRLL (0.00) L 0.78	LLLL (0.26) RLLL (0.00) L 0.81	LLLL (0.34) LRLL (0.00) L 0.78	LLLL (0.34) RLRR (0.00) L 0.65	LLLL (0.55) LRLL (0.00) L 0.67	LLLL (0.30) RRLL (0.00) L 0.82

Table 2-3 (continued).
Specific Sequences for Individual Subjects in Experiment 1.

Subject	Most frequently emitted sequence (proportion) / Least frequently emitted sequence (proportion) / Proportion of sequences starting with a left keypeck							
	VAR				VAR EXT			
	BL	EXT 1	EXT 2	REAC	BL	EXT 1	EXT 2	REAC
957	LRRR (0.20) RRLR (0.00) L 0.60	RRLL (0.21) RRLR (0.00) L 0.34	LRRR (0.18) RLLR (0.00) L 0.52	LRRR (0.23) RLRR (0.00) L 0.72	LRRR (0.16) RLRR (0.00) L 0.76	LLLL (0.19) LRLR (0.00) L 0.57	LLLL (0.30) RLRL (0.00) L 0.60	LRRR (0.24) RLRR (0.00) L 0.79
966	RLLL (0.21) LLRL (0.00) L 0.26	LLLL (0.19) LRLR (0.01) L 0.41	RLLL (0.16) LRLR (0.01) L 0.34	RRRR (0.15) LRLR (0.01) L 0.31	RRRR (0.24) LLRR (0.00) L 0.22	LLLL (0.35) LRLR (0.00) L 0.40	LLLL (0.40) LRLR (0.00) L 0.50	RRRR (0.27) LRLR (0.00) L 0.25
1158	LRRR (0.14) LRLR (0.00) L 0.56	RRLL (0.15) LLRL (0.00) L 0.41	LRRR (0.15) RLRL (0.01) L 0.58	RRLL (0.13) RRRL (0.02) L 0.48	LLLL (0.13) RLRL (0.00) L 0.44	LRLL (0.12) RLLL (0.03) L 0.53	RRRR (0.41) RLLL (0.01) L 0.22	LRRR (0.12) LLLR (0.01) L 0.50
1499	RLLL (0.14) LLRL (0.00) L 0.19	RRRL (0.17) LLRR (0.01) L 0.21	RLLL (0.13) LLRR (0.02) L 0.39	LRRR (0.15) LLLR (0.00) L 0.61	RLLL (0.18) LLLR (0.01) L 0.48	RRRR (0.22) LRRL (0.01) L 0.36	LLLL (0.31) RLLL (0.00) L 0.44	LRLL (0.21) LLLR (0.00) L 0.62
17556	LLLL (0.25) RRLR (0.00) L 0.70	LLLL (0.26) RRLR (0.00) L 0.71	LLLL (0.21) LRLR (0.00) L 0.70	LLLL (0.20) RLRR (0.00) L 0.60	LLLL (0.24) RRLR (0.00) L 0.78	LLRR (0.20) RLRR (0.00) L 0.64	LLLL (0.25) RRLR (0.00) L 0.66	RRRR (0.21) RLRL (0.00) L 0.56

Note: Specific sequences emitted for individual subjects across phases and components in Experiment 1. Each cell contains the sequence emitted most frequently for that five-session block, with the relative frequency of that sequence in parentheses, the sequence emitted least frequently for that five-session block, with the relative frequency of that sequence in parentheses, and the proportion of sequences emitted starting with a left keypeck (L). VAR represents the Vary component and VAR EXT represents the Vary Ext component. BL represents the last five sessions of the Baseline phase, EXT 1 represents the first five sessions of Extinction, EXT 2 represents the last five sessions of Extinction, and REAC represents the first five sessions of the Reacquisition phase.

Discussion

The results of Experiment 1 provide evidence for disruption of reinforced behavioral variability by extinction. Disruption was observed in terms of response rate, as well as levels of behavioral variability. We observed changes in response rate; specifically, response rates decreased during Extinction for the Vary Ext component. Additionally, for the Vary component, response rates increased from the last five sessions of Baseline to the first five sessions of Extinction. This effect resembles behavioral contrast (Reynolds, 1961): the reduction in reinforcement rate (and response rate) in the Vary Ext component was accompanied by an increase in response rate for the Vary component, even though there was no change in reinforcement rate in that component.

We also observed disruption of levels of behavioral variability by extinction. Levels of behavioral variability decreased with increased exposure to extinction. The use of a multiple schedule with identical components allowed for the direct comparison between reinforcement-maintained behavioral variability and extinction-induced behavioral variability. When we removed reinforcement in one component but continued to provide food for variable sequences in the other, we observed a systematic decrease in levels of behavioral variability only in the component in which extinction was implemented. We also observed an increase in levels of behavioral variability when the lag contingency was implemented again. These results provide some support for behavioral variability as an operant, because the removal of the reinforcement contingency resulted in a decrease in levels of behavioral variability, demonstrating the sensitivity of behavioral variability to consequences.

Experiment 2: Reinstatement

The results from Experiment 1 suggest that reinforced behavioral variability may be decreased by extinction, providing additional evidence that behavioral variability is an operant. In addition to disruption by extinction, operant behaviors also tend to be susceptible to relapse under certain conditions. Experiment 2 was designed to examine whether behavioral variability would relapse under reinstatement conditions. A typical laboratory preparation consists of studying reinstatement across three phases. In Phase 1, Baseline, a target response produces reinforcers. In Phase 2, Extinction, reinforcement is suspended, and the target response decreases in frequency. In Phase 3, Reinstatement, extinction is still in place, but reinforcers are occasionally delivered response independently (de Wit & Stewart, 1981, 1983). Reinstatement of reinforced behavioral variability has yet to be investigated. Therefore, the goal of this experiment was to determine if behavioral variability would relapse under typical reinstatement conditions.

Method

Subjects and Apparatus

Twelve adult pigeons with prior experimental histories served as the subjects for this experiment. Although reported second, Experiment 2 was the first experiment conducted in this study (see Table 2-1). Two pigeons' data were excluded due to problems with data collection. Details of subject maintenance, general procedures, and apparatus were the same as in Experiment 1.

Procedure

A multiple schedule was used to compare responding on a lag contingency and responding with yoked reinforcer delivery (i.e., in the yoked component, pigeons earned

food at the same rate as in the variability component, but behavioral variability was not required) and to investigate reinstatement of behavioral variability. As in Experiment 1, pigeons emitted four-peck sequences across two keys in a two-component multiple schedule. The two components alternated, with each being presented for 4 min at a time, four times per session. One component was designated by blue keylights and the other component was designated by white keylights (colors were counterbalanced across subjects). There was a 10-s inter-trial interval (ITI) and a 30-s ICI. Because this experiment was conducted first, the 10-s ITI was used for this experiment but was later removed for Experiments 1 and 3. Recent research has shown that the duration of the ITI does not affect overall levels of behavioral variability (Doughty & Galizio, 2015).

Experiment 2 consisted of three phases: Baseline, Extinction, and Reinstatement. In Phase 1, Baseline, a lag 10 schedule of reinforcement was in place for one component (Vary), and the other component (Yoke) served as a control. We used a lag 10 schedule to produce high levels of variability while allowing for a clear comparison between Vary and Yoke. When the Yoke component was active, food delivery was probabilistic, and the emission of any specific response sequence had no effect on food delivery. The probability that food was delivered after a given response sequence was matched to the overall rate of reinforcement in the immediately preceding Vary component. For example, if a pigeon earned food for 75% of sequences emitted in the preceding Vary component, food was delivered after each sequence with a probability of .75 for the current Yoke component. For each session, the initial component of the multiple schedule was always a Vary component. Phase 1 was in effect for 30 sessions.

There were two additional phases. Phase 2, Extinction, was similar to Baseline, except that reinforcement was suspended for both components. Phase 2 was in effect for 15 sessions. Phase 3, Reinstatement, was similar to Phase 2, except that food was delivered response independently 1.5 and 10 s after the start of each component. These food deliveries were 1.5 s in duration. Phase 3 was in effect for five sessions. Only two food deliveries occurred per component and these events occurred independent of any responding.

Data Analysis

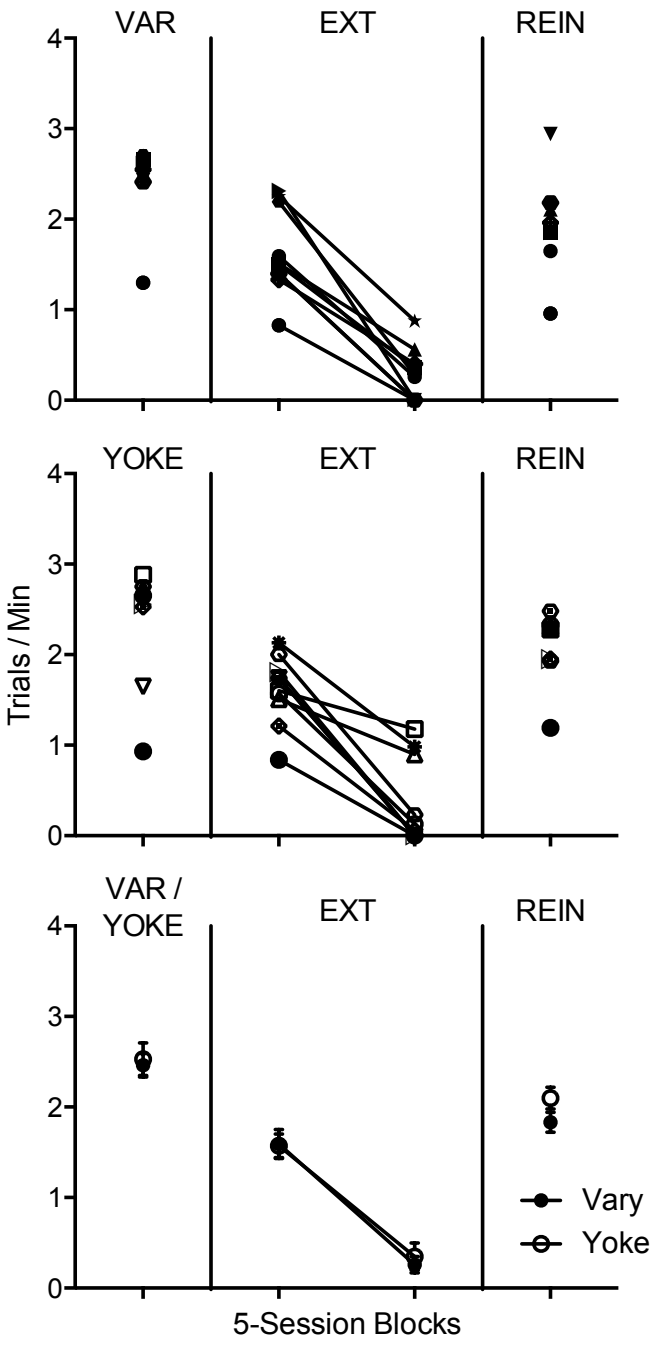
As in Experiment 1, the primary dependent measures for Experiment 2 were response rate, reinforcer rate, proportion of sequences meeting the lag contingency, and pooled U-value. Each of these measures was calculated as in Experiment 1, except that ITI time was excluded from all rate measures. Statistical analyses were conducted as in Experiment 1. Relative frequency distribution analyses were conducted as in Experiment 1.

Results

Response rates were high during Baseline and Reinstatement but decreased during Extinction for the Vary and Yoke components. Figure 2-5 shows that, for most subjects, response rates decreased from Baseline to the first five sessions of Extinction and from the first five sessions of Extinction to the last five sessions of Extinction for the Vary (top panel) and Yoke (middle panel) components. Additionally, response rates increased for all subjects during Reinstatement for both components.

The bottom panel of Figure 2-5 shows average response rates across phases for both components. Response rates changed significantly across phases [$F(3,27) = 87.043$,

Figure 2-5.
Response Rates in Experiment 2.



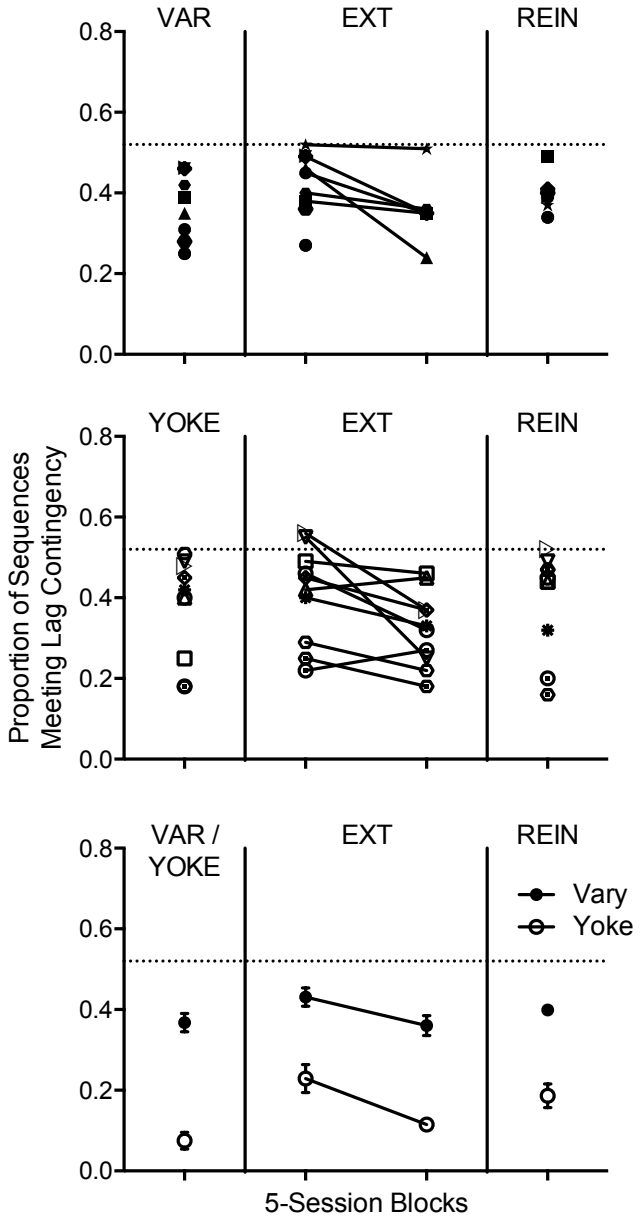
Note. Response rate (trials/min) across phases for both components in Experiment 2. Each point represents a five-session block. The top panel shows individual subject data for the Vary component. The middle panel shows individual subject data for the Yoke component. The bottom panel shows group data. Symbols for individual subjects are consistent across components and phases. Filled symbols show response rates for the Vary component, and open symbols show response rates for the Yoke component. For all graphs, the first phase is Baseline and is labeled with the contingency in place, the second phase is Extinction and is labeled with the contingency in place, and the third phase is Reinstatement. Error bars in the bottom panel show standard error of the mean.

$p < .001$, $\eta^2 = .906$] but did not change significantly across components [$F(1,9) = 3.268$, $p = .104$, $\eta^2 = .266$]. The interaction between phase and component was significant [$F(3,27) = 5.819$, $p = .003$, $\eta^2 = .393$]. As supported by planned pairwise comparisons (shown in the Supplemental Material), response rates decreased from Baseline to the first sessions of Extinction and to the last sessions of Extinction for both components. Response rates for both components increased to near-Baseline levels during Reinstatement.

There was no significant difference between reinforcers per min for the Vary ($M = 0.878$, $SEM = 0.248$) and Yoke ($M = 0.944$, $SEM = 0.317$) components in Baseline [$t(9) = -1.917$, $p = .087$]. This finding confirmed that reinforcer rates in both components were matched. Because the remainder of the experiment was conducted under extinction, reinforcement rates were always zero and were not formally analyzed.

Figure 2-6 shows that the proportion of sequences meeting the lag contingency for individual subjects across phases in the Vary component (top panel) was higher than the proportion in the Yoke component (middle panel). Figure 2-6 also shows group data across components and phases. The proportion of sequences meeting the lag contingency was generally high for the Vary component and lower for the Yoke component [$F(1,9) = 79.204$, $p < .001$, $\eta^2 = .898$] and changed across phases [$F(1.493, 13.437) = 10.312$, $p = .003$, $\eta^2 = .534$]. The interaction between phase and component was also significant [$F(3,27) = 3.319$, $p = .035$, $\eta^2 = .269$]. As supported by planned pairwise comparisons (shown in the Supplemental Material), the proportion of sequences meeting the lag contingency was higher for the Vary component than the Yoke component, and both components showed a slight increase from the last five sessions of Baseline to the first five sessions of Extinction.

Figure 2-6.
Proportion of Sequences Meeting the Lag Contingency in Experiment 2.



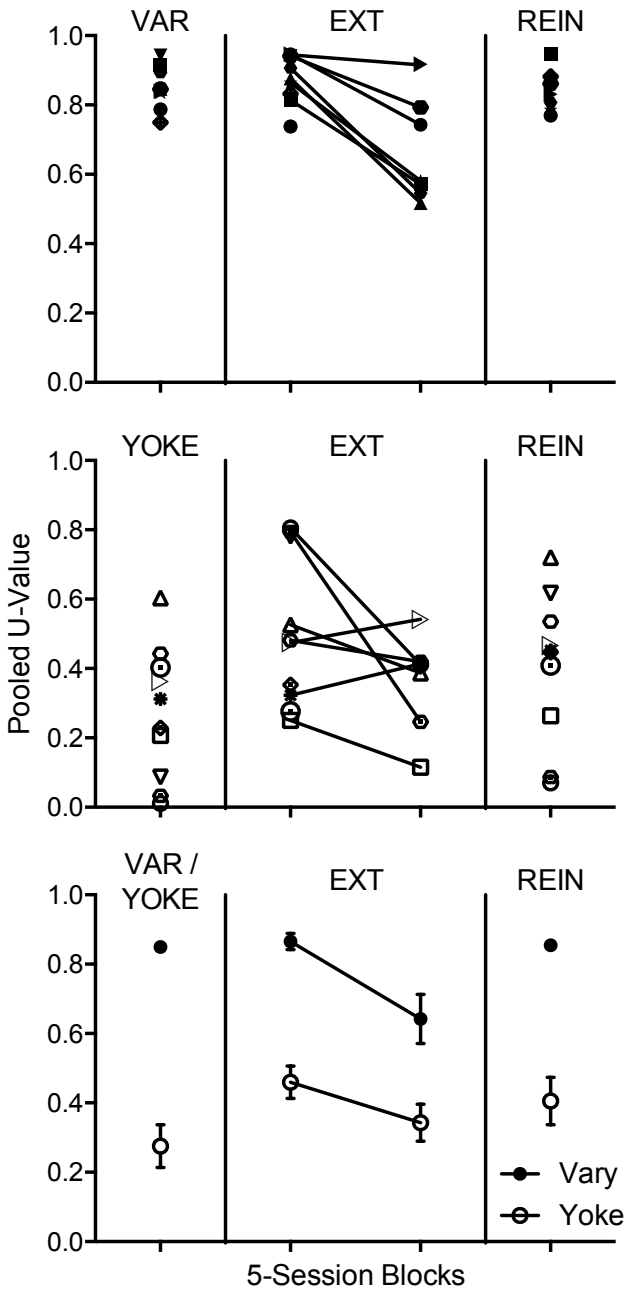
Note. Proportion of sequences meeting the lag contingency in Experiment 2. Each point represents a five-session block. The top panel shows individual subject data for the Vary component. The middle panel shows individual subject data for the Yoke component. The bottom panel shows group data. Symbols for individual subjects are consistent across components and phases. Filled symbols show proportion of sequences meeting the lag contingency for the Vary component, and open symbols show proportion of sequences meeting the lag contingency for the Yoke component. For all graphs, the first phase is Baseline and is labeled with the contingency in place, the second phase is Extinction and is labeled with the contingency in place, and the third phase is Reinstatement and is labeled with the contingency in place. Error bars in the bottom panel show standard error of the mean. In all panels, the horizontal dashed line represents the expected proportion of sequences meeting the lag contingency given random responding, determined through simulations. Missing data points represent five-session blocks in which fewer than 25 trials were emitted.

Pooled U-values were higher for the Vary component than the Yoke component throughout the experiment, and generally decreased throughout Extinction and increased during Reinstatement. Figure 2-7 shows that pooled U-values decreased for nearly all subjects during Extinction and increased during Reinstatement in the Vary component (top panel). Figure 2-7 also shows that pooled U-values were not systematically affected during Extinction for the Yoke component, although an increase was observed for several subjects during the first five sessions of Extinction (middle panel). Pooled U-values were generally not affected during Reinstatement during the Yoke component, although there was an increase for some subjects.

The bottom panel of Figure 2-7 shows average pooled U-values across phases for the Vary and Yoke components. Pooled U-values changed significantly across phases [$F(1.761, 15.846) = 6.706$, $p = .009$, $\eta^2 = .427$] and components [$F(1, 9) = 104.689$, $p < .001$, $\eta^2 = .921$], with a significant interaction [$F(3, 27) = 9.023$, $p < .001$, $\eta^2 = .501$]. As supported by planned pairwise comparisons (shown in the Supplemental Material), in Baseline, pooled U-values were higher for the Vary component than in the Yoke component. From the last five sessions of Baseline to the first five sessions of Extinction, pooled U-values did not change for the Vary component but increased for the Yoke component. Pooled U-values decreased from the first five sessions of Extinction to the last five sessions of Extinction for both components. From the last five sessions of Extinction to Reinstatement, pooled U-values did not change for the Yoke component but increased for the Vary component.

Relative frequency distributions for each subject across components and phases are shown in the Supplemental Material. Table 2-4 shows, for each individual subject

Figure 2-7.
Pooled U-Value in Experiment 2.



Note. Pooled U-value across phases for both components in Experiment 2. Each point represents a five-session block. The top panel shows individual subject data for the Vary component. The middle panel shows individual subject data for the Yoke component. The bottom panel shows group data. Symbols for individual subjects are consistent across components and phases. Filled symbols show pooled U-values for the Vary component, and open symbols show pooled U-values for the Yoke component. For all graphs, the first phase is Baseline and is labeled with the contingency in place, the second phase is Extinction and is labeled with the contingency in place, and the third phase is Reinstatement. Error bars in the bottom panel show standard error of the mean. Missing data points represent five-session blocks in which fewer than 25 trials were emitted.

across phases and components, the average number of switches and the number of distinct sequences emitted. Across all phases, subjects typically emitted sequences with more switches in the Vary component than in the Yoke component. From the last five sessions of Baseline to the first five sessions of Extinction, the average number of switches per sequence did not change for the Vary component but increased for the Yoke component. From the first five sessions to the last five sessions of Extinction, the average number of switches decreased for both components. Finally, from the last five sessions of Extinction to the first five sessions of Reinstatement, the number of switches increased for both components. The number of distinct sequences emitted per five-block session changed in the same way as the average number of switches across phases and components. Table 2-5 shows the sequences emitted most and least frequently, as well as the proportion of sequences emitted starting with a left keypeck, for each individual subject across phases and components. For most subjects, the dominant sequence in Baseline was the same as in other phases for both components. For some subjects, however, another sequence became dominant in the first or last sessions of Extinction. Similarly, the proportion of sequences beginning with a left keypeck was similar across phases for both components, except during Extinction, when some subjects showed an increase or decrease from Baseline.

Discussion

In Experiment 2, we found evidence for reinstatement of reinforced behavioral variability. In the Vary component, U-values and response rates decreased during Extinction and increased again in Reinstatement. In the Yoke component, response rates decreased during Extinction and increased during Reinstatement, but levels of variability

Table 2-4.
Average Switches per Sequence and Number of Distinct Sequences in Experiment 2.

Subject	Average switches per sequence								Number of distinct sequences per five-session block							
	VAR				YOKE				VAR				YOKE			
	BL	EXT 1	EXT 2	REIN	BL	EXT 1	EXT 2	REIN	BL	EXT 1	EXT 2	REIN	BL	EXT 1	EXT 2	REIN
55	0.99	0.66	0.80	0.03	0.00	0.00	0.08	0.16	14	14	5	6	2	1	2	9
220	1.23	0.85	0.48	1.21	0.05	0.09	0.03	0.08	16	16	8	16	4	8	5	6
223	0.81	0.89	0.36	1.06	0.40	0.32	0.18	0.54	13	15	9	15	12	11	7	14
237	1.26	1.29	-	1.13	0.03	0.74	-	0.58	16	16	-	16	7	15	-	15
381	1.18	1.29	-	0.94	0.00	0.74	-	0.04	16	16	-	16	2	15	-	5
927	0.64	0.75	0.41	0.90	0.02	0.16	0.00	0.22	11	13	8	14	6	8	1	11
936	0.97	0.96	0.45	0.78	0.15	0.20	0.22	0.25	14	16	9	16	7	9	5	10
956	1.20	1.12	0.47	0.94	0.27	0.26	0.14	0.23	14	16	14	15	9	10	7	12
957	0.75	0.73	-	0.70	0.14	0.04	-	0.11	12	10	-	11	6	4	-	7
966	0.88	1.26	-	0.79	0.07	0.19	-	0.16	15	16	-	15	8	9	-	9
Mean	0.99	0.98	0.50	0.85	0.11	0.28	0.11	0.24	14.10	14.80	8.83	14.00	6.30	9.00	4.50	9.80
(SEM)	(0.07)	(0.08)	(0.07)	(0.10)	(0.04)	(0.08)	(0.04)	(0.06)	(0.55)	(0.63)	(1.19)	(1.01)	(0.98)	(1.37)	(1.02)	(1.04)

Note: Average switches per sequence and number of distinct sequences emitted per five-session block for individual subjects and on average (with standard error of the mean in parentheses) across phases and components in Experiment 2. VAR represents the Vary component and YOKE represents the Yoke component. BL represents the last five sessions of the Baseline phase, EXT 1 represents the first five sessions of Extinction, EXT 2 represents the last five sessions of Extinction, and REIN represents the first five sessions of the Reinstatement phase. Dashes represent five-session blocks in which fewer than 25 trials were emitted.

Table 2-5.
Specific Sequences for Individual Subjects in Experiment 2.

Subject	Most frequently emitted sequence (proportion) / Least frequently emitted sequence (proportion) / Proportion of sequences starting with a left keypeck							
	VAR				YOKE			
	BL	EXT 1	EXT 2	REIN	BL	EXT 1	EXT 2	REIN
55	LLLL (0.19) RLRR (0.00) L 0.65	LLLL (0.44) RLLR (0.00) L 0.75	LLLR (0.40) RRRR (0.00) L 0.80	RRRR (0.97) RLLL (0.00) L 0.02	RRRR (1.00) LLLL (0.00) L 0.00	RRRR (1.00) LLLL (0.00) L 0.00	RRRR (0.92) LLLL (0.00) L 0.08	LLLL (0.47) LRLL (0.00) L 0.56
220	RRRR (0.20) LRRL (0.00) L 0.25	LLLL (0.38) LRRR (0.02) L 0.69	LLLL (0.52) LRRR (0.00) L 0.76	RRRR (0.17) RLRL (0.01) L 0.43	LLLL (0.83) LRRR (0.00) L 0.83	LLLL (0.83) LRRR (0.00) L 0.85	LLLL (0.95) LRRR (0.00) L 0.96	LLLL (0.79) LRRR (0.00) L 0.80
223	LLLL (0.20) RLRR (0.00) L 0.59	LLLL (0.17) RLRL (0.00) L 0.48	LLLL (0.60) LRLL (0.00) L 0.82	LLLL (0.17) LRLR (0.00) L 0.60	LLLL (0.51) RLRR (0.00) L 0.75	LLLL (0.55) LLRR (0.00) L 0.70	LLLL (0.64) LRRR (0.00) L 0.74	LLLL (0.38) LRLR (0.00) L 0.54
237	RRRR (0.19) RLLL (0.02) L 0.43	LLLL (0.19) RLRR (0.01) L 0.54	-	LLLL (0.30) LRRR (0.01) L 0.69	LLLL (0.96) LRRR (0.00) L 0.97	RRRR (0.29) LRLL (0.00) L 0.44	-	LLLL (0.58) RLLR (0.00) L 0.82
381	LLLL (0.13) LRLL (0.01) L 0.46	LLLL (0.19) RLRR (0.01) L 0.54	-	LLLL (0.28) RRRL (0.01) L 0.57	RRRR (0.98) LRRR (0.00) L 0.02	RRRR (0.29) LRLL (0.00) L 0.44	-	RRRR (0.95) RLLL (0.00) L 0.04
927	LLLL (0.22) LRLL (0.00) L 0.55	RRRR (0.25) LRRL (0.00) L 0.48	RRRR (0.53) RLLL (0.00) L 0.22	RRRR (0.21) LRLR (0.00) L 0.45	RRRR (0.78) RRLL (0.00) L 0.21	RRRR (0.74) RLLL (0.00) L 0.16	RRRR (1.00) LLLL (0.00) L 0.00	RRRR (0.67) LRLL (0.00) L 0.23
936	RRRR (0.17) RLLR (0.00) L 0.54	RRRR (0.15) LRLR (0.00) L 0.47	LLLL (0.59) LLLR (0.00) L 0.73	LLLL (0.38) RLLR (0.01) L 0.63	RRRR (0.48) RLLL (0.00) L 0.48	RRRR (0.46) RLLL (0.00) L 0.46	LLLL (0.61) LLRR (0.00) L 0.78	LLLL (0.42) RLRR (0.00) L 0.49

Table 2-5 (continued).
Specific Sequences for Individual Subjects in Experiment 2.

Subject	Most frequently emitted sequence (proportion) / Least frequently emitted sequence (proportion) / Proportion of sequences starting with a left keypeck							
	VAR				YOKE			
	BL	EXT 1	EXT 2	REIN	BL	EXT 1	EXT 2	REIN
956	LLLL (0.19) RRLL (0.00) L 0.75	LLLL (0.25) RLLL (0.01) L 0.70	LLLL (0.59) RRRL (0.00) L 0.79	LLLL (0.36) LRLL (0.00) L 0.77	RRRR (0.80) LLLL (0.00) L 0.15	RRRR (0.79) RLLL (0.00) L 0.18	RRRR (0.59) RRLL (0.00) L 0.36	RRRR (0.66) RLLR (0.00) L 030
957	LLLL (0.19) LRLL (0.00) L 0.33	LLLL (0.26) LRRR (0.00) L 0.33	-	LLLL (0.27) LRLL (0.00) L 0.45	RRRR (0.50) LRRR (0.00) L 0.38	RRRR (0.70) LRRR (0.00) L 0.25	-	LLLL (0.47) RRRL (0.00) L 0.52
966	LLLL (0.21) RLRL (0.00) L 0.71	RRRR (0.14) RRLR (0.01) L 0.61	-	LLLL (0.22) RLRL (0.00) L 0.61	RRRR (0.56) LRLL (0.00) L 0.41	RRRR (0.45) LLLR (0.00) L 0.45	-	LLLL (0.47) LRLL (0.00) L 0.56

Note: Specific sequences emitted for individual subjects across phases and components in Experiment 2. Each cell contains the sequence emitted most frequently for that five-session block, with the relative frequency of that sequence in parentheses, the sequence emitted least frequently for that five-session block, with the relative frequency of that sequence in parentheses, and the proportion of sequences emitted starting with a left keypeck (L). VAR represents the Vary component and YOKE represents the Yoke component. BL represents the last five sessions of the Baseline phase, EXT 1 represents the first five sessions of Extinction, EXT 2 represents the last five sessions of Extinction, and REIN represents the first five sessions of the Reinstatement phase. Dashes represent five-session blocks in which fewer than 25 trials were emitted.

did not change significantly throughout. These results further demonstrate the sensitivity of behavioral variability to consequences and support the notion that behavioral variability may be susceptible to relapse in a manner similar to that of operant behavior. As in Experiment 1, we observed disruption of behavioral variability as a result of extinction. In addition, we observed relapse of behavioral variability with reinstatement.

Experiment 3: Resurgence

In this experiment, we determined whether reinforced behavioral variability is susceptible to another type of relapse: resurgence. Resurgence is the reoccurrence of a previously extinguished response after reinforcement is suspended for a newly trained alternative response (e.g., Epstein, 1985). Like reinstatement, resurgence is typically studied in three phases. In Phase 1, Baseline, a target response is reinforced. In Phase 2, Alternative, reinforcement for the target behavior is suspended and an alternative response is reinforced. In Phase 3, all responding is extinguished. Resurgence is said to have occurred if the target response returns when reinforcement of the alternative response is removed.

In an attempt to distinguish between resurgence of reinforced behavioral variability and extinction-induced behavioral variability, we divided pigeons into two groups. One group responded on a lag variability schedule and the other earned food on a lag repetition schedule. Because the repetition group only had a recent history of behaving repetitively, any increase in variation observed for that group during the final phase was likely extinction-induced as opposed to evidencing resurgence of reinforced behavioral variability.

Method

Subjects and Apparatus

Twelve adult pigeons with prior experimental histories served as the subjects for this experiment. Although reported last, this experiment was conducted second (see Table 1). Data for one pigeon from the Vary group and one pigeon from the Repeat group were excluded due to failure to earn at least 25% of reinforcers after 15 sessions of Baseline. Details of subject maintenance, general procedures, and apparatus were the same as in Experiments 1 and 2.

Procedure

In this experiment, we used a group design to examine resurgence of behavioral variability. As in the previous experiments, pigeons emitted four-peck sequences across two keys. Experiment 3 consisted of three phases: Baseline, Alternative, and Resurgence. Pigeons were divided into Vary and Repeat groups. In Phase 1, Baseline, a lag 8 variability schedule of reinforcement was in place for the Vary group. We used a lag 8 variability schedule because it was strict enough to result in high levels of behavioral variability but would also allow relatively frequent reinforcers. For the Repeat group, a lag 3 repetition contingency was in place for Phase 1 (see Cherot et al., 1996; Odum et al., 2006). A lag repetition contingency is similar to a lag variability contingency, except that a sequence will only produce food if it is the same as any of a certain number of previous responses. In this way, a specific target sequence is not required; instead, the pigeon simply must repeat a sequence it has emitted recently. We used a lag 3 repetition contingency because this value has been used in previous research (Cherot et al., 1996; Odum et al., 2006). In addition, this contingency resulted in reinforcement rates that were

similar to or higher than the Vary components in the previous experiments and the Vary group in the present experiment. For both groups, the sequences LLLL and RRRR were never eligible for reinforcement, because of the tendency to perseverate on these sequences (see Cherot et al., 1996; Odum et al., 2006). As in Experiment 1, there was a 0-s ITI between sequences for both groups. Phase 1 was in effect for 15 sessions.

There were two other phases. Phase 2, Alternative, was similar to Baseline, except that the lag 3 repetition contingency was now in place for both groups. For both groups, response sequences produced food if they were the same as any sequence emitted in the previous three trials. Phase 2 was in effect for 25 sessions. Phase 3, Resurgence, was similar to previous phases, except that there were no food deliveries. Phase 3 was in effect for five sessions.

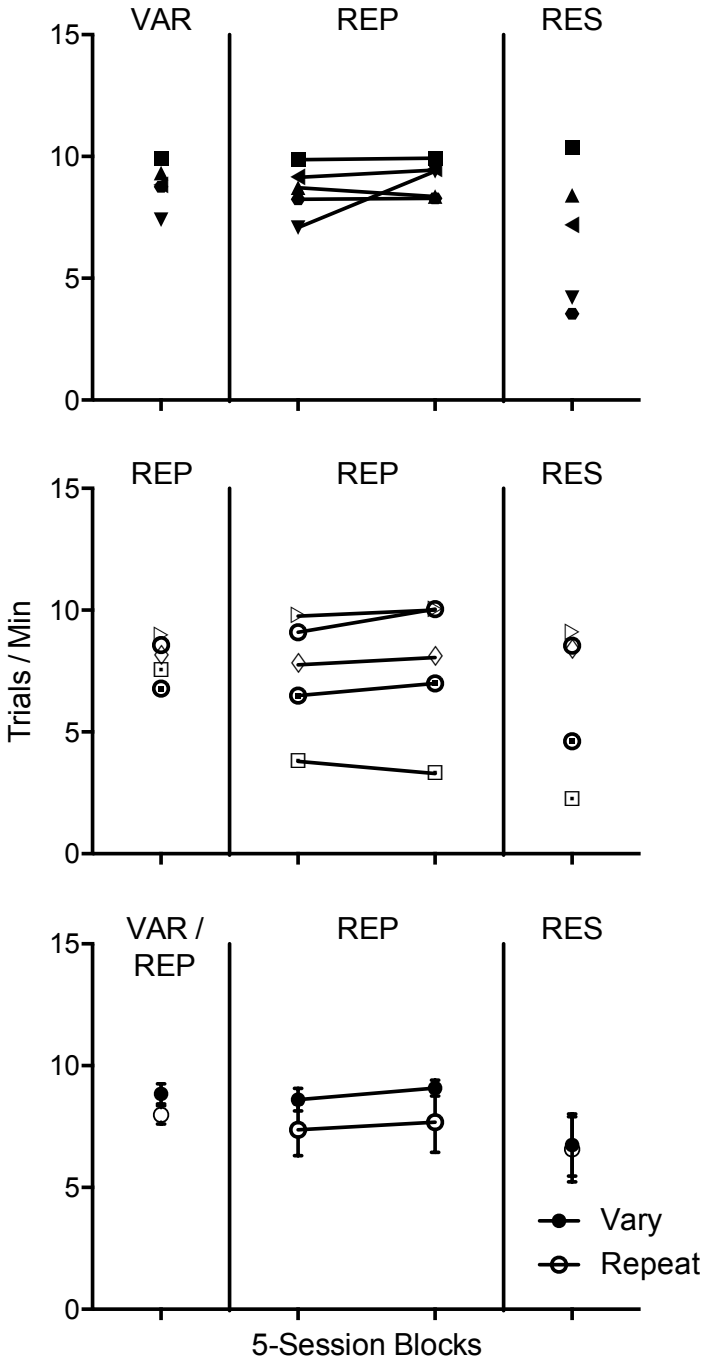
Data Analysis

As in Experiments 1 and 2, the primary dependent measures for Experiment 3 were response rate, reinforcement rate, proportion of sequences meeting the lag variability contingency, and pooled U-value. Each of these measures was calculated as in Experiments 1 and 2. Statistical analyses were conducted as in Experiments 1 and 2 except that a two-way mixed ANOVA was used with the group as a between-subjects factor and the phase as a within-subjects factor. Relative frequency distribution analyses were conducted as in previous experiments.

Results

Response rates did not systematically change across any phase of the experiment for either group. The top panel of Figure 2-8 shows similar response rates for individual subjects across phases in the Vary group, and the middle panel shows similar response

Figure 2-8.
Response Rates in Experiment 3.



Note. Response rate (trials/min) across phases for both groups in Experiment 3. Each point represents a five-session block. The top panel shows individual subject data for the Vary group. The middle panel shows individual subject data for the Repeat group. The bottom panel shows group data. Symbols for individual subjects are consistent across phases. Filled symbols show response rates for the Vary group, and open symbols show response rates for the Repeat group. For all graphs, the first phase is Baseline and is labeled with the contingency in place, the second phase is Alternative and is labeled with the contingency in place, and the third phase is Resurgence. Error bars in the bottom panel show standard error of the mean.

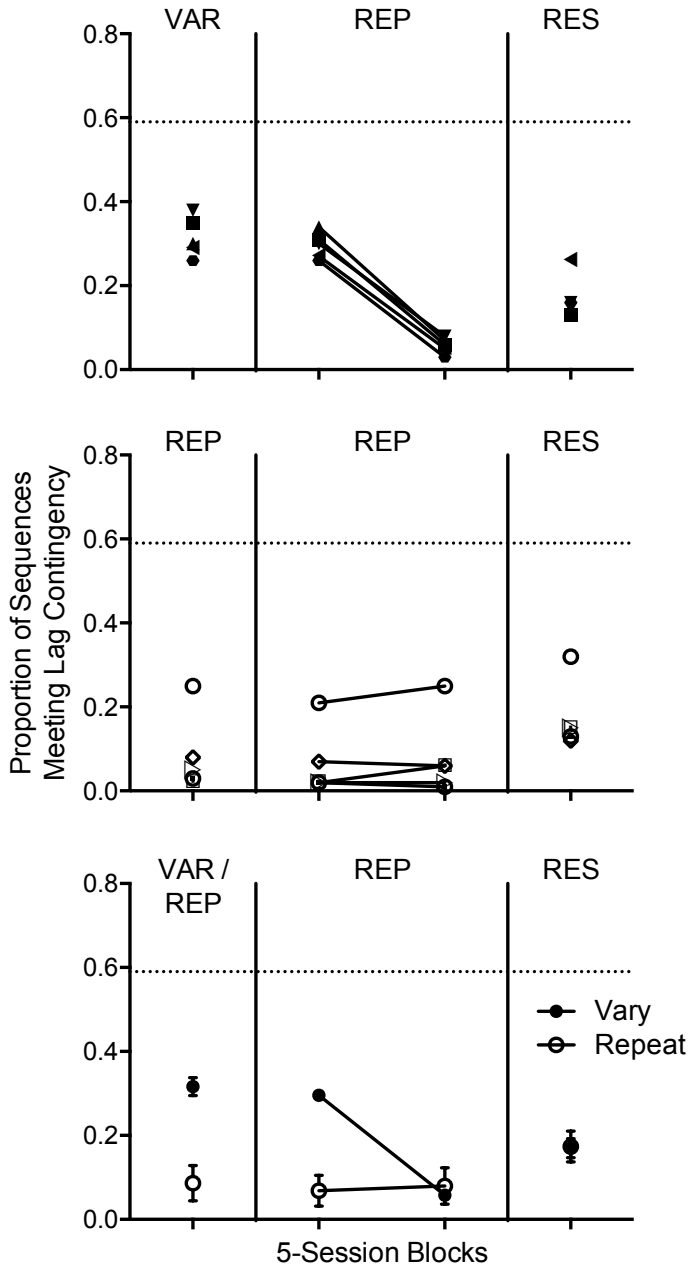
rates for individual subjects across phases in the Repeat group. Although response rates did change slightly across phases for some individual pigeons, there were no systematic differences overall, except when extinction was in place during the Resurgence phase, in which response rates decreased.

The bottom panel of Figure 2-8 shows average response rate across each phase in Experiment 3. There was a significant main effect of phase [$F(3,24) = 4.726$, $p = .010$, $\eta^2 = .371$], but no significant main effect of group [$F(1,8) = .674$, $p = .435$, $\eta^2 = .078$], and the interaction between phase and group was not significant [$F(3,24) = 0.515$, $p = .676$, $\eta^2 = .061$]. As supported by planned pairwise comparisons (shown in the Supplemental Material), at the group level, response rates did not change for either group throughout the experiment, except for a slight decrease from the last five sessions of Alternative to Resurgence.

We also analyzed reinforcer rates across groups and phases. Reinforcers per min was not significantly different across phases [$F(1.114, 8.911) = 4.167$, $p = .069$, $\eta^2 = .343$] or groups [$F(1, 8) = .497$, $p = .501$, $\eta^2 = .059$]. The interaction between phase and group was also not significant [$F(2, 16) = 1.389$, $p = .278$, $\eta^2 = .148$]. As supported by planned pairwise comparisons (shown in the Supplemental Material), reinforcer rates were not significantly different across groups or phases.

An analysis of the proportion of sequences meeting the lag variability contingency showed a decrease throughout the Alternative phase for the Vary group, no systematic change across Baseline and Alternative phase for the Repeat group, and an increase during Resurgence for every subject in both groups. Figure 2-9 shows individual subject data for the Vary group (top panel) and Repeat group (middle panel) across

Figure 2-9.
Proportion of Sequences Meeting the Lag Contingency in Experiment 3.



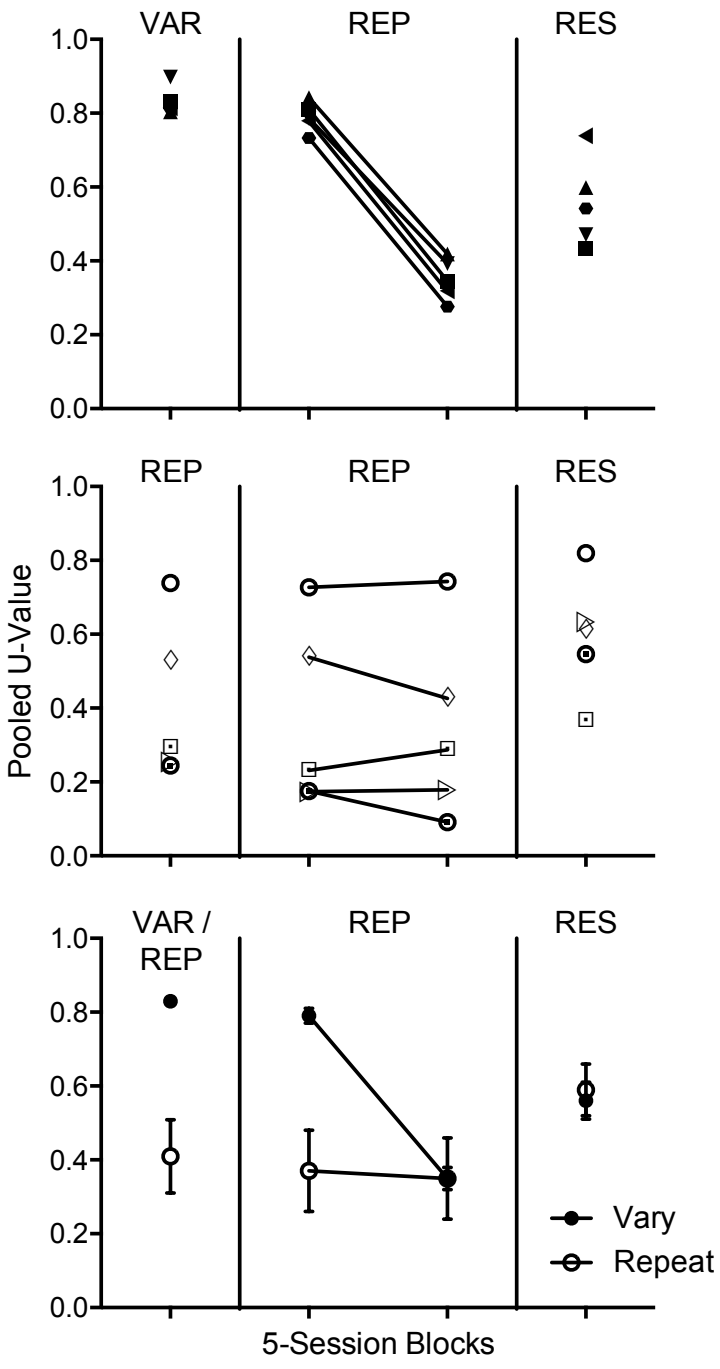
Note. Proportion of sequences meeting the lag contingency in Experiment 3. Each point represents a five-session block. The top panel shows individual subject data for the Vary group. The middle panel shows individual subject data for the Repeat group. The bottom panel shows group data. Symbols for individual subjects are consistent across phases. Filled symbols show proportion of sequences meeting the lag contingency for the Vary group, and open symbols show proportion of sequences meeting the lag contingency for the Repeat group. For all graphs, the first phase is Baseline and is labeled with the contingency in place, the second phase is Extinction and is labeled with the contingency in place, and the third phase is Resurgence. Error bars in the bottom panel show standard error of the mean. In all panels, the horizontal dashed line represents the expected proportion of sequences meeting the lag contingency given random responding, determined through simulations.

phases, as well as group data in the bottom panel. The proportion of sequences meeting the lag variability contingency changed significantly across phases [$F(3,24) = 34.343$, $p < .001$, $\eta^2 = .811$] and groups [$F(1,8) = 7.204$, $p < .028$, $\eta^2 = .474$], with a significant interaction [$F(3,24) = 47.902$, $p < .001$, $\eta^2 = .857$]. As supported by planned pairwise comparisons (shown in the Supplemental Material), the proportion of sequences meeting the lag variability contingency was higher in Baseline for the Vary group than for the Repeat group and did not change from the last five sessions of Baseline to the first five sessions of Alternative for either group. From the first five sessions to the last five sessions of Alternative, the proportion of sequences meeting the lag variability contingency stayed low for the Repeat group and decreased to similar levels as the Repeat Group for the Vary group. The proportion of sequences meeting the lag variability contingency increased slightly from the last five sessions of Alternative to Resurgence for both groups.

Pooled U-values were higher for the Vary group than the Repeat group during Baseline but were low for both groups in Alternative and increased during Resurgence. Figure 2-10 shows that pooled U-values decreased in the final five sessions of the Alternative phase and increased during Resurgence for all individual subjects in the Vary group (top panel). Figure 2-10 also shows that pooled U-values were similar across Baseline and Alternative but increased during Resurgence for all individual subjects in the Repeat group.

The bottom panel of Figure 2-10 shows average pooled U-values across phases for the Vary and Repeat groups. Pooled U-values were significantly different across phases [$F(1.320, 10.562) = 22.454$, $p < .001$, $\eta^2 = .737$] but only trended towards

Figure 2-10.
Pooled U-Value in Experiment 3.



Note. Pooled U-value across phases for both groups in Experiment 3. Each point represents a five-session block. The top panel shows individual subject data for the Vary group. The middle panel shows individual subject data for the Repeat group. The bottom panel shows group data. Symbols for individual subjects are consistent across phases. Filled symbols show pooled U-values for the Vary group, and open symbols show pooled U-values for the Repeat group. For all graphs, the first phase is Baseline and is labeled with the contingency in place, the second phase is Alternative and is labeled with the contingency in place, and the third phase is Resurgence. Error bars in the bottom panel show standard error of the mean.

significance across groups [$F(1, 8) = 4.509$, $p = .066$, $\eta^2 = .360$]. There was a significant interaction between phase and group [$F(1.320, 10.562) = 23.391$, $p < .001$, $\eta^2 = .745$]. As supported by planned pairwise comparisons (shown in the Supplemental Material), pooled U-values were higher for the Vary group than for the Repeat group in Baseline. From the last five sessions of Baseline to the first five sessions of Alternative, pooled U-values did not change for either group. From the first five sessions to the last five sessions of Alternative, pooled U-values did not change for the Repeat group but decreased to similar levels as that in the Repeat Group for the Vary group. From the last five sessions of Alternative to Resurgence, pooled U-values increased similarly for both groups.

Relative frequency distributions for each subject across components and phases are shown in the Supplemental Material. Table 2-6 shows, for each individual subject across phases and components, the average number of switches and the number of distinct sequences emitted. During Baseline, the Vary group emitted sequences with more switches than the Repeat group. From the last five sessions of Baseline to the first five sessions of Alternative, the number of switches stayed approximately the same for both groups. From the first five sessions to the last five sessions of Alternative, however, the average number of switches per sequence decreased for the Vary group and stayed relatively constant for the Repeat group. Finally, from the last five sessions of Alternative to Resurgence, the average number of switches stayed constant for the Vary group and decreased for the Repeat group. The number of distinct sequences emitted per five-session block followed a similar pattern across phases and groups, except that both groups showed an increase from the last five sessions of Alternative to Resurgence. Table

2-7 shows the sequences emitted most and least frequently, as well as the proportion of sequences emitted starting with a left keypeck, for each individual subject across phases and components. For the Vary group, the dominant sequence in Baseline was not necessarily the dominant sequence for other phases; however, the dominant sequences in Baseline and Resurgence were usually the same or started with the same key(s) (e.g., RRLR and RRRR in Baseline and Resurgence, respectively, for one subject). For the Repeat group, the dominant sequence in Baseline was usually the same as the dominant sequence in other phases.

Discussion

Overall, levels of behavioral variability for the Vary group were high with a lag variability schedule in place but decreased when a lag repetition schedule was implemented. Following the suspension of reinforcers for behaving repetitively, levels of behavioral variability increased, providing some evidence for resurgence, although levels of behavioral variability were not as high in Resurgence as they were in Baseline. However, levels of behavioral variability for the Repeat group were low during Baseline and Alternative, when a lag repetition schedule was in place, but increased following the suspension of reinforcers, highlighting the role of extinction-induced behavioral variability. That said, even though pooled U-values for the Repeat group increased during Resurgence, the average number of switches per sequence decreased. In other words, between-sequence variability increased while within-sequence variability decreased. Pigeons in the Repeat group made more distinct sequences, but the makeup of those sequences became more repetitive.

Table 2-6.
Average Switches per Sequence and Number of Distinct Sequences in Experiment 3.

		Average switches per sequence				Number of distinct sequences per five-session block			
Group	Subject	BL	ALT 1	ALT 2	RES	BL	ALT 1	ALT 2	RES
VAR	220	1.71	1.61	0.63	1.08	15	15	6	15
	223	1.27	1.18	0.96	0.86	15	16	10	14
	237	1.68	1.46	0.71	0.56	16	16	11	14
	936	1.11	1.05	0.94	0.46	12	12	7	15
	1158	1.63	1.29	0.71	0.89	15	16	10	16
	Mean	1.48	1.32	0.79	0.77	14.60	15.00	8.80	14.80
	(SEM)	(0.12)	(0.10)	(0.07)	(0.11)	(0.68)	(0.77)	(0.97)	(0.37)
REP	55	1.85	1.69	2.16	1.90	15	13	16	16
	957	0.77	0.82	0.96	0.62	7	6	6	14
	966	0.97	0.87	0.89	0.70	7	5	3	14
	1499	0.41	0.25	0.21	0.02	7	5	7	5
	17556	0.89	0.91	0.85	0.81	12	11	10	14
	Mean	0.98	0.91	1.01	0.81	9.60	8.00	8.40	12.60
	(SEM)	(0.24)	(0.23)	(0.32)	(0.30)	(1.66)	(1.67)	(2.20)	(1.94)

Note: Average switches per sequence and number of distinct sequences emitted per five-session block for individual subjects and on average (with standard error of the mean in parentheses) across phases and groups in Experiment 3. VAR represents the Vary group and REP represents the Repeat group. BL represents the last five sessions of the Baseline phase, ALT 1 represents the first five sessions of the Alternative phase, ALT 2 represents the last five sessions of the Alternative phase, and RES represents the first five sessions of the Resurgence phase.

Table 2-7.
Specific Sequences for Individual Subjects in Experiment 3.

		Most frequently emitted sequence (proportion) / Least frequently emitted sequence (proportion) / Proportion of sequences starting with a left keypeck			
Group	Subject	BL	ALT 1	ALT 2	RES
Vary	220	LRRL (0.17) LLRL (0.00) L 0.55	RLRR (0.24) LLRL (0.00) L 0.45	LRRR (0.50) LLLL (0.00) L 0.50	LRRR (0.67) LLRL (0.00) L 0.85
	223	RRLL (0.26) LRLR (0.00) L 0.34	RRLL (0.21) LRLR (0.00) L 0.44	RRLL (0.55) LLRR (0.00) L 0.04	RRLL (0.40) LRLR (0.00) L 0.10
	237	RRLR (0.13) RLLL (0.00) L 0.52	LLRR (0.27) RLLL (0.01) L 0.83	LRRR (0.54) RLLL (0.00) L 0.66	RRRR (0.54) LRLL (0.00) L 0.28
	936	RRLL (0.18) LRLL (0.00) L 0.39	RRLL (0.31) LRLL (0.00) L 0.29	RLLL (0.71) RRRR (0.00) L 0.07	RRRR (0.27) LRLR (0.00) L 0.21
	1158	RLRR (0.18) LRRL (0.00) L 0.57	RLLL (0.31) LLLR (0.00) L 0.29	RLLL (0.62) RRRR (0.00) L 0.37	RLLL (0.27) LLRL (0.01) L 0.29

Table 2-7 (continued).
Specific Sequences for Individual Subjects in Experiment 3.

		Most frequently emitted sequence (proportion) / Least frequently emitted sequence (proportion) / Proportion of sequences starting with a left keypeck			
Group	Subject	BL	ALT 1	ALT 2	RES
Repeat	55	LRLL (0.25) RLRR (0.00) L 0.48	LRLL (0.25) LRRR (0.00) L 0.74	LRLR (0.27) RRRR (0.00) L 0.80	LRLR (0.22) RRRR (0.00) L 0.78
	957	LRRR (0.74) RRLL (0.00) L 0.76	LRRR (0.80) RLLL (0.00) L 0.82	LRRR (0.94) LLLL (0.00) L 0.95	LRRR (0.36) LRLL (0.00) L 0.73
	966	RLLL (0.76) RRRR (0.00) L 0.04	RLLL (0.83) RRRR (0.00) L 0.13	RLLL (0.85) RRRR (0.00) L 0.11	LLLL (0.25) RRLR (0.00) L 0.32
	1499	LLLL (0.59) LRRR (0.00) L 0.60	LLLL (0.34) RRRR (0.00) L 0.34	LLLL (0.26) LLLR (0.00) L 0.26	LLLL (0.26) LRRR (0.00) L 0.26
	17556	LRRR (0.41) LRRL (0.00) L 0.79	LRRR (0.38) LRLL (0.00) L 0.84	LRRR (0.85) RLLL (0.00) L 0.82	LRRR (0.29) LRLR (0.00) L 0.89

Note: Specific sequences emitted for individual subjects across phases and groups in Experiment 3. Each cell contains the sequence emitted most frequently for that five-session block, with the relative frequency of that sequence in parentheses, the sequence emitted least frequently for that five-session block, with the relative frequency of that sequence in parentheses, and the proportion of sequences emitted starting with a left keypeck (L). VAR represents the Vary group and REP represents the Repeat group. BL represents the last five sessions of the Baseline phase, ALT 1 represents the first five sessions of the Alternative phase, ALT 2 represents the last five sessions of the Alternative phase, and RES represents the first five sessions of the Resurgence phase.

Because the Repeat group did not have recent history of responding variably, it was likely that increases in levels of behavioral variability for this group during the Resurgence phase would be induced by extinction. Many of these subjects did participate in previous experiments on behavioral variability; however, extinction-induced response variability is a more parsimonious explanation than resurgence of behavior learned in previous experiments. Because we saw similar increases in pooled U-value from the last five sessions of Alternative to Resurgence across groups, the increase for the Vary group may not be due to resurgence but may instead be due to extinction-induced variability. These results, in combination with the results of the previous experiments, support the idea that behavioral variability can be disrupted by extinction and can relapse given certain conditions. However, with extinction as a disruptor, caution is warranted due to the potential confounding influence of extinction-induced response variability.

General Discussion

Our results show that behavioral variability can be disrupted and is susceptible to relapse under certain circumstances. In Experiment 1, levels of behavioral variability decreased during extinction and increased when the lag contingency was restored. In Experiment 2, levels of behavioral variability decreased during extinction and increased when food was delivered response independently (i.e., reinstatement). In Experiment 3, levels of behavioral variability decreased when repetition was instead followed by food and then increased during extinction, although it is difficult to determine whether this finding was the result of resurgence or extinction-induced behavioral variability. These results demonstrate that behavioral variability is sensitive to consequences and that it may be susceptible to relapse in a manner similar to that of operant behavior.

This study had several limitations. First, pigeons were not experimentally naïve. When studying relapse with a subject that has an extensive behavioral history, the results must be interpreted cautiously, especially for Experiment 3. Additionally, in Experiment 2, we interpreted our findings as evidence for reinstatement, because of the delivery of response-independent food during reinstatement testing. However, those programmed food deliveries could have been experienced as response-independent or could have followed keypecks. If the latter, the results of Experiment 2 could actually illustrate reacquisition, similar to Experiment 1.

The present findings are consistent with previous research showing that behavioral variability has similar characteristics to other dimensions of operant behavior. Variable behavior can be maintained by reinforcement, depends on the reinforcement contingency in place, and can be brought under discriminative control (e.g., Page & Neuringer, 1985). Although prior studies have shown that behavioral variability is more persistent than behavioral repetition, and that disruption only occurs in terms of rate of responding rather than levels of variability (e.g., Cohen et al., 1990; Doughty & Lattal, 2001; Odum et al., 2006; Wagner & Neuringer, 2006; Ward et al., 2006), our results demonstrate that variable behavior is not only disrupted in terms of response rate, but also in terms of overall levels of behavioral variability.

One major methodological difference between the present study and similar previous studies is the type of disruptor used. Most studies concerning the disruption of behavioral variability have used non-extinction disruptors, such as response-independent food delivery (e.g., Doughty & Lattal, 2001), drugs (e.g., Cohen et al., 1990; Ward et al., 2006), and delay to reinforcement (Odum et al., 2006; Wagner & Neuringer, 2006).

Extinction is an important disruptor to study, because of the extent to which extinction is experienced in everyday life, across species and situations. However, the use of extinction poses a challenge in behavioral variability research because of the potential for observing extinction-induced response variability. This difficulty may explain why the effects of extinction on behavioral variability have not been extensively studied (Neuringer et al., 2001).

Neuringer and colleagues (2001) examined the impact of extinction on reinforced behavioral variability. Overall levels of behavioral variability increased, and the specific sequences emitted were different with extinction in place, highlighting the importance of distinguishing between reinforced and extinction-induced behavioral variability. There are several differences between this study and the present experiments. For example, Neuringer and colleagues used a group design, whereas in our Experiments 1 and 2, we used a multiple schedule to directly compare levels of behavioral variability in the context of reinforcement and extinction. Additionally, Neuringer and colleagues exposed subjects to only four sessions of extinction and observed an increase in behavioral variability, attributed to extinction-induced variability. In our Experiments 1 and 2, subjects were exposed to extinction contingencies for 10 and 15 sessions, respectively. Although some subjects showed an initial increase in behavioral variability within the first several sessions of extinction, our most reliable finding was an overall decrease in behavioral variability. It is possible that such a decrease can only be observed after longer exposure to extinction. Additional evidence for this interpretation is that we observed extinction-induced increases in behavioral variability in Experiment 3 in which subjects experienced extinction for only five sessions in the Resurgence test.

The field of research concerned with behavioral variability is limited by the current analytic techniques (Kong et al., 2017). U-value is the measure most commonly used in behavioral variability studies (for reviews, see Neuringer, 2002, 2009, 2012, 2016, among others). U-value has many advantages: it provides a summary measure of the distribution of responding across all possible alternatives, it is relatively simple to compute, and it easily detects differences in behavioral variability based on whether or not a variability contingency is in place (i.e., U-values are high with a variability contingency in place and low with a control contingency in place).

However, U-value has limitations as a measure of behavioral variability. First, U-value is dependent on the total number of response sequences used in the calculation of the measure (see Figure 2-1). When few trials are emitted (i.e., when the sample size is small), U-value is constrained. This limitation is a particularly important consideration for the present study, because extinction was used in each experiment. In extinction, the number of sequences decreased substantially, which necessarily impacts U-value. In the present study, we used a pooled U-value, calculated using five-session blocks, which prevented U-value analyses from being conducted with too few trials. By including more sessions in the analysis, we increased the number of response sequences that were used in the calculation of the measure and were more likely to have a representative U-value.

Another limitation of U-value is that it is a molar measure that only summarizes the total distribution of response sequences. Therefore, U-value is insensitive to the order of sequences or which particular sequences are emitted (Kong et al., 2017). When U-value alone is examined, more molecular patterns of repetitive responding may be overlooked because the molar level distribution of response sequences is similar.

Examining relative frequency distributions may provide a more complete measure of behavioral variability than U-value alone. Relative frequency distribution analyses involve examining the incidence of every possible response alternative (e.g., Doughty & Galizio, 2015; Doughty et al., 2013; Machado, 1997; Neuringer et al., 2001; Odum et al., 2006). Relative frequency distributions reveal whether any response options have been systematically omitted, which would affect U-value calculation. Relative frequency distributions may also uncover differences in responding that are not reflected in U-value; the same U-value may be obtained with different patterns of responding (e.g., changes in the average number of switches, number of distinct sequences, proportion of sequences emitted beginning with one key, etc.). For example, Doughty and colleagues (2013) found that U-values were lower when the magnitude of reinforcement was higher, and this decrease was largely due to an increase in the occurrence of sequences ending in repetitions (e.g., LRRR as opposed to LLLR). In another study, Odum and colleagues (2006) found under a multiple schedule that delay to reinforcement did not decrease U-values under a lag variability schedule, but that sequences from a component requiring repetition of a target sequence became more common in the variability component.

Given the importance of using these more molecular measures, we have provided relative frequency distributions for individual subjects across phases in each experiment in Tables 2-7 and in the Supplemental Materials. Although the results of these analyses were idiosyncratic across subjects, there were a few general findings. In all experiments, there tended to be a more even distribution of responding across sequences when a lag variability contingency was in place than when a control contingency was in place. In Experiment 1, responding became more restricted during Extinction for some subjects but

even more evenly distributed for others. In Experiment 2, fewer sequences were emitted during Extinction, but responding became more evenly distributed across many sequences during Reinstatement. In Experiment 3, responding was distributed across many sequences when the lag variability contingency was in place, and only a few sequences were usually emitted with a lag repetition contingency in place. During Resurgence, more sequences were emitted for all subjects, with and without a recent history of varying. A more detailed analysis of these relative frequency distributions can be found in the Supplemental Material.

The present results have important theoretical implications for understanding behavioral variability. Although Neuringer (2002, 2009, 2012, 2016) has conceptualized variability as an operant dimension of behavior, other explanations have been proposed to explain how behavioral variability can arise from reinforcement (i.e., lag schedules). Specifically, Machado (1997), Machado & Tonneau (2012), and Holth (2012) have suggested that variability itself is not reinforced when a lag schedule is in place; instead, some other aspect of behavior is reinforced inadvertently, resulting in high levels of behavioral variability as a byproduct.

Machado (1997) found that pigeons behaved with similar levels of behavioral variability when a lag schedule was in place and when switches between keys, or changeovers, were reinforced instead. In the lag schedule, pigeons would only earn food for sequences that had not been emitted recently. When switches were reinforced, pigeons would earn food anytime a sequence with a certain number of switches between keys was emitted (e.g., LLLL has no switches, LRRR has one switch, and LRLL has two switches), but the pigeon need not emit sequences variably. A pigeon could emit the same

sequence repeatedly, as long as it had the required number of switches. However, high levels of behavioral variability were instead observed with both contingencies. Machado concluded that behavioral variability may arise as a result of generalization and limitations of stimulus control. In other words, reinforcers delivered following left keypecking may also strengthen right keypecking, and it may be difficult for a pigeon to exactly replicate a previous sequence, especially when longer sequences are used. However, when Doughty and Galizio (2015) arranged for shorter sequences than used in the prior experiments, reinforcing switches was insufficient to produce variable responding. Additionally, the results of the present study provide evidence that at least in some cases, increased switching does not lead to an increase in behavioral variability (see Experiment 3). Together, these results suggest that the generality of the explanation that variability arises secondarily, from reinforced switching, may be limited.

Machado and Tonneau (2012) also proposed the balance hypothesis (see also Barba, 2015). This hypothesis assumes that, with a lag schedule in place, reinforcers delivered in variability contingencies act on the properties of a sequence. Specifically, a particular sequence may be emitted and followed by reinforcement. The probability of that sequence occurring again in the future may increase due to the reinforcer delivery. However, due to the nature of a lag contingency, that sequence may be emitted again but not followed by reinforcement. In this case, the likelihood of that sequence occurring again may decrease. This process may continue until each sequence is occurring some of the time, resulting in variable behavior. In a similar hypothesis, Holth (2012) has questioned the sequence as the relevant, reinforced behavioral unit. Instead he has suggested that a variety of response units may be reinforced, such as specific keypecks

and switches between keys. As a result of the lag contingency, these discrete response units may be repeatedly reinforced and extinguished in a cyclical manner, producing variable behavior.

Each interpretation of behavioral variability – as an operant (e.g., Neuringer, 2002), as a byproduct of reinforcing switches (Machado, 1997), or as a byproduct of cyclical reinforcement and extinction of sequences (Machado & Tonneau, 2012) or more basic responses (Holth, 2012) – has merits. The results of the present study support the conceptualization of variability as an operant dimension of behavior, but also are not inconsistent with the hypotheses of behavioral variability as a byproduct. Although we observed some clear evidence for relapse of behavioral variability, it is also important to note that relapse is not unique to operant behavior. For example, classically conditioned behavior can also relapse (e.g., Bouton, 2002). Therefore, more research is needed to further investigate the potential mechanisms of reinforced behavioral variability.

Another potential future direction would be to examine different variability schedules. For example, we used a lag schedule of reinforcement for all experiments, but there are other schedules of reinforcement that make reinforcer deliveries contingent on variable responding, such as a relative frequency threshold contingency (e.g., Denney & Neuringer, 1998). Whereas a lag contingency provides reinforcement for responses that have not been emitted recently, a relative frequency threshold contingency provides reinforcers for responses that have been emitted infrequently, and it may have some advantages over a lag schedule. Further, the present study used relatively stringent lag requirements. Future studies should examine different variability contingencies, as well as different variability requirements.

Reinforced behavioral variability has important clinical implications. Deficits in behavioral variability are characteristic of some psychological disorders and may be expressed in the form of behavioral rigidity and inflexibility (Kashdan & Rottenberg, 2010). For example, individuals with autism spectrum disorders (ASD) display stereotyped behavioral patterns and have difficulty engaging in novel actions (D'Cruz et al., 2013; Jiujias et al., 2017). Additionally, repetitive behavioral and thought patterns are characteristic of individuals with depression (Jacobson et al., 2001; Nolen-Hoeksema et al., 2008). Rigid rule following is another manifestation of behavioral inflexibility, which can prevent individuals from contacting natural contingencies (Galizio, 1979; Hayes et al., 1986). Due to its possible etiological role within, and ubiquity across, psychological disorders, behavioral rigidity could be considered a transdiagnostic pathological process.

Implementing a treatment that provides reinforcers for behaving variably may help to expand an individual's behavioral repertoire in an adaptive direction. Interventions designed to modify behavioral variability have been tested in individuals with depression (e.g., Hopkinson & Neuringer, 2003) and ASD (e.g., Betz et al., 2011; Wolfe et al., 2014), with promising results. Interventions with typically developing populations have yet to be widely applied but would be useful to investigate, as behavioral variability may promote problem solving, creativity, and learning (e.g., Grunow & Neuringer, 2002; Weiss & Neuringer, 2012).

Relapse of reinforced behavioral variability may also be of clinical importance. In clinical settings, the goal is usually to teach individuals to behave with appropriate levels of behavioral variability depending on the situation. Therefore, the susceptibility of behavioral variability to relapse is encouraging for these applications. If behavioral

variability is prone to relapse, then protocols based on reinforcement of behavioral variability are potentially robust treatment options. For example, if errors were to occur during the delivery of a clinical protocol and reinforcers were not delivered, behavioral variability may be temporarily elicited (extinction-induced variability) or suppressed (extinction of reinforced variability), depending on the time frame of the lapse in treatment integrity. By improving adherence to the protocol, recovery of reinforced variable behavior may be possible. Such recovery would be an illustration of reacquisition. Our reinstatement findings also suggest that simply providing stimuli that were used as reinforcers during treatment may be enough to, at least temporarily, increase behavioral variability. These findings could potentially be usefully applied in response generalization if response-independent reinforcers are provided in a novel context. New behaviors would then have the opportunity to contact naturally occurring contingencies in the novel context, expanding the behavioral repertoire.

This line of research also suggests the potential of studying renewal and other forms of relapse of behavioral variability. Renewal is a form of relapse in which a behavior is reinforced in one context and extinguished in another context (e.g., Berry et al., 2014; Bouton, 2002). The shift to the original context or a novel context may induce renewal of the behavior in question. As an example, behavioral variability may be reinforced in one context (e.g., the therapeutic context) and disrupted in another (e.g., the home context). A return to the therapeutic context or a transition to a novel context (e.g., a recreational or educational context) could result in renewal of behavioral variability. As in the present experiments, we would expect to see relapse of behavioral variability under

renewal conditions as well, based on the similarities in how these relapse phenomena are explained by behavioral momentum theory (Berry et al., 2014).

Another form of relapse that may be interesting to examine is spontaneous recovery. Spontaneous recovery occurs when a behavior is extinguished and then returns after a period of time without exposure to the contingencies (Rescorla, 2004). If behavioral variability can spontaneously recover after extinction, then the effects of treatment fidelity errors could be only temporary. Relapse of behavioral variability is an important consideration if increased levels of behavioral variability are a therapeutic goal. The results of the present study provide evidence for extinction, reacquisition, reinstatement, and possibly resurgence of reinforced behavioral variability, as well as extinction-induced response variability. These results support the notion that variability is sensitive to consequences and may be prone to relapse in a similar manner as operant behavior. However, these findings also raise questions about how to distinguish between reinforced and extinction-induced behavioral variability, as well as the best way to measure variable behavior. Identifying the conditions under which behavioral variability is susceptible to relapse has important theoretical and clinical implications, and future research should be aimed at better understanding this phenomenon.

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CHAPTER 3

STUDY TWO:

AN INVESTIGATION OF RESURGENCE OF REINFORCED BEHAVIORAL VARIABILITY IN HUMANS [16]

Introduction

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). For example, a lag schedule, in which the current response must differ from a certain number of previous responses to produce reinforcement, generates high response variability. Additionally, the degree of behavioral variability depends on the stringency of the lag 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.

[16] Chapter 3 of this dissertation was adapted from Galizio, A., Friedel, J. E., & Odum, A. L. (under review). An investigation of resurgence of reinforced behavioral variability in humans. *Journal of the Experimental Analysis of Behavior.* See Appendix B for permission letter.

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. 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 the rectangles were only variable when drawing rectangles produced points for variability in 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, there is also evidence that appears to contradict this view. Learned behaviors are typically disrupted by environmental changes, such as extinction, delay to reinforcement, pre-session exposure to the reinforcer, or various drugs (e.g., Nevin & Grace, 2000). However, the evidence of disruption of reinforced behavioral variability is mixed. Extinction has been shown to selectively decrease levels of behavioral variability (Galizio et al., 2018; Neuringer et al., 2001) as would be expected. However, although certain drugs have been shown to disrupt overall response rates, they do not seem to

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), pre-session exposure to the reinforcer, or response-independent reinforcer presentations (Doughty & Lattal, 2001).

When operant behavior is disrupted, certain circumstances can cause relapse of the original behavior. Relapse of behavioral variability would provide further evidence that it is operant behavior, but such evidence is sparse (Galizio et al., 2018). Galizio et al. studied several different relapse phenomena in the context of reinforced behavioral variability in pigeons – reacquisition, reinstatement, and resurgence. In the first phase of each experiment, pigeons earned food for emitting sequences of keypecks according to a lag schedule, and levels of behavioral variability were high. Responding was extinguished in the second phase, which resulted in a decrease in variability. The third phase differed for each experiment. In the first experiment, the original reinforcement contingency was restored, resulting in a rapid increase in behavioral variability (i.e., reacquisition). In the second experiment, response-independent food deliveries produced an increase in behavioral variability (i.e., reinstatement). In the final experiment, an alternative response, repetition, was reinforced in the second phase. This alternative response was then extinguished in the third phase, and levels of variability increased (i.e., resurgence). The finding that behavioral variability is susceptible to relapse provides additional, albeit limited, evidence that variability is an operant.

Resurgence is a particularly relevant type of relapse. Differential reinforcement of alternative behavior (DRA) is a common treatment strategy in reducing undesirable behavior and promoting desirable behavior in humans. However, resurgence is a common, and usually unwanted, side effect of this kind of treatment (Epstein, 1985; Smith et al., 2017). However, resurgence could be beneficial for adaptive behaviors. For example, children with autism spectrum disorder (ASD) sometimes behave overly repetitively, even when it would be beneficial to respond variably (American Psychological Association [APA], 2013). If a child with ASD were taught to play variably in a clinical setting, but then experienced reinforcement only for repetition at home, resurgence of behavioral variability when reinforcement for repetition was suspended could be desirable. Because variability is adaptive in many contexts, the resurgence of variability could be clinically useful. Using the resurgence paradigm to study relapse of variability in a laboratory setting could ultimately inform clinical research and may provide additional 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. In this experiment, college students completed a computer-based task in which points were delivered when participants drew rectangles that satisfied a variability contingency (Kong et al., 2019; Ross & Neuringer, 2002). Relapse was assessed in three phases. In the first phase, *baseline*, points were delivered only when rectangles varied in terms of one dimension (i.e., size or location). In the second phase, *alternative*, points were delivered only when rectangles varied in terms of the other dimension. In the third phase, *extinction*, no points were delivered for any rectangles. The order of presentation of the

two dimensions – location and size – was counterbalanced across participants, such that half of the participants were required to vary the size of the rectangle in baseline and the location of the rectangle in alternative, and vice versa for the other half of participants. An increase in variability of the target dimension during extinction would be indicative of resurgence.

Method

Participants

Undergraduate students (n = 51) 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 3-1. 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.

Table 3-1.
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.

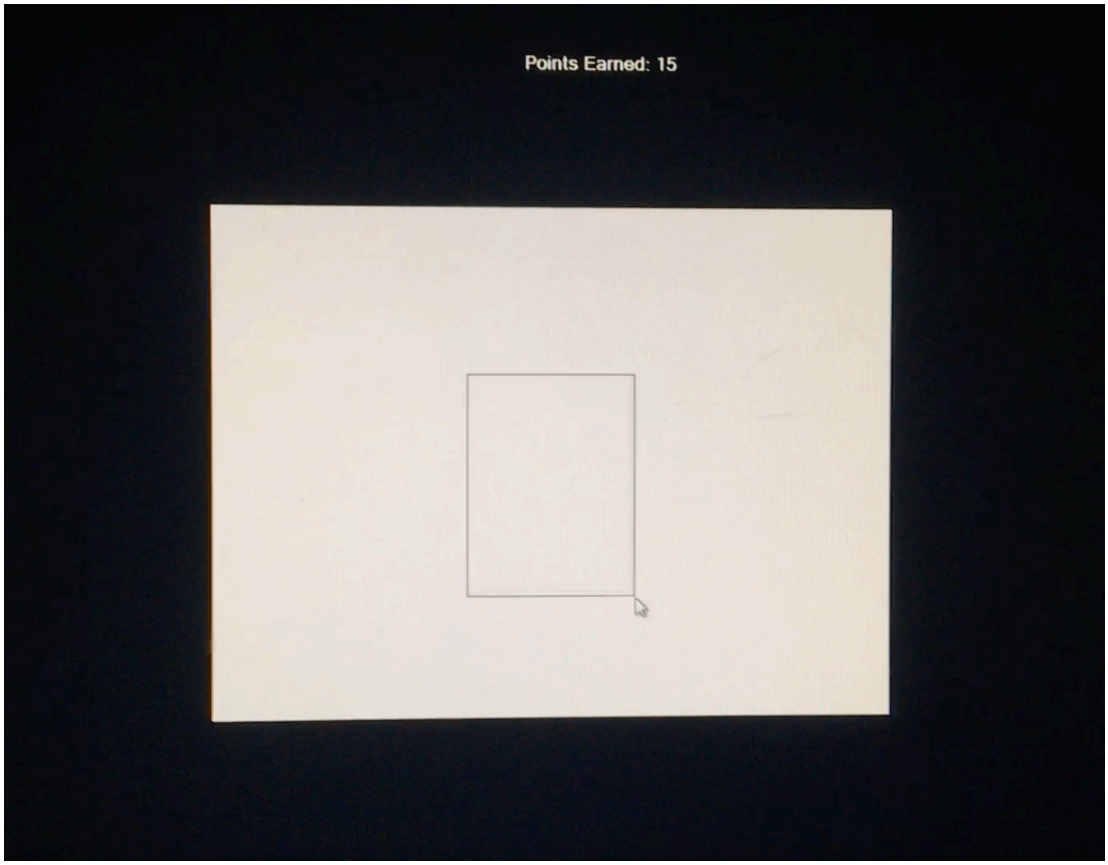
Procedure

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 x 480 pixels); the outer border of the screen was black, and the cursor was restricted to the white center area (see Figure 3-1). 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

Figure 3-1.
Example Screenshot During the Task.



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 rectangle that was created 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 likelihood 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). In the second phase, alternative, participants constructed 300 rectangles and earned points when a rectangle was sufficiently variable in terms of the alternative dimension (the dimension that was not reinforced in baseline). 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 minutes 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. 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,

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

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. 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 Šidák correction was used to ensure a Type I familywise error rate of 0.05.

U-value is a useful, global measure of variability but, among other limitations, does not provide information about which specific response categories are represented (see Kong et al., 2017). Therefore, we used relative frequency distributions to analyze any systematic patterns of responding (e.g., Doughty et al., 2013), and especially to assess changes in patterns of responding across phases. Specifically, the relative frequency of each response category was calculated by dividing the number of rectangles in that category by the total number of rectangles. Relative frequencies were calculated for each category of each dimension, size and location, in each phase. Next, we calculated difference scores for the target dimension by subtracting the relative frequency of one category in one phase from the relative frequency of the same category in another phase. The absolute values of these difference scores were then averaged within a single participant for each pair of phases. Higher absolute mean differences were indicative of a greater change in pattern of responding (i.e., the relative frequencies of all possible

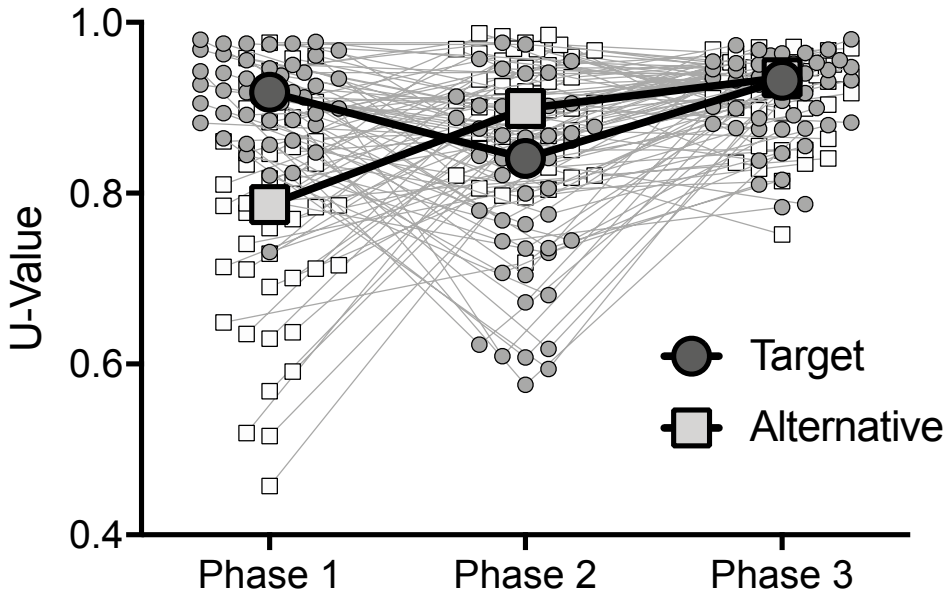
sequences) across phases, whereas lower absolute mean differences were indicative of minimal change across phases. A *k*-means cluster analysis, an algorithm that divides the data into *k* clusters, or classes, based on similarity (see Foreman, 2014), was conducted to analyze these relative frequency distributions. Data for participants with similar relative frequency distributions in terms of absolute mean differences were classified together using this technique. A more thorough discussion of the *k*-means cluster analysis and its results can be found in Appendix C.

Results

U-Value

Overall levels of variability were generally sensitive to the contingencies in place throughout the experiment. Figure 3-2 shows median and individual U-values for the target and alternative dimensions (size and location, counterbalanced) across phases. In the first phase, baseline, points were delivered only for varying on the target dimension. Target U-values were significantly higher than alternative U-values, $t(46) = 9.174$, $p < .0001$, 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, variability on the target dimension was placed on extinction and varying on the alternative dimension resulted in point delivery. U-values for the target dimension decreased significantly from baseline to alternative, $t(46) = 6.966$, $p < .0001$, and conversely, U-values for the alternative dimension increased significantly from baseline to alternative, $t(46) = 8.206$, $p < .0001$. Consistent with these results, U-values were significantly higher for the alternative dimension than for the

Figure 3-2.
U-Value Across Phases.



Note. U-value (y-axis) as a function of Phases 1 (baseline), 2 (alternative), and 3 (extinction), for the target dimension (circles) and alternative dimension (squares). Larger symbols represent medians and smaller symbols represent individual data.

target during the alternative phase, $t(46) = 5.998$, $p < .0001$, 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. U-values for the target dimension increased significantly from alternative to extinction, $t(46) = 7.114$, $p < .0001$, which is indicative of resurgence of target responding. However, U-values for the alterative dimension did not change significantly from alternative to extinction, $t(46) = 1.328$, $p = 1.0$, and U-values for the target and alternative dimensions were not significantly different during extinction, $t(46) = 0.212$, $p = 1.0$. The results of the repeated-measures ANOVA corroborated these findings (see Table 3-2).

Table 3-2.
Repeated-Measures ANOVA for U-Value.

Repeated-Measures ANOVA for U-Value					
Source	SS	DF	MS	*F*	*p*
Phase	0.2711	2	0.1356	21.04	<0.0001
Dimension	0.01431	1	0.01431	1.661	0.2039
Phase x Dimension	0.5727	2	0.2863	58.63	<0.0001

Cluster Analysis and Relative Frequency Distributions

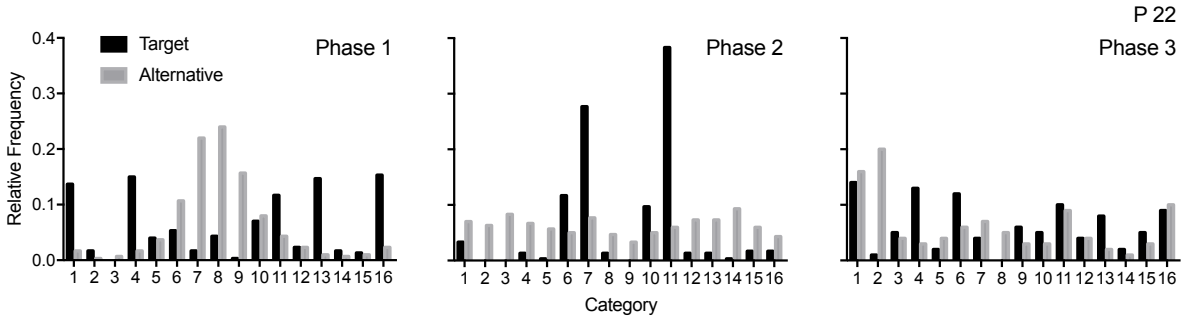
A *k*-means cluster analysis was conducted on the absolute mean differences for the target dimension between phases. The cluster analysis resulted in four distinct classes ($k = 4$; see Appendix C). Based on visual inspection of the classes identified in the cluster analysis, we developed descriptions of the various response patterns. The four classes included responding consistent with resurgence, rule-governed behavior, and extinction-induced response variability, as well as a category for response patterns not consistent with any of these explanations. *Resurgence*, Class 1, was said to have occurred if absolute mean differences were higher between baseline and alternative and between alternative and extinction, but lower between baseline and extinction, indicative of a reoccurrence of variable responding on the target dimension. *Rule-governed behavior*, Class 2, involved relatively low absolute mean differences throughout all phases, indicating a general insensitivity to the change in contingencies. *Extinction-induced response variability*, Class 3, involved a relatively high absolute mean difference between all phases, indicating responsiveness to the contingencies in baseline and alternative and an overall increase in variability during extinction, when extinction was in place. Class 4, *uncategorized*, involved nonsystematic data that were not consistent with any of the other three explanations. The following figures show the relative frequency of

all 16 possible categories of size and location across phases for representative participants in each class, selected via visual inspection. A flatter distribution would indicate more uniform relative frequencies across all categories and, therefore, greater behavioral variability. A less even distribution would indicate that rectangles of some categories were reliably produced more frequently than others and, therefore, less variability. In addition to the comparisons of responding across the classes described below, we also conducted an exploratory comparison of reinforcer rate for target and alternative responses across the clusters. There was no difference in the proportion of rectangles that received points across the different classes (i.e., no main effect of class on receiving points), but participants in the rule-governed behavior class received fewer points in the alternative phase than in baseline. This analysis may be found in Appendix C.

Class 1: Resurgence

Participants in the resurgence class showed a reoccurrence of variable responding on the target dimension. Figure 3-3 shows the relative frequency distributions of rectangles in all of the possible categories of size and location (category definitions based on Ross & Neuringer, 2002; see above) for a representative participant from the Resurgence class. In the first phase, baseline, the participant emitted rectangles that were more variable along the target dimension, as evidenced by the lower relative frequencies across a higher number of categories. Rectangles were less variable for the alternative dimension; most rectangles emitted were in Categories 6-9. This pattern changed in the second phase, alternative, when variability of the alternative dimension produced points. The alternative dimension of the created rectangles became more variable and uniformly distributed across the alternative categories. The created rectangles were also less

Figure 3-3.
Relative Frequency Distributions: Resurgence Class.



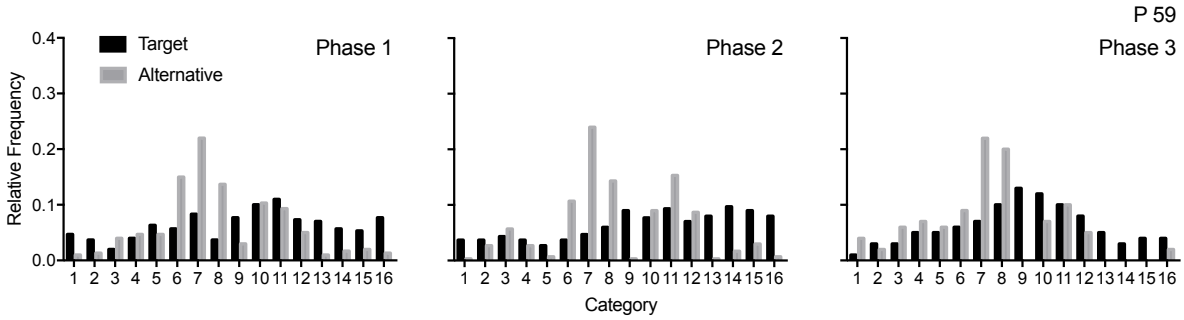
Note. Relative frequency distributions across Phases 1 (baseline), 2 (alternative), and 3 (extinction) for a representative participant (P22) from the resurgence class. This pattern of results is consistent with resurgence of reinforced behavioral variability during extinction. Category of response is shown on the x-axis and relative frequency of each category is on the y-axis. Black bars represent responding on the target dimension of behavior, and grey bars represent responding on the alternative.

variable along the target dimension, with most rectangles being in Categories 6, 7, 10, and 11. Finally, in the third phase, extinction, in which no points were delivered, variation of rectangles by the target dimension increased, but variation by the alternative dimension decreased. In other words, during extinction, we observed a reoccurrence of responding similar to that in baseline, which had previously been reinforced and then extinguished – a resurgence effect.

Class 2: Rule-Governed Behavior

Participants in the rule-governed behavior class showed relative insensitivity to the contingencies across phases of the experiment. Figure 3-4 shows relative frequency distributions of rectangles in all of the possible categories of size and location (category definitions based on Ross & Neuringer, 2002; see above) for a representative participant from this class. In baseline, the participant produced rectangles that varied along the target dimension, size, in accordance with the contingencies. However, in alternative and

Figure 3-4.
Relative Frequency Distributions: Rule-Governed Behavior Class.



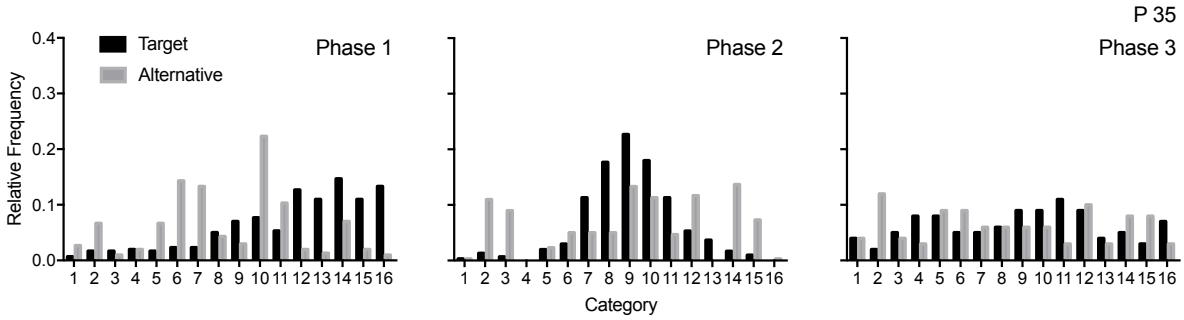
Note. Relative frequency distributions across Phases 1 (baseline), 2 (alternative), and 3 (extinction) for a representative participant (P59) from the rule-governed behavior class. This pattern of results is consistent with rule-governed behavior. Category of response is shown on the x-axis and relative frequency of each category is on the y-axis. Black bars represent responding on the target dimension of behavior, and grey bars represent responding on the alternative.

extinction, the general pattern of responding did not change, despite the change in contingencies. For example, in baseline, most rectangles were in Categories 6-8 of the 16 possible categories, by location, and this same pattern was observed in alternative and extinction. This finding shows a general insensitivity to the change in contingencies. After developing a response pattern, the participant continued to respond that way regardless of the current contingency.

Class 3: Extinction-Induced Response Variability

For participants in the extinction-induced response variability class, responding in extinction was more variable than in previous phases. Figure 3-5 shows relative frequency distributions of rectangles in all of the possible categories of size and location (category definitions based on Ross & Neuringer, 2002; see above) for a representative participant from this class. The target dimension for this participant was size and the alternative dimension was location. For this participant, we observed responding

Figure 3-5.
Relative Frequency Distributions: Extinction-Induced Response Variability Class.



Note. Relative frequency distributions across Phases 1 (baseline), 2 (alternative), and 3 (extinction) for a representative participant (P35) from the extinction-induced response variability class. This pattern of results is consistent with extinction-induced response variability. Category of response is shown on the x-axis and relative frequency of each category is on the y-axis. Black bars represent responding on the target dimension of behavior, and grey bars represent responding on the alternative.

consistent with the contingencies in place for baseline and alternative. In baseline, when variability by the target dimension, size, resulted in point delivery, the participant generally produced rectangles that varied by size but less so by location. In alternative, when variability by the alternative dimension, location, produced points, the participant generally produced rectangles that varied more by location and less by size. However, in extinction, when points were no longer delivered, behavior became more variable across both dimensions, size and location.

Class 4: Uncategorized

The final class was labeled *uncategorized*. The uncategorized class contained participants who showed nonsystematic responding. Data from participants in this class were not consistent with any of the above descriptions.

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). In the second phase, alternative, participants earned points for emitting variable rectangles along the alternative 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. In extinction, levels of variability were high across both dimensions. One explanation for these findings is that the removal of reinforcement in extinction resulted in the reoccurrence of previously extinguished variable target responding – resurgence. These data provide some evidence for resurgence of reinforced behavioral variability and may support the idea that behavioral variability is an operant.

Although the variability task we used reliably produced and maintained variable behavior (Ross & Neuringer, 2002), it may be difficult to distinguish between resurgence of reinforced behavioral variability and other phenomena. The cluster analysis we conducted identified four main patterns of responding, or classes. Data from participants in the first class supported the finding of resurgence of reinforced behavioral variability. Specifically, in baseline, when variability along the target dimension was reinforced, participants in this class 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., greater variability of the target dimension compared to the alternative dimension), a resurgence effect. However, we must consider alternative explanations to account for the behavior of participants in the other classes: rule-governed behavior, extinction-induced response variability, and uncategorized.

The behavior of participants in the rule-governed behavior class initially showed sensitivity to the programmed contingencies but failed to adjust when those contingencies were altered, indicating control by some other source (e.g., self-imposed rules; Galizio, 1979). It would certainly be possible for participants to frequently satisfy the variability contingencies used in the present experiment by using strategies other than random variation. For example, in baseline, a participant's pattern of responding may have developed involving repeatedly producing equally sized rectangles that moved systematically around the edges of the screen in the same order. If the target dimension for this participant were location, then this self-imposed rule may have been effective in producing many of the possible points. Engaging in this kind of higher-order stereotypy would not be considered stochastically variable but could still satisfy the threshold contingency, which only required a low likelihood of occurrence. Therefore, the participant may have continued to respond using the same stereotypic pattern in the next phase, even though the contingencies were reversed. If the rule they developed in the first phase were governing responding in the second phase, the participant would be unlikely to earn as many points in the second phase. After contacting the change in contingencies,

the behavior of many participants changed in order to continue to produce points most effectively, but some participants' behavior seemed to be insensitive to the contingency change. This relative insensitivity to the contingencies in place was characteristic of the patterns of responding for participants in the rule-governed behavior class.

There are numerous possible reasons that participants in the rule-governed behavior class appeared to be insensitive to the contingencies in place. One possibility is that they simply did not detect the contingency change. If we had used a more stringent threshold value, requiring higher levels of variability, or if we had added different discriminative stimuli in each phase, the change would have more salient and participants would have been more likely to adjust their behavior (e.g., Budhani & Blair, 2005; Davison & Jenkins, 1985). Another possibility is that the points used in the present study may not have been sufficiently reinforcing. If a participant was not motivated to earn points, then failing to earn points would not be enough to change their behavior. Although some research has shown that real rewards are treated similarly to hypothetical rewards (e.g., Johnson & Bickel, 2002), other research has shown that human behavior is not always easily modified using hypothetical points (e.g., Matthews et al., 1977). If our points had been exchangeable for money, for instance, our points would likely have been more reinforcing, and participants may have been even more sensitive to contingency changes.

An additional possibility is that participants' behavior was impacted by our instructions. 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.

Regardless of the reason, participants in the rule-governed behavior class seemed to be responding in accordance with contingencies other than the programmed experimental contingencies, most likely self-imposed rules. 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).

Participants in the extinction-induced response variability class behaved highly variably across both dimensions when extinction was introduced in the final phase. Importantly, patterns of responding in extinction did not closely resemble those in the baseline or alternative phases (see Figure 5). Therefore, the high levels of variability observed in extinction were likely induced by extinction, as opposed to resurgence of directly reinforced variable behavior or persistence of rule-governed behavior. Because

relapse procedures frequently rely on extinction as a disruptor (e.g., Epstein, 1985), the distinction between behavioral variability arising from reinforcement versus 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, which is why relative frequency distributions were required to reveal this pattern of responding. Relative frequency distributions can begin to distinguish, variable responding induced by extinction from reinforced behavioral variability (e.g., Neuringer et al., 2001). For example, Neuringer et al. found that relative frequency distributions during extinction resembled those during reinforcement of variability; however, responses made less frequently during reinforcement tended to be made more frequently in extinction, and vice versa. That said, further research is needed to fully address this issue and attempt to further differentiate between the contributions of reinforced behavioral variability and extinction-induced response variability.

Although the cluster analysis revealed three distinct classes with clear theoretical interpretations – resurgence of reinforced variability, rule-governed behavior, and extinction-induced response variability – the final class revealed by the cluster analysis did not have a readily apparent explanation. Some participants in this class may not have been attending to the task, therefore providing nonsystematic data, which would not be pertinent to our understanding of relapse of reinforced variability. However, it is also possible that there are sound accounts for the data from this class that we have not yet thoroughly considered. For example, for some participants in this class, absolute mean

differences were high between baseline and alternative and between baseline and extinction but were low between alternative and extinction. This result could indicate high levels of variability of the target and alternative dimensions in baseline and alternative, respectively, consistent with the contingencies in place, but minimal change from alternative to extinction. In this example, variability of the alternative dimension was not disrupted throughout extinction, even with extinction in place. Behavioral momentum theory (see Nevin & Grace, 2000) may offer a plausible explanation for the persistence of variability of the alternative dimension. However, not enough participants fit this description to produce their own unique category, so other alternatives will need to be explored in future research.

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). One attempt to address the problems associated with U-value as a measure of variability is the use of relative frequency distributions (e.g., Doughty et al., 2013; Doughty & Galizio, 2015). However, a problem with using relative frequency distributions is that it can be challenging to quantify patterns of responding. The cluster analysis reported here may serve as a viable tool for categorizing such patterns of responding to isolate different sources of observed variability (e.g., reinforcement, extinction, or rules).

Given that we used a resurgence preparation to examine relapse of reinforced behavioral variability, there are several 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 overview, 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 some 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. Relapse of reinforced behavioral variability has been demonstrated in pigeons (Galizio et al., 2018), but this will be the first published study[17] to directly examine and demonstrate relapse of variability in humans.

On a practical level, these findings may also inform applications in clinical 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

[17] An unpublished dissertation has demonstrated resurgence of reinforced behavioral variability in humans using a different preparation (Bishop, 2008).

Bishop, M. R. (2008). Resurgence of operant variability. *Unpublished dissertation, University of Nevada, Reno.*

relapse may inform both theoretical interpretations and treatment strategies in clinical settings.

The present findings support the idea that variability may be an operant dimension of behavior. However, the results also elucidate the difficulty in studying reinforced behavioral variability in a relapse preparation, due to the difficulties of parsing extinction-induced variability from relapse of reinforced behavioral variability. The results also highlight the complexity of studying reinforced behavioral variability in humans, due to the confounding factor of rule-governed behavior. This research further demonstrates the potential value of using cluster analysis to analyze and classify heterogeneous data.

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CHAPTER 4

STUDY THREE:

CHOICE FOR REINFORCED BEHAVIORAL VARIABILITY IN CHILDREN WITH AUTISM SPECTRUM DISORDER [18]

Introduction

Variable responding is sometimes functional; yet some individuals struggle to behave variably even when it would be beneficial to do so. For example, whereas children may access social reinforcement from peers by engaging in variable play behavior, individuals with autism spectrum disorder (ASD) tend to behave repetitively, interfering with these social contingencies (e.g., McConnell, 2002). The display of restricted and repetitive behavior is one of the diagnostic criteria for individuals with ASD (American Psychiatric Association [APA], 2013). Behaving repetitively in situations that call for variation is maladaptive, emphasizing the importance of interventions that increase levels of variability.

Neuringer (2002) has proposed that variability may be an operant dimension of behavior, which has implications for designing interventions to support variable responding. If behavioral variability is an operant, then variable responding can be increased and maintained by reinforcement. Thus, reinforcement-based interventions may be successful in sustaining variable behavior in typically developing individuals, as well as in individuals with ASD.

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[18] Chapter 4 of this dissertation was adapted from Galizio, A., Higbee, T. S., & Odum, A. L. (2020). Choice for reinforced behavioral variability in children with autism spectrum disorder. *Journal of the Experimental Analysis of Behavior, 113*(3), 495-514. https://doi.org/10.1002/jeab.591. See Appendix D for permission letter.

Providing reinforcement contingent on sufficiently variable responding has been shown to effectively increase behavioral variability in children in ASD (for reviews, see Rodriguez & Thompson, 2015, and Wolfe et al., 2014). Specifically, certain schedules of reinforcement, such as lag schedules, reliably result in increased levels of behavioral variability. In a lag schedule of reinforcement, a response will result in reinforcement only if it differs from a specified number of previous responses (e.g., Page & Neuringer, 1985). For example, in a lag 1 schedule, a response must differ from the immediately previous response to produce reinforcement. Lag schedules are relatively easy to implement in applied settings and have been used successfully in a number of studies examining behavioral variability in children with ASD (Wolfe et al., 2014).

Lag schedules (as well as other variability schedules, such as percentile schedules [e.g., Miller & Neuringer, 2000] and differential reinforcement of novel responses [e.g., Betz et al., 2011], among others) have frequently been used to increase behavioral variability in individuals with ASD. Miller and Neuringer (2000) reinforced behavioral variability of an arbitrary response, button pressing, in individuals with ASD. Additionally, variability schedules have been used to increase behavioral variability of socially significant behaviors, such as verbal behavior. Researchers have investigated reinforced behavioral variability in phonemes (Esch et al., 2009), intraverbal responses (Contreras & Betz, 2016), mands (Brodhead et al., 2016; Sellers et al., 2016), and conversations (Lee et al., 2002; Lee & Sturmey, 2006, 2014). Reinforced behavioral variability has also been demonstrated in other important behaviors, such as play (Baruni et al., 2014; Napolitano et al., 2010). The present study is focused on increasing behavioral variability in play behavior, using playsets and figurines.

In addition to maintenance by contingent reinforcement, operant behavior can be brought under discriminative stimulus control. Likewise, behavioral variability can be controlled by environmental stimuli. Discriminative stimuli can be used to indicate whether variable or repetitive behavior will be reinforced at any given time. Such discriminative control of operant variability has been demonstrated in pigeons (Page & Neuringer, 1985; Ward et al., 2008), rats (Denney & Neuringer, 2006), and children with ASD (Brodhead et al., 2016).

In situations where distinct discriminative stimuli clearly indicate whether variable or repetitive responding will be reinforced, it is possible to assess preference across the two alternatives. A common method of assessing choice is a concurrent chains schedules of reinforcement (e.g., Squires & Fantino, 1971). In a concurrent chains schedule, subjects are first exposed to two response options (i.e., initial links), available concurrently. Responding to one of these initial links will produce one outcome, or terminal link, whereas responding to the other initial link will produce the other terminal link. Responding for each initial link is taken as a measure of preference for the conditions in one terminal link over the other. To assess preference for reinforcement of behavioral variability or repetition, a concurrent chains schedule can be arranged such that one terminal link requires variable responding and the other terminal link requires repetitive responding to produce reinforcement. If a subject responds more to the initial link that leads to the variability terminal link than to the initial link leading to the repetition terminal link, then it can be inferred that the subject would prefer to respond according to the variability contingency than the repetition contingency.

Several studies have been conducted to assess choice between responding on a variability schedule and responding on a repetition schedule using a concurrent chains preparation. Abreu-Rodrigues et al. (2005) arranged a concurrent chains schedule in which pigeons could choose to experience either a terminal link that required variable responding to produce food or a terminal link that required repetitive responding to produce food. In this study, pigeons generally preferred to respond on a lag schedule, as long as the lag schedule was relatively lenient (e.g., lag 1). However, as the lag requirement increased (up to lag 10), preference shifted to the alternative requiring repetitive responding. Similar results were found when the effects of different lag requirements were compared, such that more lenient lag requirements were preferred more than stricter requirements (Pontes et al., 2012). Importantly, this effect holds true even when reinforcer rates are equated across the two alternatives, meaning that a preference for one alternative over the other cannot be explained by rate of reinforcement (e.g., Arantes et al., 2012). Data from these studies suggest that, all else being equal, pigeons would prefer to behave variably than repetitively, but only when the variability requirement is lenient. Comparable results have also been found in college students (Abreu-Rodrigues et al., 2017; Abreu-Rodrigues et al., 2007).

The finding that reinforcement for variable responding is often preferred over reinforcement for repetitive responding, all else being equal, is consistent with previous research showing that organisms tend to show a preference for variability. For example, when given the choice between responding on a fixed-ratio (FR) or variable-ratio (VR) schedule, pigeons typically prefer to experience the VR schedule (e.g., Field et al., 1996; Herrnstein, 1964; Mazur, 1986; Sherman & Thomas, 1968). Even if the average response

requirement is similar for both schedules, or even higher for the VR schedule, pigeons more often choose to respond on the VR schedule, in which the current response requirement is unpredictable.

Although the available evidence suggests that humans and pigeons would generally prefer to vary than repeat, as long as the lag requirement is not overly strict (e.g., Abreu-Rodrigues et al., 2005), this finding has not yet been extended to clinical populations. For individuals who tend to behave too repetitively, such as individuals with ASD, it would be important to determine whether a general preference for reinforcement of behavioral variability over repetition still applies. It is unclear whether the repetitive responding often observed in individuals with ASD occurs because of a preference for reinforcement of repetitive behavior or because they simply have not yet learned how to vary their behavior.

The purpose of the present study was two-fold: (1) to teach children with ASD who played repetitively to play variably using a lag schedule of reinforcement and then (2) to assess choice between variability and repetition of play behavior. Specifically, we provided reinforcement for variable play behavior in the presence of stimuli of one color and for repetitive play behavior in the presence of stimuli of another color. If, after being taught to play variably, individuals with ASD still prefer repetition, then it would be useful to design future clinical interventions that would shift preference and encourage variable behavior instead (cf. Neuringer, 1992). If, however, after being taught to play variably, individuals with ASD prefer to vary, as has been shown in other populations, clinical interventions could instead be focused simply on teaching variable behavior. Determining under what conditions children with ASD will choose to play variably or

repetitively could inform clinicians on the most effective interventions to promote variability.

Method

Participants

Participants included 3 male preschoolers aged 3-5 years with a diagnosis of ASD. Participants were recruited through the Autism Support Services: Education, Research, and Training (ASSERT) preschool, and all participants were students currently enrolled at the ASSERT preschool receiving 20 hours of early intensive behavioral intervention (EIBI) per week. Criteria for inclusion included a formal diagnosis of ASD, motivation to respond for edible reinforcers, and tolerance of physical prompts, determined through diagnostic assessments and caregiver and clinician reports. Further, participants were included if they already engaged in some play behavior but not in variable play behavior. This final criterion was determined through several inclusion assessment sessions (see Procedure). Participant characteristics for Jason, Cole, and Bruce (pseudonyms) are outlined in Table 4-1.

Table 4-1.
Participant Characteristics.

Participant	Age	Time in EIBI	VB-MAPP Level 1	VB-MAPP Level 2	VB-MAPP Level 3
Jason	3.50 years	4 months	11.0	0.00	0.00
Cole	3.25 years	3 months	18.0	0.00	0.00
Bruce	4.50 years	14 months	45.0	50.5	14.5

Note. Includes age in years at the start of the experiment, total amount of time spent in EIBI at ASSERT in months at the start of the experiment, and Verbal Behavior Milestones Assessment and Placement Program (VB-MAPP; Sundberg, 2008) scores for Level 1, 2, and 3 at the start of the experiment.

Setting and Materials

All sessions took place in a small research room, containing a small table and two chairs, as well as edible reinforcers, playsets, colored cards, colored bracelets, a timer, and a video camera. Each playset consisted of a large three-dimensional background and four corresponding figurines. We used five different playsets (castle, farm, fire station, house, and vet office; see Table 4-2 for details). Red and blue cards and bracelets were used as discriminative stimuli. Cards were attached to the outside of the door into the research room using Velcro. Bracelets were hung on the wall directly inside the room. Edibles and playsets for each participant were determined using preference assessments (see Procedure).

Dependent Measures and Data Collection[19]

Our primary dependent measure was the number of appropriate play actions emitted in a session, independent and prompted, which was used to calculate response rates (total appropriate play actions per min). In addition, we recorded the number of reinforcers delivered by the experimenter, which was used to calculate reinforcer rates (total reinforcers per min). We also measured how many of these actions would have met a lag 1 schedule and how many novel (different) actions were emitted per session and across all sessions. Finally, we measured the number of selections for variability or repetition in choice sessions. Our operational definitions are outlined below and were based on previous research in our lab.

[19] One commonly used measure of behavioral variability is U-value, which quantifies the distribution of responses across all possible response options (see Page & Neuringer, 1985). However, calculation of U-value requires a finite number of possible sequences. It would be exceedingly difficult to specify all possible responses our participants could make (e.g., any figurine making any movement in any location). For this reason, it is not used in the present study.

Table 4-2.

Playsets, Figurines, and Pictures.

Playset	Figurines	Picture
Castle	king, knight, princess, horse	
Farm	boy farmer, girl farmer, cow, sheep	
Fire Station	fireman with black hat, fireman with yellow hat, firewoman, cat	
House	mom, dad, baby, dog	
Vet Office	vet, girl, giraffe, zebra	

Appropriate play actions were defined as any movement (e.g., walking) of a figurine (e.g., princess) making physical contact with a location on the playset (e.g., castle drawbridge).[20] To meet this definition, the participant needed to hold a figurine and move his hand and the figurine together. Each play action was identified by three components: the figurine used, the movement made, and the location on the playset. For example, the participant making the princess walk across the drawbridge would be an appropriate play action. However, the participant making the princess walk on the table next to the playset would not be an appropriate play action, because the figurine did not contact a location on the playset. One exception would be if the participant moved two figurines together without touching the playset. For this action to meet our criteria, each figurine would need to be held in a different hand and would need to make physical contact while moving. For example, the participant could make the horse walk on the table with one hand and make the princess sit on the horse with the other hand while it was moving. An additional exception to this definition involved the movement component of the action. Simply placing the figurine on the playset did not meet the requirements, because the participant's hand and the figurine were not moving together. However, dropping the figurine through a hole or down a slide on the playset was considered appropriate. An appropriate play action ended when the figurine stopped moving for more than 1 s, when the figurine moved to a new location on the playset,

[20] Operational definitions for appropriate play actions were based on previous research in our lab, specifically two unpublished dissertations.

Contreras, B. P. (2017). Evaluation of multiple exemplar training plus discrimination training to promote generalization of response variability. *Unpublished dissertation, Utah State University.*

Harris, M. K. E. (2016). An analysis of variability of play behavior with preschool children with autism. *Unpublished dissertation, Utah State University.*

when the figurine no longer made physical contact with the playset, or when the figurine no longer made physical contact with the participant's hand.

Data collectors viewed a video recording of each session and recorded every appropriate play action that occurred. For each action, data collectors recorded the timestamp at the end of the action, the figurine used, the movement made, and the location on the playset (or other figurine). Data collectors agreed on labels for common movements (e.g., if the figurine was tapped more than once on the playset, the movement was considered "walk," but if the figurine was tapped more than once but was moved >2 in away from the playset between taps, the movement was considered "jump") and boundaries for locations on the playset. For each action the data collectors also recorded whether the action was independent or prompted. The action was considered independent unless the experimenter's hand made physical contact with the participant during the play action. If the experimenter's hand directed any part of the play action (i.e., selection of the figurine, movement of the figurine, or selection of location), the action was considered prompted (P). The only exception was if the experimenter touched the participant's elbow or shoulder but did not direct any part of the play action. In other words, the experimenter provided a prompt to engage with the playset, but did not direct the selection of the figurine, the movement of the figurine, or selection of location. This kind of prompt was considered a prompt to action and was recorded as a P+ and considered independent for all calculations. Additionally, data collectors recorded whether reinforcement was delivered for every play action. Reinforcement consisted of a brief praise statement (e.g., "Good job!") and delivery of a small edible item, identified prior to each session by a preference assessment; see below).

To measure response variability, data collectors also recorded whether each play action would have met a lag 1 schedule and whether it was novel. The action was considered to have *met the lag 1 schedule* if it differed from the immediately previous action in every way. That is, the action must have been different in terms of the figurine, movement, and location to be counted. We required that all aspects of the action differ from the previous action to increase discriminability between the vary and repeat conditions (see below). The first action of the session could not be considered for meeting a lag 1 because there was no prior action to compare to, and the first action of the session was always reinforced. The action was considered to be *novel* if it was different than every prior independent action in that session in at least one way. Only independent actions could be considered novel. See Table 4-3 for an example series of independent appropriate play actions and whether they would be considered to meet the lag 1 or would be considered novel within the session.

Table 4-3.
Five Example Independent Appropriate Play Actions Completed with the Castle.

	Figurine	Movement	Location	Lag 1	Novel
1	Princess	Walk	Drawbridge	NA (first)	Yes
2	King	Launch	Catapult	Yes	Yes
3	Princess	Walk	Drawbridge	Yes	No
4	Horse	Walk	Grass	No	Yes
5	Princess	Jump	Drawbridge	Yes	Yes

Note. Includes whether each action would have met a lag 1 schedule and whether it would have been considered novel.

Finally, the primary data collector recorded the cumulative number of novel responses across the experiment for each participant. In other words, the first occurrence of a specific play action would be scored as novel for that session and added to the

cumulative number of novel responses. If that same play action occurred in the next session, it would be scored as novel for that session, but would not be added to the cumulative number of novel responses because it had already occurred once during the experiment.

Inter-Observer Agreement

We collected inter-observer agreement (IOA) data for at least 33% of all sessions across all conditions for each participant. We calculated point-by-point IOA by comparing the lists of appropriate play actions from both data collectors. We scored agreements if both data collectors recorded the same timestamp (within 3 s), figure, movement, location, independent/prompted, reinforcer delivered or not, met lag 1 or not, and novel or not. Any discrepancies were scored as disagreements. We then divided the number of agreements by the number of agreements and disagreements and multiplied by 100 to yield a percentage of agreement for each session. Across all conditions and phases, Jason's average IOA was 95.7%, Cole's average IOA was 92.0%, and Bruce's average IOA was 89.6%. Table 4-4 shows average (and range) IOA for each condition, phase, and participant.

Experimental Design

Following our initial inclusion and preference assessments, the experiment consisted of three phases: baseline, discrimination training, and choice. We employed a multi-element design embedded within a non-concurrent multiple-baseline design. To assess preference during the choice phase, we used a concurrent chains schedule.

Table 4-4.
Inter-Observer Agreement (IOA) and Treatment Integrity (TI) Across Conditions and Participants.

Participant	Phase	Condition	IOA	TI
Jason	BL	Vary	100% (100%-100%)	100% (100%-100%)
		Repeat	100% (100%-100%)	100% (100%-100%)
	DT	Vary	90.9% (67%-100%)	97.3% (90%-100%)
		Repeat	98.4% (96%-100%)	99.4% (90%-100%)
	Choice	Vary	95.3% (90%-100%)	100% (100%-100%)
		Repeat	98.3% (94%-100%)	100% (100%-100%)
	Overall	Vary	92.6% (67%-100%)	98.1% (90%-100%)
		Repeat	98.5% (94%-100%)	99.6% (90%-100%)
Cole	BL	Vary	69.5% (55%-75%)	100% (100%-100%)
		Repeat	79.0% (68%-90%)	100% (100%-100%)
	DT	Vary	94.1% (86%-100%)	95.3% (80%-100%)
		Repeat	97.6% (93%-100%)	100% (100%-100%)
	Choice	Vary	91.8% (88%-95%)	92.5% (80%-100%)
		Repeat	98.8% (97%-100%)	100% (100%-100%)
	Overall	Vary	89.4% (55%-100%)	95.7% (80%-100%)
		Repeat	94.6% (68%-100%)	100% (100%-100%)
Bruce	BL	Vary	71.0% (43%-85%)	100% (100%-100%)
		Repeat	81.0% (49%-100%)	100% (100%-100%)
	DT	Vary	92.9% (82%-98%)	88.6% (80%-100%)
		Repeat	99.4% (98%-100%)	100% (100%-100%)
	Choice	Vary	95.3% (89%-99%)	95.0% (90%-100%)
		Repeat	94.8% (89%-100%)	100% (100%-100%)
	Overall	Vary	86.6% (43%-99%)	93.8% (80%-100%)
		Repeat	92.5% (49%-100%)	100% (100%-100%)

Note. Mean and range are displayed.

Procedure

Inclusion Assessments

We conducted three 5-min inclusion assessments with potential participants. In these play sessions, individuals were instructed to "go play" with a playset and figurines (e.g., playground). The playsets used in the inclusion assessments were not the same as the ones used in the actual experiment. No programmed consequences occurred during this session. Participants were included if they touched the playset at least once per

session and if they emitted 10 or fewer independent appropriate responses that would have met a lag 1 schedule.

Paired-Stimulus Preference Assessments

We next identified two playsets for each participant by conducting a 5-item paired-stimulus preference assessment (see procedures described by Fisher et al., 1992). We used two similarly ranked playsets for each participant. For Jason and Cole, the top two preferred playsets were ranked approximately equally. For Bruce, the highest preferred playset was selected almost exclusively when present, so we instead used the second and third most preferred playsets, which were ranked similarly. Each of the two playsets was randomly assigned to either the vary or repeat condition (see below). For Jason, the Fire Station (selected on 63% of opportunities) was used as the vary playset, and the Castle (selected on 75% of opportunities) was used as the repeat playset. For Cole, the Vet Office (63%) was used as the vary playset, and the House (75%) was used as the repeat playset. For Bruce, the Fire Station (50%) was used as the vary playset, and the Castle (50%) was used as the repeat playset.

Lastly, before beginning any experimental sessions, we conducted a paired-stimulus preference assessment with the colored cards that would be used throughout the study to determine whether there was any color bias. Each trial consisted of the instructor placing the two colored cards in front of the participant and saying “Pick one.” After a selection was made, the instructor gave a neutral statement (e.g., “Okay.”) and removed the cards. Ten trials were interspersed throughout the child’s typical instructional session. If the participant selected either color on >60% of trials, the session was repeated the following day to determine whether the bias was stable over time. Jason selected red over

blue on 60% of trials across 2 days, Cole selected red over blue on 50% of trials across 2 days, and Bruce selected red over blue on 40% of trials across 1 day. These data indicate that none of the participants had a bias for either red or blue.

Baseline

Each weekday, we conducted up to six 5-min sessions with each participant. Sessions were separated by at least 5 min. Before the session, the experimenter placed one of the two playsets and corresponding figurines on the table in the research room. During baseline, a yellow card was attached to the door outside of the room, and a yellow bracelet was attached to the wall immediately inside the room. The playset used in each session was randomized, with the constraint that no more than two sessions with the same playset were run consecutively. During baseline sessions, the participant approached the door to the research room and completed an observing response. To complete the observing response, the participant took the yellow card off of the door, opened the door, carried the card inside the room, approached the bracelet attached to the wall, placed the yellow card above the yellow bracelet, took the bracelet from the wall, and put the bracelet on his wrist. The experimenter physically prompted the participant to complete all of these steps if necessary. The experimenter then started a timer, gave the instruction, "Go play," and prompted the child to sit down.

There were no programmed consequences for playing during baseline. If the participant attempted to talk to or approach the experimenter, the experimenter redirected them to sit back down. If the participant dropped a figurine on the floor or knocked over the playset, the experimenter returned the items to the table. If the participant engaged in any challenging behavior, the experimenter either ignored or blocked, depending on the

type of behavior and the participant's behavior plan (e.g., the experimenter ignored crying but blocked self-injurious behavior). The experimenter terminated the session by saying, "All done," after 5 min, if the child was engaging in challenging behavior that posed a danger to himself or the experimenter (which never occurred), or if the child requested to use the bathroom (which occurred twice for Bruce). When terminating a session early, we used the data if more than half of the session had been completed (which occurred once) and we discarded the data if less than half of the session had been completed (which occurred once).

Stability. A minimum of five baseline sessions was conducted with each playset, and sessions continued until response rates and the proportion of responses that would have met a lag 1 schedule reached stability, which was assessed through visual inspection of trend and variance for the final five sessions with each playset.

Discrimination Training

Sessions during discrimination training were similar to those in baseline, with a few key differences. First, we determined the edible reinforcers that would be used in each session using a one-trial multiple-stimulus-without-replacement (MSWO) preference assessment (Carr et al., 2000). After the MSWO, the experimenter led the child to the door of the research room to complete the observing response, as in baseline. Second, whereas a yellow card was attached to the door in baseline, in discrimination training the card was either red or blue, depending on the condition. Third, two bracelets were hanging on the wall inside the room – one red and one blue. The child was prompted to place the card above the matching colored bracelet and then to put on the bracelet. The session then began with the instruction, "Go play," as in baseline. There

were two conditions of discrimination training sessions – vary and repeat. Vary and repeat sessions were alternated randomly, with the constraint that there were no more than two consecutive sessions of the same condition.

Vary. In the vary condition, the assigned vary playset was always used, the colored card and bracelet were blue, and play was reinforced on a lag 1 schedule. In every session, the first appropriate play action was always reinforced. Reinforcement consisted of the experimenter providing a small piece of the selected edible item and giving a brief praise statement (e.g., "Good job!"). Reinforcement was delivered within 3 s of the child completing a play action. Subsequent appropriate play actions were reinforced only if they satisfied the lag 1 schedule. That is, a play action was reinforced if it differed from the immediately previous play action in every respect – figurine, movement, and location. If the participant emitted a play action that did not meet the lag 1 schedule, the experimenter ignored the action and then physically prompted an action that would meet the lag 1 schedule. The prompted play action was then reinforced and another play action that would meet the lag 1 schedule was prompted and reinforced. After two prompted play actions that met the lag 1 schedule, the experimenter waited for the participant to complete a play action independently. If the participant did not emit an appropriate play action within 10 s of consuming the previous reinforcer, the experimenter prompted two play actions that would meet the lag 1 schedule. Throughout each session, physical prompting was faded using most-to-least fading. The fading steps were hand-over-hand, from the wrist, from the forearm, from the elbow, a tap on the elbow, and a tap on the shoulder. At least two prompts were completed at each level before moving to the next. If the participant resisted the prompt or attempted to complete

an action that would not meet the lag 1 schedule during the prompt, the experimenter moved to a more intrusive prompt level until the participant was responsive to physical prompts. To determine whether a response met the lag 1 schedule, the response was compared with the immediately previous response, regardless of whether the previous response was independent or prompted.

Repeat. In the repeat condition, the assigned repeat playset was always used, the colored card and bracelet were red, and play was reinforced on a repetition schedule. Appropriate play actions were reinforced only if they were identical to the first action of the session in every respect – figurine, movement, and location. Reinforcement and prompting details were the same as in the vary condition.

Stability. A minimum of ten discrimination training sessions was conducted with each condition. Responding was considered stable when a number of criteria were satisfied. First, the percentage of appropriate play actions emitted independently (as opposed to prompted) needed to be 80% or higher for five consecutive sessions of each condition (after 100 sessions, this criterion changed to four out of the final five sessions completed at least 80% independently; this modification was only applied for Cole). Second, responding needed to be differentiated across conditions in terms of the proportion of responses that would have met a lag 1 schedule and the number of novel responses, defined as no overlap across conditions for the final five sessions of each condition. Finally, response rates and the proportion of responses that would have met a lag 1 schedule needed to reach stability, which was assessed through visual inspection of trend and variance for the final five sessions of each condition.

Choice

After stability was reached in the discrimination training phase, participants were presented with choices in a concurrent chains paradigm. In choice sessions, both colored cards, red and blue, were placed on the door and the playsets were not set up in advance. During the initial link, the observing response was the same as in previous conditions, except that the experimenter physically stopped the participant in front of the two cards and gave the instruction, "Pick one." After the participant selected and removed one of the cards, the experimenter brought the corresponding playset into the research room and set it up while helping the participant complete the observing response as needed. During the terminal link, sessions were identical to discrimination training sessions, but the condition for the session was determined by the participant's selection in the initial link. After ten choice sessions, two discrimination training sessions (one of each condition; i.e., forced choice) were conducted to ensure exposure to both conditions if exclusive preference developed. Finally, ten more choice sessions were conducted.

Treatment Integrity

We assessed treatment integrity (TI) of implementation of the procedures for at least 33% of all sessions across all conditions for each participant. For each session, we scored the following treatment components: whether the experimenter (1) set up the session correctly (correct cards, bracelets, and playsets, depending on the condition), (2) conducted the MSWO with edible items correctly (or did not conduct the MSWO if baseline), (3) prompted the observing response correctly, (4) began the session with the instruction "go play" and ended with "all done" after 5 min, (5) delivered every reinforcer by providing a small piece of the selected edible and a brief praise statement

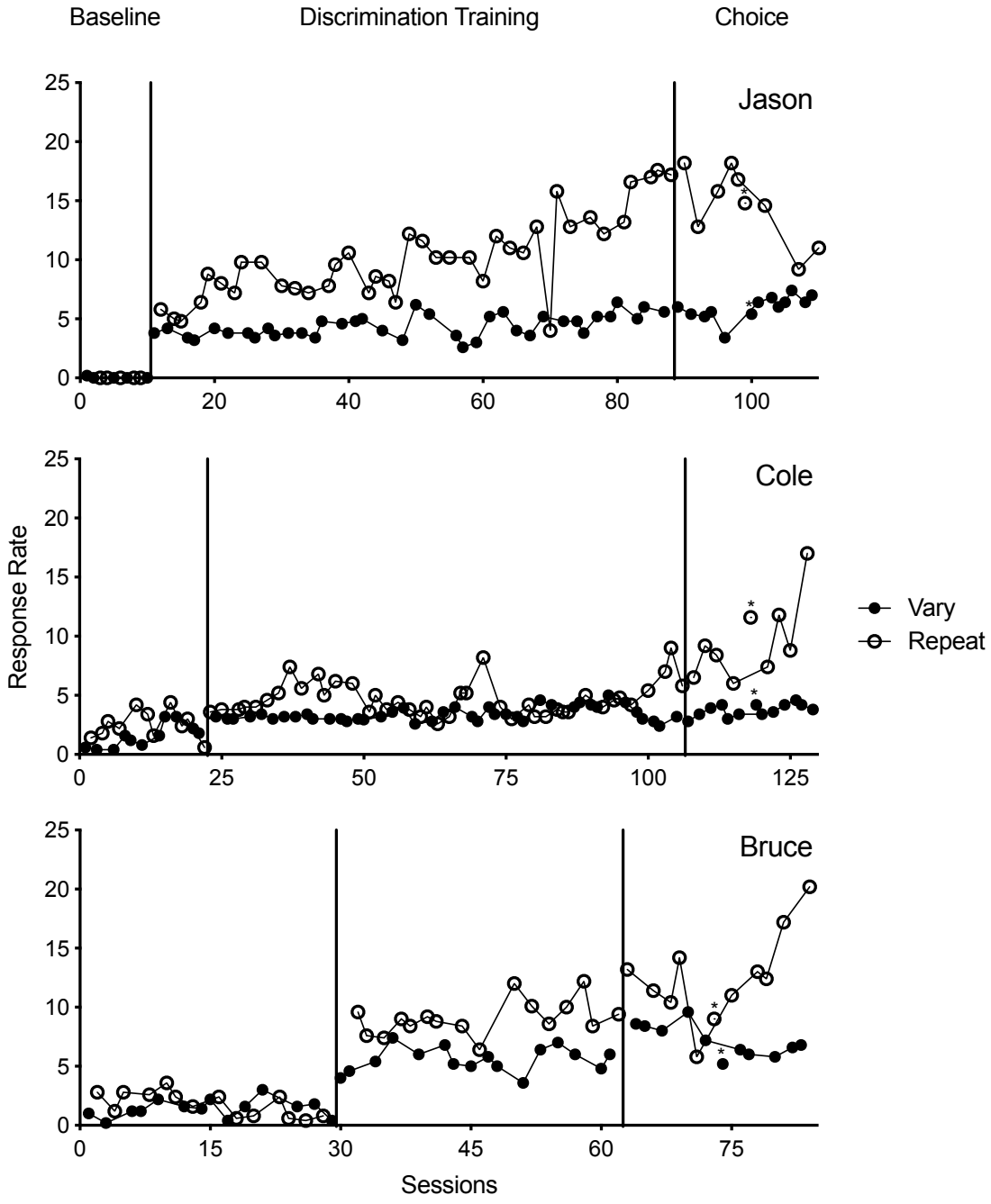
(or did not deliver reinforcement if baseline), (6) delivered reinforcement for every prompted or independent play action that met the appropriate contingency and did not deliver reinforcement for play actions that did not meet the appropriate contingency (or if baseline), (7) provided prompts when the participant was nonresponsive for 10 s and provided prompts when the participant emitted a play action that did not meet the appropriate contingency (or provided no prompts if baseline), (8) provided no unnecessary prompts, (9) provided prompts that met the appropriate contingency according to the condition (or provided no prompts in baseline), and (10) ignored or blocked challenging behaviors if needed. If the experimenter implemented a component of the procedure correctly at every opportunity throughout the session, that component was scored as correct. If the experimenter implemented any component of the procedure incorrectly at any time during the session, that component was scored as incorrect. We then divided the number of components implemented correctly by the total number of components and multiplied by 100 to yield a percentage of correct implementation for each session. Across all conditions and phases, Jason's average TI for each session was 98.9%, Cole's average TI was 97.8%, and Bruce's average TI was 96.9%. Table 4-4 shows average (and range) TI for sessions within each condition, phase, and participant. We collected IOA for at least 33% of sessions for which TI was scored (average = 99%; range = 89%-100%).

Results

Response and Reinforcer Rates

Figure 4-1 shows response rates for the vary and repeat conditions across sessions for Jason, Cole, and Bruce. In baseline, response rates were low (fewer than five

Figure 4-1.
Response Rates.



Note. Response rates (appropriate play actions per min) across sessions. Closed and open circles represent response rates for the vary and repeat conditions, respectively, in each phase (although the contingencies were not yet in place during baseline, the closed and open circles indicate sessions with the playsets that would later be used in vary and repeat sessions). Asterisks indicate the two forced-choice sessions during the choice phase. Note that the x-axis (sessions) is scaled differently across participants.

appropriate play actions per min) and undifferentiated across playsets for all participants. In discrimination training, response rates increased for all participants. For Jason, response rates increased for the vary condition and remained relatively constant throughout the phase. For the repeat condition, Jason's response rates increased steadily throughout the phase. For Cole, response rates increased slightly from baseline for both conditions and remained relatively constant throughout the phase. Bruce's response rates also increased and remained relatively stable for both conditions during discrimination training. During choice, response rates generally remained stable compared to discrimination training, with a few exceptions. Jason's response rates decreased but remained in the same range as in discrimination training, for the repeat condition during choice. Additionally, response rates increased dramatically for the repeat condition throughout the choice phase for Cole and Bruce. Response rates for the repeat condition were generally equal to or higher than the vary condition for all participants during discrimination training and choice. Table 4-5 displays descriptive statistics (mean and standard deviation) for response and reinforcer rates across conditions, phases, and participants. Reinforcer rates were identical to, or only slightly lower than, response rates during discrimination training and choice for all participants.

Proportion Independent

Figure 4-2 shows the proportion of appropriate play actions that were emitted independently (unprompted or prompted only with a tap on the elbow or shoulder) for the vary and repeat conditions across the discrimination training and choice phases for Jason, Cole, and Bruce. In baseline, all actions were independent because the experimenter was not yet prompting responses, so proportion independent data are not shown for that phase

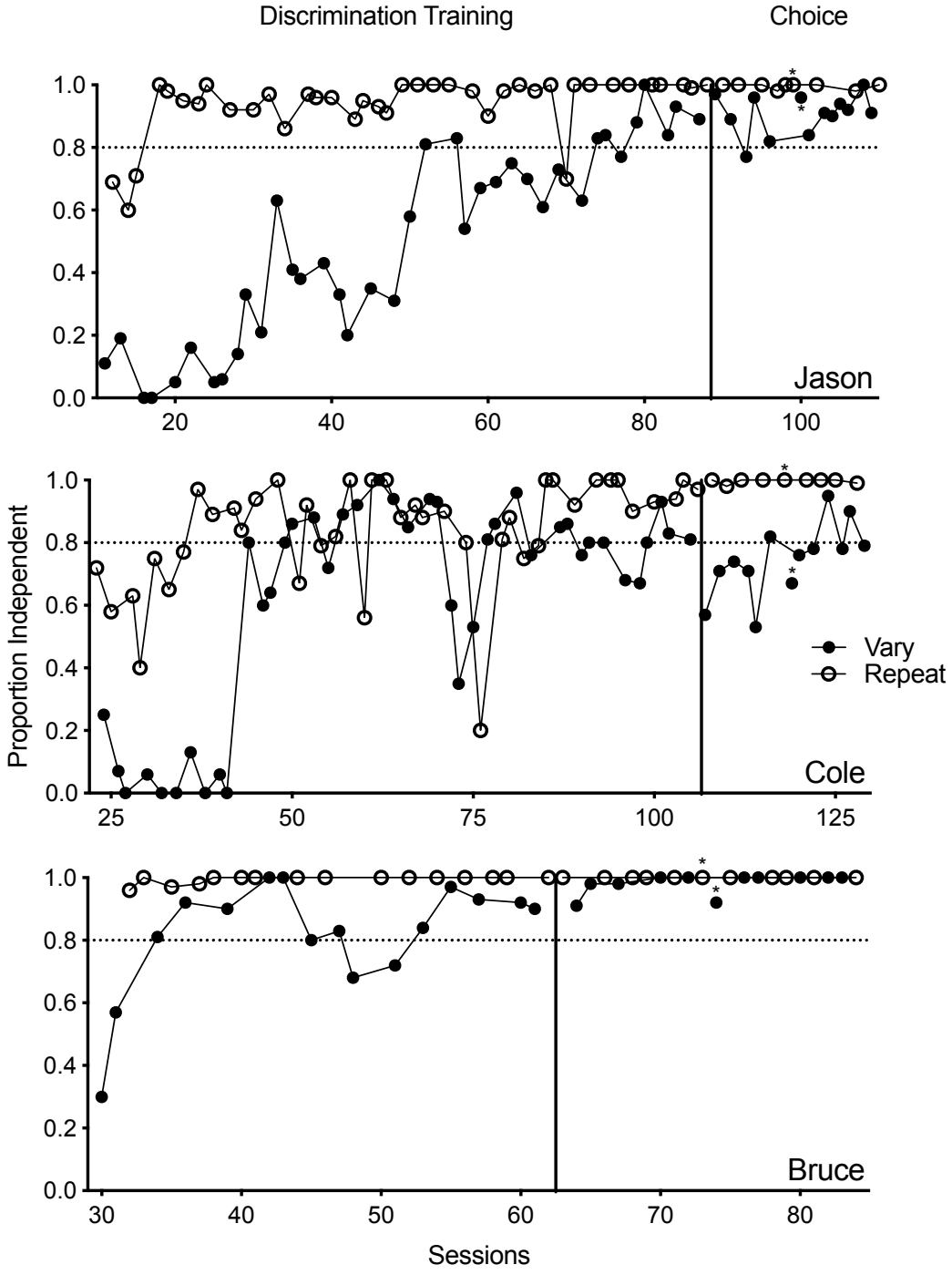
Table 4-5.
Response Rate (RR), Reinforcer Rate (SRR), Proportion of Independent Appropriate Play Actions That Would Have Met a Lag Schedule (Lag), and Number of Novel Independent Appropriate Play Actions per Session (Novel) Across Conditions and Participants.

Participant	Phase	Condition	RR	SRR	Lag	Novel
Jason	BL	Vary	0.04 (0.09)	0.00 (0.00)	0.00 (0.00)	0.20 (0.45)
		Repeat	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	DT	Vary	4.40 (0.95)	4.27 (0.93)	0.82 (0.29)	3.82 (2.10)
		Repeat	10.26 (3.57)	10.24 (3.58)	0.00 (0.00)	1.13 (0.40)
	Choice	Vary	6.00 (1.04)	5.83 (1.05)	0.97 (0.03)	5.17 (0.83)
		Repeat	14.58 (3.33)	14.58 (3.33)	0.00 (0.00)	1.00 (0.00)
Cole	BL	Vary	1.55 (1.01)	0.00 (0.00)	0.13 (0.16)	5.73 (4.10)
		Repeat	2.53 (1.18)	0.00 (0.00)	0.04 (0.05)	6.27 (3.69)
	DT	Vary	3.42 (0.60)	3.33 (0.59)	0.78 (0.34)	6.95 (4.38)
		Repeat	4.84 (1.76)	4.84 (1.76)	0.00 (0.00)	1.02 (0.15)
	Choice	Vary	3.71 (0.54)	3.48 (0.45)	0.89 (0.11)	9.42 (2.43)
		Repeat	9.39 (3.56)	9.40 (3.53)	0.00 (0.00)	1.13 (0.35)
Bruce	BL	Vary	1.14 (0.77)	0.00 (0.00)	0.10 (0.11)	6.07 (3.25)
		Repeat	1.79 (1.05)	0.00 (0.00)	0.34 (0.32)	6.64 (3.37)
	DT	Vary	5.54 (1.03)	5.18 (1.19)	0.87 (0.13)	12.59 (4.46)
		Repeat	9.09 (1.47)	9.04 (1.47)	0.00 (0.00)	1.12 (0.49)
	Choice	Vary	7.34 (1.25)	7.02 (1.17)	0.95 (0.05)	7.20 (2.94)
		Repeat	12.88 (3.89)	12.88 (3.89)	0.00 (0.00)	1.00 (0.00)

Note. Mean and standard deviation are displayed.

(absolute response rates, however, are reported in Figure 4-1). In discrimination training, proportion independent responding increased for all participants. In all cases, independent responding in the repeat condition was acquired much more quickly than in the vary condition, but proportion independent responding was similar (i.e., 0.8 or greater) for both conditions by the end of the phase due to our stability criteria. For Jason and Bruce, independent responding remained high for both conditions in choice. However, independent responding was disrupted by the introduction of choice in the vary condition for Cole, though by the end of the choice phase, independent responding did once again increase to levels observed at the end of discrimination training.

Figure 4-2.
Proportion of Appropriate Play Actions Completed Independently.



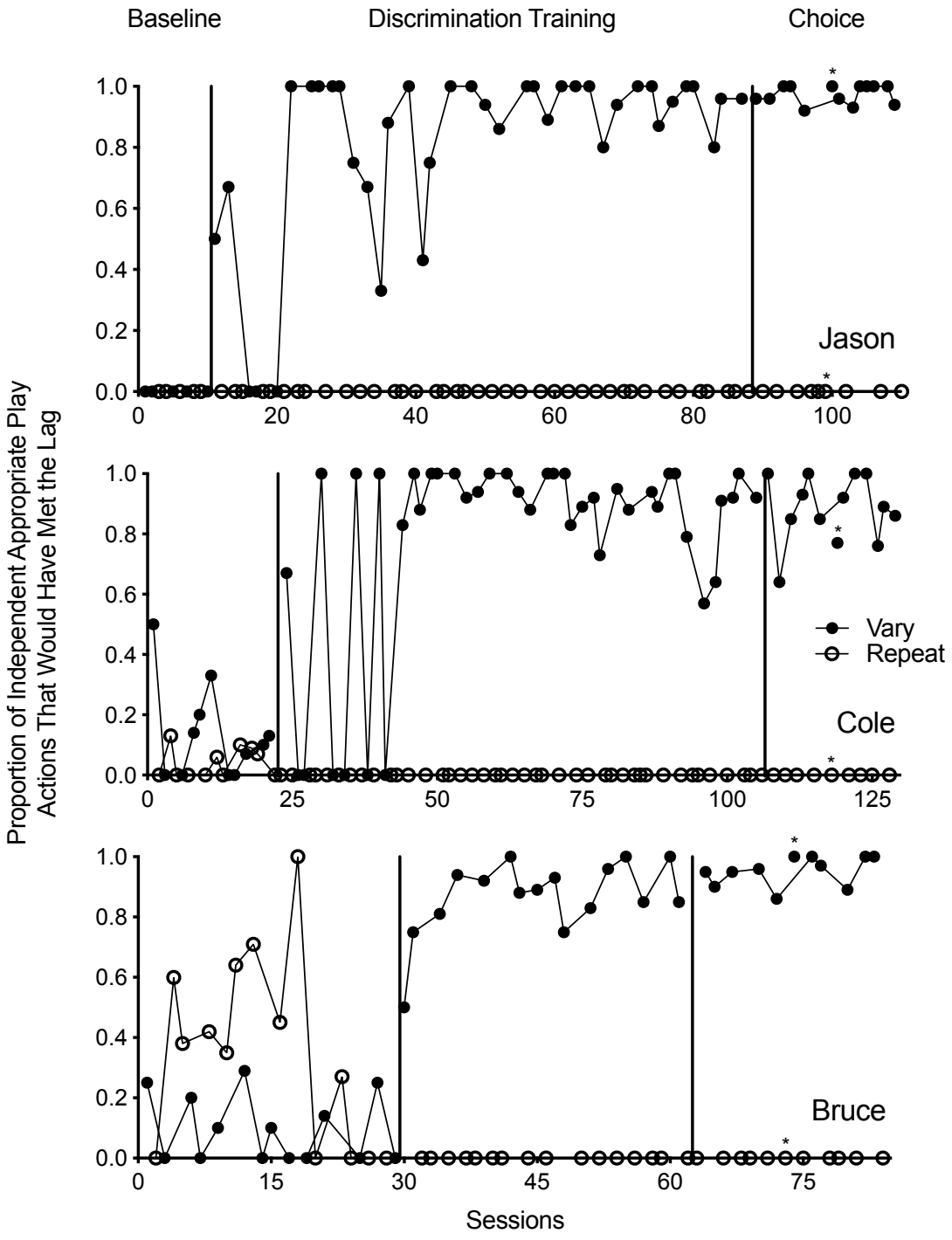
Note. Prompted responses are not included in this figure. Closed and open circles represent the proportion independent for the vary and repeat conditions, respectively, in each phase. Because all responses during baseline were necessarily completed independently, this condition is not included in the graph. Asterisks indicate the two forced-choice sessions during the choice phase. The horizontal dotted line is placed at 0.8, which was a criterion for determining stability. Note that the x-axis (sessions) is scaled differently across participants.

Proportion Meeting Lag

Figure 4-3 shows the proportion of independent appropriate play actions that would have met a lag 1 schedule of reinforcement for the vary and repeat conditions across sessions for Jason, Cole, and Bruce. Prompted actions were not included in this measure. In baseline, the proportion of play actions that would have met the lag was low for Jason, and highly variable for Cole and Bruce[21]. However, by the end of baseline, the proportion of play actions that would have met the lag was low and undifferentiated across playsets for all participants. Throughout discrimination training, no responses would have met a lag schedule in the repeat condition for all participants, indicating very low levels of behavioral variability as expected due to the repetition contingency in place. Conversely, for the vary condition, the proportion of play actions meeting the lag schedule increased throughout discrimination training for all participants, indicating increases in behavioral variability as a result of the implementation of the lag schedule. The proportion of play actions that would have met a lag schedule remained relatively stable throughout the choice phase for all conditions and participants. Differentiation in this measure across conditions indicates that participants were generally sensitive to the contingencies in place: They behaved highly repetitively when a repetition contingency was in place and highly variably when the lag schedule was in place. Table 4-5 displays descriptive statistics (mean and standard deviation) for the proportion of independent

[21] The wide variation in terms of the proportion of sequences that would have met a lag schedule during baseline is interesting, because there were no contingencies on the level of behavioral variability during this phase. There are several potential explanations for the occasionally high levels of behavioral variability during baseline. First, when presented with novel stimuli, organisms tend to engage in exploratory behavior, which could account for high levels of variability. Additionally, response rates during baseline were generally very low, which means that proportions are not always a representative measure of the behavior. Finally, it should be noted that baseline levels of variability were not systematically related to behavior in discrimination training or choice sessions for any participants.

Figure 4-3.
Proportion of Independent Appropriate Play Actions That Would Have Met the Lag.



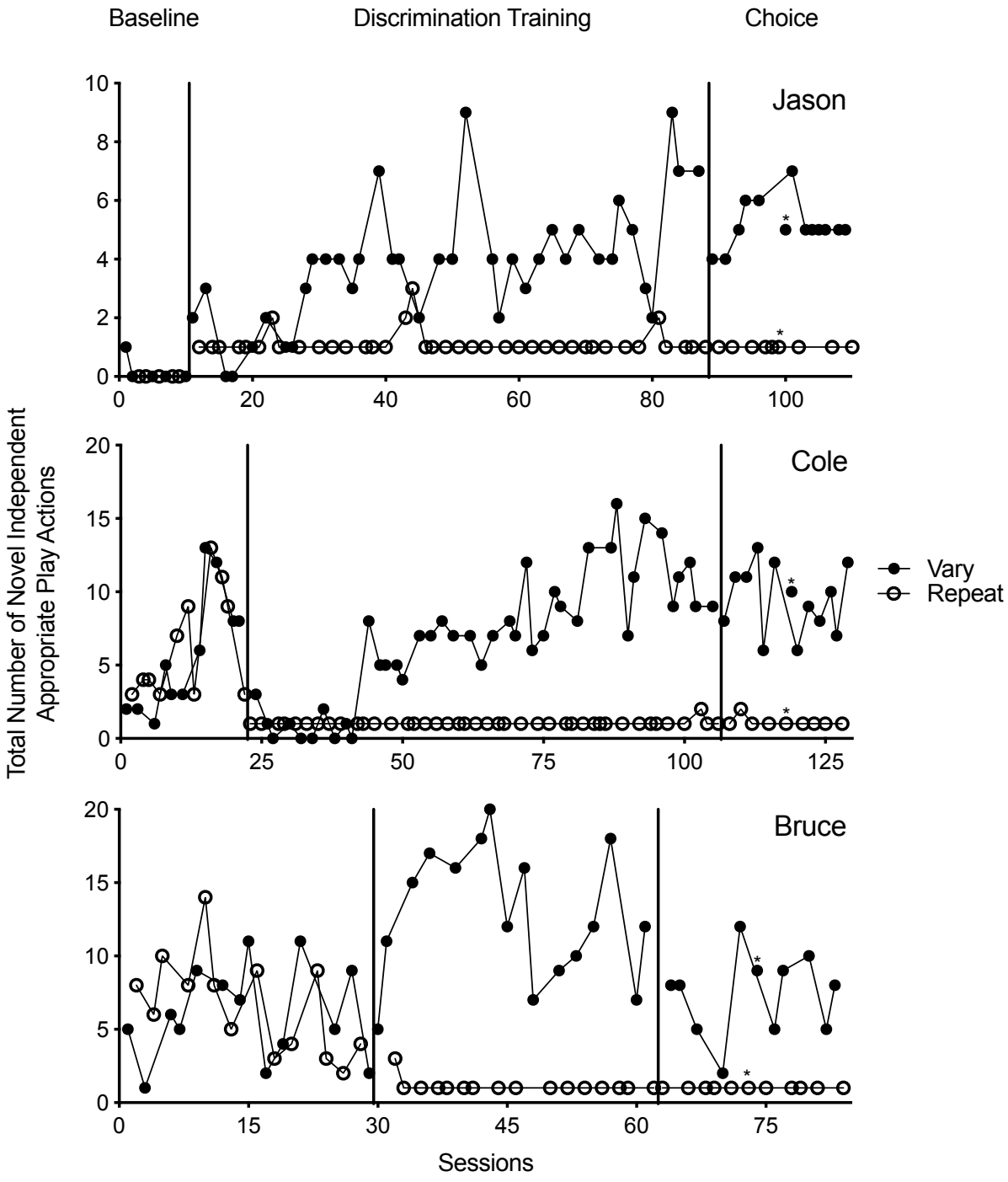
Note. Closed and open circles represent the proportion of responses that would have met the lag for the vary and repeat conditions, respectively, in each phase (although the contingencies were not yet in place during baseline, the closed and open circles indicate sessions with the playsets that would later be used in vary and repeat sessions). Asterisks indicate the two forced-choice sessions during the choice phase. Note that the x-axis (sessions) is scaled differently across participants.

play actions that would have met a lag schedule across conditions, phases, and participants.

Novel Responses

Figure 4-4 shows the total number of novel independent appropriate play actions *per session* (cumulative novel responses *across all sessions* are shown in the Supporting Information, accessible through the published article) for the vary and repeat conditions for Jason, Cole, and Bruce. Prompted actions were not included in this measure. In baseline, the number of novel play actions emitted was low for Jason, and highly variable for Cole and Bruce. Overall, the number of novel play actions was undifferentiated across both playsets for all participants. Throughout discrimination training, the number of novel play actions emitted per session was low in the repeat condition for all participants. Typically, only one new play action was made per session, consistent with the repetition contingency, although occasionally participants made up to three different play actions. On the contrary, the number of novel play actions emitted per session increased dramatically in the vary condition for all participants during discrimination training, indicating greater behavioral variability. During choice, the number of novel responses remained low for the repeat condition and high for the vary condition. For Bruce, the number of novel responses emitted per session in the vary condition decreased from discrimination training to choice. Although responding was still highly differentiated across conditions, this decrease was indicative of Bruce's responding becoming more efficient, in that he was emitting fewer different actions but still meeting the lag schedule reliably. Table 4-5 displays descriptive statistics (mean and standard deviation) across conditions, phases, and participants.

Figure 4-4.
Total Number of Novel Appropriate Play Actions per Session.



Note. Closed and open circles represent the number of novel responses per session for the vary and repeat conditions, respectively, in each phase (although the contingencies were not yet in place during baseline, the closed and open circles indicate sessions with the playsets that would later be used in vary and repeat sessions). Asterisks indicate the two forced-choice sessions during the choice phase. Note that the x-axis (sessions) is scaled differently across participants.

Choice

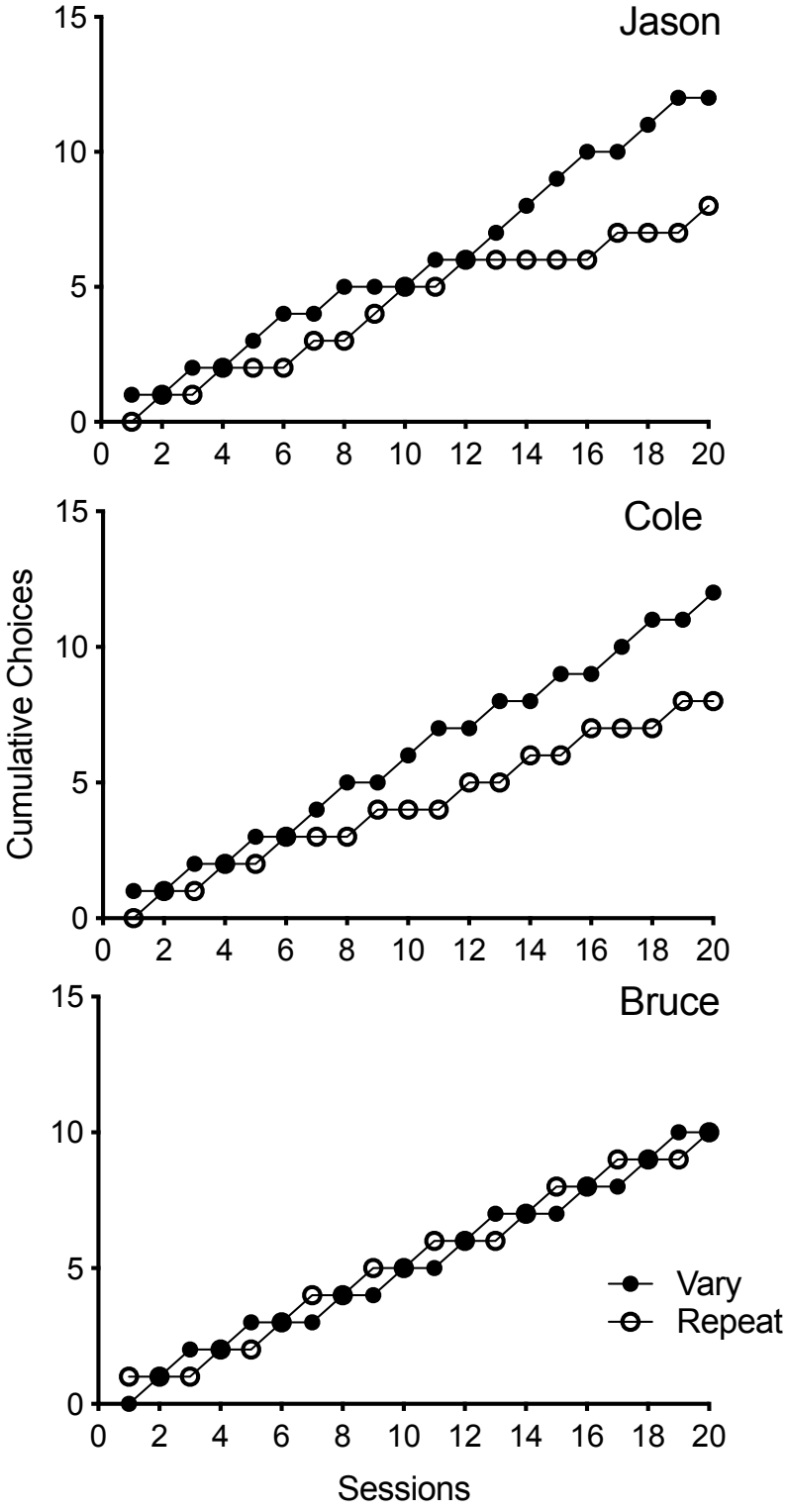
Figure 4-5 shows the cumulative number of choices made for the vary and repeat conditions across sessions during the choice phase for Jason, Cole, and Bruce. Jason's proportion choice for the vary condition was 0.60 (12 selections of the vary condition out of 20 opportunities), indicating a slight preference for reinforcement of behavioral variability. Similarly, Cole's proportion choice for the vary condition was 0.60 (12 selections of the vary condition out of 20 opportunities), again indicating a slight preference for reinforcement of behavioral variability. Finally, Bruce selected the vary and repeat conditions equally frequently (0.50), indicating no preference for either condition.

Discussion

The results of the present study replicate and extend previous research in the field of reinforced behavioral variability. Our findings again demonstrate that behavioral variability can be increased in children with ASD using positive reinforcement (e.g., Wolfe et al., 2012; Rodriguez & Thompson, 2015), specifically with play behavior. Further, we replicated the finding that behavioral variability can be brought under discriminative stimulus control in this population (e.g., Brodhead et al., 2016). Finally, although previous data have shown that pigeons and college students prefer behavioral variability under some conditions (e.g., Abreu-Rodrigues et al., 2005; Abreu-Rodrigues et al., 2017; Arantes et al., 2012; Pontes et al., 2012), our experiment is the first to extend these results to individuals with ASD.

Reinforcement of variable play behavior in children with ASD is highly clinically relevant. The primary deficits involved in ASD include restricted, repetitive behavior and

Figure 4-5.
Cumulative Choices for Vary and Repeat Conditions Across Choice Sessions.



Note. Closed and open circles represent cumulative choices for the vary and repeat conditions, respectively.

impaired social interactions (APA, 2013), both of which may be improved by reinforcing variable play. Play is one of the most important activities for a child's development (e.g., Buysse et al., 1996; McCune, 1995). When children are able to play variably, they are more likely to discover the benefits of various toys and activities, which could expand their behavioral repertoires, aid in gross and fine motor development, and promote language. Engaging in behavioral variability may also help children to sample the available options in the environment, meaning they are more likely to discover and access preferred reinforcers (e.g., Mullins & Rincover, 1985). Additionally, repetitive play behavior is likely to lead to social isolation (Jordan, 2003). Typically developing children are more likely to engage in variable play (Williams et al., 2001), which means that they may be more likely to interact with a child with ASD who also plays variably. Such interactions are critical for building social skills and overcoming social and communication deficits in individuals with ASD (Jordan, 2003). The present results are promising, because if variable play behavior can be maintained with reinforcement, we can more easily intervene clinically with children with ASD. Future research should be conducted to determine other play behaviors (e.g., pretend play with props instead of playsets with figurines) for which variability could be reinforced.

Another important finding in the present study is that behavioral variability and repetition can be brought under discriminative stimulus control. Such stimulus control has already been reliably demonstrated in animal subjects (e.g., Denney & Neuringer, 1999; Doughty & Galizio, 2015; Galizio et al., 2018), but finding the same effect in applied settings has presented more of a challenge. Previous research has demonstrated discriminated variable responding in children with ASD (e.g., Brodhead et al., 2016), but

it is unclear to what extent stimulus conditions must differ to promote discrimination in individuals with ASD. In the present study, we used different colors, as well as different playsets, across stimulus conditions. By making the stimulus conditions different on multiple dimensions, we hoped to increase the likelihood of discrimination, and we were successful. One drawback of our approach of using multiple stimuli (color and playset) to distinguish between conditions is that it is not clear which stimuli the participants were attending to (i.e., which stimuli were actually controlling the behavior). Future research should be conducted to isolate stimuli and achieve stimulus control in more similar conditions, which may more accurately reflect everyday life.

Our results also extend previous research on choice and behavioral variability in other populations. Consistent with findings with pigeons (e.g., Abreu-Rodrigues et al., 2005) and college students (e.g., Abreu-Rodrigues et al., 2017), the present experiment showed that, after being taught to behave variably using a lag schedule, some individuals with ASD also display a slight preference for reinforcement of behavioral variability over repetition. Although one participant selected the two conditions equally often, indicating indifference, the other two participants selected the variability condition more often than the repetition condition. We had originally hypothesized that individuals with ASD would prefer repetition because repetition is one of the diagnostic criteria, so this result was surprising. These findings indicate that some individuals with ASD may behave repetitively, not necessarily because they prefer to, but because they have not yet learned how to behave variably. At the least, our data do not support the interpretation that individuals with ASD prefer to behave repetitively when they are able to behave both variably and repetitively.

However, an important consideration regarding our data is whether they indicate true preference for reinforcement of behavioral variability or a procedural artifact. Theoretically, participants could be choosing based on a preference for higher reinforcer rates, which would be consistent with literature related to the matching law (e.g., Herrnstein, 1974). Indeed, matching response rates to reinforcer rates has previously been demonstrated in terms of behavioral variability and repetition, in that the level of behavioral variability seems to be sensitive to whether variability or repetition is reinforced more often (Neuringer, 1992). However, differences in reinforcer rates cannot account for our findings. For all participants in the present study, reinforcer rates were reliably higher in the repeat condition than the vary condition (see Figure 4-1). If reinforcer rates were affecting preference, we would have expected to see a preference for reinforcement of repetition; however, none of the participants selected the repeat condition more frequently than the vary condition. Therefore, differences in reinforcer rate cannot explain our findings.

Clearly, reinforcer rates did not drive preference in the present experiment. Reinforcer rates were consistently substantially higher in the repeat condition, yet participants' choices did not reflect that fact. The finding that participants prefer the condition with a lower reinforcer rate and higher response effort is at odds with our traditional understanding of choice. One potential way to reconcile this finding with the well-established literature that subjects tend to prefer higher reinforcer rates is to consider that our reported reinforcer rates only include the experimentally programmed reinforcers. That is, our reinforcer rates were calculated considering a reinforcer as the delivery of an edible item and brief praise. Although these clearly functioned as

reinforcers, evidenced by increases in behavioral variability or repetition, depending on the condition, we cannot rule out the possibility that our participants were contacting other naturally occurring reinforcers. If playing variably is somehow inherently reinforcing, then participants may well have been experiencing a higher reinforcer rate in the variability condition if we could account for programmed and natural reinforcers. If so, then choice for reinforcement of behavioral variability would be unsurprising and consistent with matching and other theories of choice that rely on reinforcer rates. However, this hypothesis would be extraordinarily difficult to test, as we are unable to detect the intrinsic reinforcing value of a condition using this procedure.

Another potential variable that could be impacting our findings is the use of physical prompting. For some individuals, physical prompts may be reinforcing, for others punishing, and for others neutral. As shown in Figure 4-2, acquisition of independent responding was slower in the vary condition for all participants; i.e., more physical prompts were required in the vary condition. Therefore, if a participant found physical prompting to be reinforcing, that could explain their selection for variability. To reduce this possibility, we continued discrimination training until at least 80% of the participants' responses were made without prompting in both conditions. By the end of discrimination training, the level of prompting utilized in each condition was similar, reducing the utility of this explanation.

Another possible explanation for our results is the potential presence of inherent biases. If a participant preferred one color over the other or one playset over the other, those biases could explain choice behavior. In other words, the participants could have been selecting conditions based on color or playset, rather than the variability and

repetition contingencies associated with those stimuli. To mitigate the potential effect of biases, we assessed preference for color and playset prior to beginning the experiment. After conducting preference assessments, we made sure to use playsets and colors that were similarly preferred for each participant. We also determined that there were no side biases; that is, none of the participants showed a substantially greater likelihood of selecting the color on the right or left (30% of Jason's selections were on the left, 45% of Cole's, and 60% of Bruce's). Even so, future research should be conducted to further eliminate the possibility of biases, by limiting the number of potentially preferable stimuli used in the experiment and frequently assessing preferences independently.

This experiment did have several limitations. First, it is unclear whether behavioral variability and repetition were more under the discriminative control of the playset or the color. We tried to ensure that participants were attending to the color stimuli by requiring them to match the color to the bracelet in the observing response (similar to the procedures used by Brodhead et al., 2016). However future studies should be conducted to determine whether the color and/or playset stimuli were truly controlling behavior. A second limitation is that the participants only had two conditions from which to choose – vary and repeat. In future research, it would be valuable to add a control condition, in which no responses are reinforced, as one of the available options, which would increase our confidence that participants' selections accurately reflected their preferences. Including a control condition in the present study could have helped to distinguish between true indifference and indiscriminate responding for Bruce. A third limitation is our sample size. Additional research with more participants is needed to determine the generality of our findings.

One future direction of this line of research involves parametric manipulations. Pontes et al. (2012) found that the variability requirement affected preference. It would be interesting to determine whether the variability requirement affects preference for children with ASD similarly. We may reduce preference for reinforcement of behavioral variability by increasing the lag requirement (e.g., lag 2 instead of lag 1), or we may increase preference by reducing the requirement (e.g., lag 1 on 2 of 3 aspects of the play action instead of all 3 aspects). We could also manipulate the repetition requirement, perhaps increasing choice for reinforcement of behavioral variability by increasing the repetition requirement (e.g., requiring two identical play actions to produce reinforcement instead of one). These kinds of results would support the idea that preference was in fact driven by the variability contingency.

Another potential future direction would be to attempt to distinguish between a preference for behaving variably and a preference for earning reinforcers for behaving variably. It would be important to know whether behavioral variability has any intrinsic reinforcing properties or whether a variability contingency is required to maintain a preference for the vary condition. One possible way to test this hypothesis would be to return to baseline conditions during choice sessions. For example, we could offer a choice between the vary and repeat conditions. Following the selection, the participants would then be allowed to interact with the playset in any way, without the experimenter delivering reinforcers or prompts. If a participant selected the vary condition and then continued to behave variably in the absence of external reinforcers, we would have evidence that the participant actually preferred playing variably to playing repetitively. It

would also suggest that variability may be inherently reinforcing. Unfortunately, the present study did not address this question.

In conclusion, the results of the present experiment show that variable play behavior can be maintained by reinforcement in individuals with ASD, participants can learn to play variably in one situation and play repetitively in another, and that when given the choice between playing variably or repetitively, children with ASD may slightly prefer variability. Even though one of the diagnostic criteria for ASD is that individuals tend to behave repetitively, the reason for such stereotypy is unclear. Our research suggests that some individuals with ASD may prefer to behave variably after they are given the option (i.e., after variable behavior is taught). This finding is clinically important because, if individuals with ASD prefer variability when they are taught how, then it would be most effective to design interventions that teach a variety of behaviors and reinforce emitting those behaviors variably.

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CHAPTER 5

STUDY FOUR:

REINFORCED BEHAVIORAL VARIABILITY IN THE VALPROATE RAT MODEL OF AUTISM SPECTRUM DISORDER [22]

Introduction

Behavioral variability can be adaptive, yet some individuals struggle to behave appropriately variably (Neuringer, 2002). The ability to behave variably is important in our society, because it may facilitate social interactions, promote creativity, and support learning (Neuringer, 2004). Overly repetitive responding may inhibit these vital skills and can even threaten an individual's safety (e.g., repetitive self-injurious behavior; Whitehouse & Lewis, 2015). Restricted, repetitive behavior is characteristic of many disorders, including autism spectrum disorder (ASD); in fact, stereotypy is one of the core diagnostic criteria for ASD (American Psychiatric Association [APA], 2013). ASD affects 1 in 59 children in the US, and the prevalence is consistently on the rise (Baio et al., 2018). Given the potential benefits of behavioral variability and the potential risks of excessive stereotypy, there is a critical need to investigate methods of increasing variability in individuals with ASD.

It has been proposed that variability may be an operant dimension of behavior, in that behavioral variability can be increased and maintained by reinforcement and controlled by discriminative stimuli (Neuringer, 2002). Under specific reinforcement contingencies (e.g., lag *x*, in which a response must differ from *x* previous responses to

[22] This study was funded by a Graduate Student Translational Research Grant (Society for the Experimental Analysis of Behavior) for $5000. Support was also provided by the Utah State University College of Education and Human Services and Psychology Department.

produce reinforcement), high levels of behavioral variability can be obtained (Page & Neuringer, 1985). Reinforced behavioral variability has been studied extensively in the basic animal laboratory (pigeons and rats), and the implications of this research are clear (Neuringer, 2004). Promoting reinforced behavioral variability could potentially be used in interventions to treat overly repetitive behavior in individuals with ASD and similar disorders. Some applications of reinforced behavioral variability principles have already been implemented in individuals with ASD (Rodriguez & Thompson, 2015; Wolfe et al., 2014). For example, children with ASD can learn to vary verbal and play behaviors using lag schedules (Brodhead et al., 2017; Galizio et al., 2020). There is convincing evidence that variability can be increased using reinforcement in both humans and nonhumans.

Translational research on reinforced behavioral variability is crucial for developing and refining clinical interventions to promote behavioral variability in individuals with ASD. Translational research simultaneously involves a focus on basic experimental approaches and concern for the generality of behavioral principles to applied problems. When these two goals are united, we can achieve "innovation through synthesis" (Mace & Critchfield, 2010, p. 296), and we can begin to bridge the gap between basic and applied research. The current study was translational in nature, as evidenced by our use of some of the strong experimental methodologies that distinguish basic behavioral research (e.g., nonhuman subjects, steady-state procedures, and elements of single-subject design; Critchfield, 2011*a*), as well as our goal of leveraging basic laboratory research to validate principles that could better prepare us to address an applied problem, ASD, in the future (Critchfield, 2011*b*). Furthermore, we brought an applied concern back to the basic laboratory by using an animal model of ASD, which

was discovered using neuroscientific methods. Our approach is consistent with the bidirectional nature of translational research; i.e., basic research that influences applied research and applied concerns that inform basic research (McIlvane, 2009).

Very few translational models have been tested in reinforced behavioral variability tasks. Hunziker and colleagues (1996) examined performance in a reinforced behavioral variability task for spontaneously hypertensive rats (SHR), which are a well-established model of attention deficit hyperactivity disorder (ADHD). SHR rats engaged in higher levels of behavioral variability than controls, further supporting the utility of SHR rats as a model of ADHD. More recently, Arnold and Newland (2018) examined performance in a reinforced behavioral variability task for BALB/c mice, one of many early rodent models of ASD. Contrary to what we would expect based on the symptoms of ASD, these mice sometimes exhibited higher levels of behavioral variability than controls, calling into question the validity of the BALB/c model. These preclinical models combine the social significance of applied research and experimental control of basic research but have not yet been fully leveraged to understand behavioral variability in individuals with ASD.

A number of potential animal models of ASD have been proposed (Lewis et al., 2007), but one promising variation is early exposure to valproate (VPA; a teratogenic drug used to treat epilepsy and mental illness, also known as valproic acid) in rats (Roullet et al., 2013; Schneider & Przewłocki, 2005). The VPA rat model of ASD has strong face and construct validity; children born to women who took VPA during pregnancy (i.e., children with fetal valproate syndrome; FVS) are more likely to be diagnosed with ASD and display social deficits and spontaneous stereotypy (Mabunga et

al., 2015). One study found that, although the observed overall incidence of ASD was 1.6% in this population, 6.3% of children exposed to VPA in utero were later diagnosed with ASD, indicating that VPA exposure increases the probability of an ASD diagnosis almost four-fold (Bromley et al., 2008). Although it is important to note that not every child exposed to VPA will develop ASD, and not every child with ASD was exposed to VPA, this rat model suggests that environmental variables can significantly impact the likelihood of an ASD diagnosis (Patterson, 2011). Given this link, exploration of the VPA rat model of ASD has been encouraged (Tordjman et al., 2007).

Rats exposed to VPA in utero (Erdoğan et al., 2017; Varghese et al., 2017) or during the first postnatal days (which correspond to the third trimester of gestation in humans; Reynolds et al., 2012) show behavioral and neural abnormalities consistent with those seen in humans with ASD. VPA rats show impairments in social interaction (e.g., Favre et al., 2015; Schneider et al., 2008) and communication (Mabunga et al., 2015; Nicolini & Fahnestock, 2018), two hallmarks of ASD. Restricted and repetitive behaviors, another critical behavioral marker in ASD, are also commonly observed in VPA rats using simple behavioral assays (e.g., Markram et al., 2008; Mehta et al., 2011; Servadio et al., 2015); however, VPA rats have not yet been tested in more complex reinforced behavioral variability tasks. To fill this gap, we conducted a translational study with the aim to investigate the problem of restricted, repetitive behavior in ASD, using a reinforced behavioral variability paradigm and the VPA rat model of ASD. We also conducted commonly used assessments of social interaction, repetitive behavior, and motor activity in an attempt to replicate prior research supporting the VPA rat as a model of ASD.

Method

Subjects

All procedures were approved by the Utah State University Institutional Animal Care and Use Committee prior to beginning the study. Four pregnant female Long Evans rats (Reynolds et al., 2012) were obtained in cohorts of two from Charles River for the present study. Pregnant females arrived in the lab on gestational day 10 and were quarantined for 48 hours. The rats were then moved to a colony room with other pregnant females. Throughout pregnancy and weaning, rats had continuous access to food and water. On gestational day 12, each pregnant rat received one subcutaneous injection of 0.9% saline (SAL) for the control group or 400 mg/kg valproate dissolved in 0.9% saline (VPA; Kim et al., 2011) for the experimental group. The first cohort of two pregnant rats was exposed to VPA and the second cohort of two pregnant rats was exposed to SAL (i.e., control). Drugs were obtained from Sigma-Aldrich. Rats were handled and weighed daily for the remainder of the pregnancy. In addition to the rat bedding in the home cage, we also offered tissue paper and other nesting materials. All pregnant rats gave birth on gestational day 22. On post-natal days (PND) 1-7, cages were not disturbed, and the colony room was kept as quiet as possible to minimize stress for the mother and offspring. From PND 8 until PND 21, we handled and weighed all rats daily. On PND 12, we began recording the total number of open eyes across all rat pups. For each rat pup, a score of 0 indicated both eyes closed, a score of 1 indicated one eye open and one eye closed, and a score of 2 indicated both eyes open. On PND 21, rat pups were weaned, and sex was determined. Males and females were moved to separate colony rooms and housed in isolation for at least 24 h. Following the social-interaction assessment (see

Initial Assessments below), rats were housed in pairs (for details, see Matching below). Dams of the same group (VPA or SAL) were housed together. Rats remained pair-housed throughout the remainder of the study. All rats had continuous access to food and water in the home cage until initial assessments were completed. All assessments described in the Procedure were performed for both offspring and dams.

Before conducting the initial assessments, we also obtained 2 male and 2 female Long Evans rats per cohort. These rats were approximately 21 days old upon arrival. These rats served as stimulus rats for the social-interaction assessment and were approximately the same age and weight as the experimental rats. These rats did not complete any other assessments and were used for a different experiment following the social-interaction assessment.

After initial assessments were completed, both offspring and dams were maintained at 80% of their free-feeding body weights according to the average growth curve (Charles River, 2019) through post-session supplemental feeding. Specifically, immediately following the behavioral testing session for that day, rats were placed in separate cages and provided with a pre-designated amount of food. Rats were fed separately to avoid conflict. After one hour, rats were returned to pair-housed home cages, along with any leftover food. All rats had continuous access to water in feeding and home cages and continued to be handled and weighed daily.

The 2 pregnant VPA rats gave birth to $n = 21$ viable offspring (11 male and 10 female), and the 2 pregnant SAL rats gave birth to $n = 22$ viable offspring (10 male and 12 female).

Apparatus

In addition to testing rats in a reinforced behavioral variability paradigm, we also conducted commonly used assessments of social interaction, repetitive behavior, and motor behavior. For these initial assessments, we used a large plastic container (52 cm [length] x 35 cm [width] x 35 cm [height]), extra rat home cages (45 cm x 25 cm x 20 cm), bedding, a Y-maze (three arms, each 50 cm x 15 cm x 30 cm), 20 assorted marbles (1.5-cm diameter), and a video camera. Additionally, six standard operant chambers, 30 cm x 26 cm x 30 cm, enclosed in sound- and light-attenuating cubicles, 64 cm x 38 cm x 54 cm, were used for the reinforced behavioral variability task. Each chamber was equipped with a 28-V DC shielded houselight, centered at the top of the front wall, to provide general illumination. Centered on the same wall, there were two retractable levers, 5 cm x 1.5 cm, with red, yellow, and green LED stimulus lights 4 cm above each lever. Levers were positioned 10 cm apart and 8 cm above the floor of the chamber. Between the two levers, there was a 6-cm x 2-cm x 5-cm aperture, containing a 28-V DC lightbulb, into which 45-mg grain pellets were delivered using a pellet dispenser. A ventilation fan was used to mask extraneous sounds. All equipment was cleaned thoroughly after each use. Two operant chambers were designated for use by male rats only, two operant chambers were designated for use by female offspring, and two operant chambers were designated for use by the dams. Control of experimental events and data recording were conducted on a computer in an adjacent room using Med Associates® interfacing and software.

Procedure

Initial Assessments

Social-Interaction Assessment. Even though social interaction was not the focus of this study, a deficit in social interaction is one of the core features of ASD. Therefore, we first sought to replicate previous research showing a relation between VPA exposure and deficits in social interaction. Specifically, we conducted a *social-interaction open-field test* (see Schneider et al., 2008) on PND 22-23 for offspring, including offspring, dams, and stimulus rats. All rats were isolated for 24 h prior to the procedure to promote social interaction during the test (Niesink & Van Ree, 1989; Schneider et al., 2008). First, each stimulus rat completed one social-interaction assessment with a same-sex stimulus rat so that all stimulus rats were habituated to the apparatus prior to introducing experimental rats. Each experimental rat was then tested with one of the stimulus rats of the same sex. Although experimental rats were assessed only once, the stimulus rats were used multiple times with various experimental rats. Therefore, the stimulus rats were housed in isolation for a minimum of 3.5 h between assessments (Niesink & Van Ree, 1989; Schneider & Przewłocki, 2005). The two dams in each cohort were tested together. For each cohort, half of experimental rats were tested on PND 22 for offspring and half on PND 23 for offspring. To conduct the assessment, an experimental rat and stimulus rat were placed in the bedding-filled arena (typical rat home cage for offspring and stimulus rats, large plastic container for dams) for 15 min (e.g., Schneider et al., 2008). Each session was video recorded for later scoring (see Data Analysis below for details).

Y-Maze Assessment. Although the primary aim of this experiment was to assess behavioral variability and repetition in an operant paradigm, we first sought to replicate

previous research showing a relation between VPA exposure and restricted, repetitive behaviors, using more basic behavioral assays. To begin, we tested both offspring and dams in an unbaited *Y-maze* (also known as *spontaneous alternation paradigm*; see Crawley, 2004; Markram et al., 2008) on the day after the social-interaction assessments were completed (PND 24 for offspring). Two trials were conducted, in which the rat was placed in one arm at the start of the Y-maze, and the rat was observed until it entered one of the other two arms. Whichever arm the rat entered was recorded. For data collection, we determined that an arm had been "entered" when the rat's entire body, including tail, was completely across the threshold of the arm. If the rat did not enter either arm within 30 s, the rat was removed from the maze, the trial was scored as an omission, and the trial was repeated until the rat entered either arm. Testing was conducted until every rat completed two trials. If the rat explored different arms on the first and second trials, it was scored as an alternation. If the rat explored the same arm twice, it was scored as a repetition.

Marble-Burying Assessment. Next, we administered a *marble-burying task* (see Angoa-Pérez et al., 2013; Mehta et al., 2011) to both offspring and dams. For each cohort, half of experimental rats were tested on PND 25 for offspring and half on PND 26 for offspring. Rats were individually placed in an arena (typical rat home cage for offspring, large plastic container for dams) containing 5 cm of bedding and 20 marbles, arranged in five rows of four, on top of the bedding. After 30 min, the rat was removed and the number of marbles at least two-thirds submerged beneath bedding was counted.

Open-Field Assessment. Finally, we measured self-grooming and motor activity in an *open-field test* (see Mehta et al., 2011) in both offspring and dams. For each cohort,

half of experimental rats were tested on PND 27 for offspring and half on PND 28 for offspring. Rats were individually placed in an arena (large plastic container for offspring and dams), with no bedding available, for 30 min. Each session was video recorded for later scoring (see Data Analysis below for details). Food restriction began following this session and continued throughout operant training.

Operant Training

Matching. After the social-interaction assessment (see above), all rats were pair-housed with a randomly selected same-sex rat from the same litter whenever possible. If there were an odd number of males or females in a litter, the remaining rats were housed across litters of the same group (VPA or SAL) or were singly housed if necessary (in the VPA group, two female pairs were housed across litters due to the unexpected loss of one female from each litter, and one male was housed individually due to an odd number of males; in the SAL group, one female pair and one male pair were housed across litters due to an odd number of each sex). Two dams of the same group (VPA or SAL) were housed together. In each pair, one of the rats served as a matched control for the other during operant training. Sessions for matched pairs were always conducted concurrently in separate operant chambers. Both rats in each pair completed the same number of sessions in each phase described below and always changed phases at the same time. In each pair, one rat was randomly assigned to the variability group, and the other was assigned to the yoked control group (see Reinforced Behavioral Variability below).

Pretraining: Magazine Training. The day after all of the initial assessments were completed (PND 29 for offspring), dams and offspring began pretraining in operant chambers. All sessions throughout operant training began with a 2-min blackout. Rats

received a minimum of one session of magazine training, in which a pellet was delivered according to a variable-time (VT) 60-s schedule. In other words, pellets were delivered every 60 s on average, using a Fleshler-Hoffman distribution (Fleshler & Hoffman, 1962). The houselight was on throughout the session, except during pellet deliveries, during which the houselight turned off and the magazine light turned on for 5 s. Sessions ended after 40 pellets were delivered. A maximum of three sessions was conducted until both rats in a pair consumed all 40 pellets during the most recent session, after which they proceeded to autoshaping.

Pretraining: Autoshaping. Next, rats received lever-pressing training using an autoshaping procedure (see Gibbon et al., 1977). During autoshaping, a series of trials occurred, each of which began with the extension of one of the levers and illumination of the corresponding stimulus lights. The lever remained extended for 10 s or until the rat pressed the lever, at which point the lever was retracted and a pellet was delivered. A 50-s inter-trial interval (ITI) occurred after each pellet delivery. Sessions ended after 40 pellets have been delivered. For all trials in a single session, only one of the levers was extended (left or right, counterbalanced across rats). In the next session, the alternate lever was extended instead. Autoshaping sessions were conducted in two-session sets, such that exposure to each lever was identical, until both rats in a pair had pressed the extended lever on at least 80% of trials in the most recent session for each lever. After satisfying this criterion, both rats proceeded to fixed ratio (FR) training.

Pretraining: FR Training. Next, rats completed three FR training sessions. In these sessions, both levers (right and left) were extended and the corresponding lever lights were lit. After one response to either lever, both levers were retracted, and lever

lights were extinguished for a 0.5-s interresponse interval (IRI). This process continued until the required number of responses had been made. After the final response, levers were retracted, all lights were extinguished, and a pellet was delivered with a probability of 0.33. When a pellet was delivered, the magazine light turned on for 5 s. On trials when the pellet was not delivered, a timeout occurred, in which all lights were extinguished for 5 s. The next trial began immediately after the pellet delivery or timeout. The session ended after 40 pellet deliveries or 45 min. The FR requirement was a single response (i.e., FR 1) for the first session and was increased to FR 2 and FR 3 for the second and third sessions, respectively. After the FR 3 training session, rats proceeded to baseline.

Reinforced Behavioral Variability

Baseline. To assess behavioral variability with no contingency in place, we first conducted a baseline phase with probabilistic reinforcement. Baseline was identical to the FR training sessions, except that four responses were required (i.e., FR 4). On each trial, one of 16 possible sequences of lever presses was completed by the rat (e.g., LRLR, RRLL, where L and R indicate left and right lever-press responses, respectively). Each sequence was followed by food with a probability of 0.33, as in FR training, which was projected to approximate the probability of reinforcement in the variability condition based on previous research (e.g., Galizio et al., 2018). Sessions ended after 50 pellet deliveries or 45 min. Each phase throughout the reinforced behavioral variability task (baseline and variability or yoked control) was in place for 30 sessions (fixed-time criterion [Perone, 1991], based on previous research in our lab [e.g., Galizio et al., 2018]). After both rats in a pair had completed 30 baseline sessions, the rat assigned to

the variability group proceeded to the vary condition, and the rat assigned to the yoked control group proceeded to the yoked condition.

Variability (Vary). The vary condition was similar to baseline, except that pellets were no longer delivered probabilistically. Instead, pellets were only delivered for sequences that satisfied a variability contingency. Specifically, we employed a weighted relative-frequency threshold contingency to determine which sequences would be reinforced (see Doughty & Galizio, 2015). In the threshold contingency, the relative frequency of all 16 possible sequences was calculated on each trial after the fourth lever press. The relative frequency of each sequence was cumulative and was updated across all sessions experienced in this condition. If the relative frequency of the current sequence was equal to or less than a certain threshold value (in this experiment, we used a 0.067 threshold value; see Neuringer et al., 2000), then the sequence produced food. If the relative frequency was higher than the threshold value, then the sequence resulted in a blackout. In other words, only sequences that had been emitted infrequently in the past (<6.7% occurrence) would be followed by food. After each pellet delivery, all relative frequencies were multiplied by a 0.95 weighting coefficient to more heavily weight recently emitted sequences. Sessions ended after 50 pellet deliveries or 45 min, and a total of 30 sessions was conducted, as in baseline.

Yoked Control (Yoked). The yoked condition was similar to the vary condition, except that the threshold contingency was not in place. Instead, the reinforcer rate for the control rat was yoked to the reinforcer rate for the corresponding variability rat (see Page & Neuringer, 1985). Pairs of rats (one in the variability group and one in the yoked control group) were tested concurrently. When the variability rat earned a reinforcer, a

signal was sent to the operant chamber containing the control rat. After the next sequence the control rat completed, a reinforcer was delivered, regardless of whether the sequence would have met the threshold contingency. If multiple reinforcers were delivered for the variability rat before the control rat had completed the next sequence, then the number of reinforcers was stored. If any reinforcers had been stored when the control rat completed a sequence, a pellet was delivered. If not, the sequence resulted in a timeout. When the variability session ended (after 50 reinforcers or 45 min), the yoked control session also ended, as long as there were no stored reinforcers for the control rat. If any stored reinforcers remained, the control rat continued to complete trials until all of the stored reinforcers had been delivered or until 5 additional min had elapsed (i.e., maximum session time of 50 min). A total of 30 sessions was conducted, as in the baseline and vary conditions.

Data Analysis

Our dependent measure for the social-interaction assessment was the total duration of social interactions initiated by each rat. This duration was measured by scoring video recordings for each session. A social interaction was defined as sniffing or licking any part of the body of the other rat, approaching the other rat (less than 1 in of space between rats and oriented towards the other rat; e.g., following, chasing, etc.), or engaging in play behavior with the other rat (e.g., pinning [Rat 1 standing with two paws on top of Rat 2's ventral side] and climbing [Rat 1 standing with two paws on top of Rat 2's dorsal side]; Markram et al., 2008). We only scored a social interaction for the rat who initiated the interaction (e.g., if Rat 1 sniffed Rat 2, then we scored an interaction for

Rat 1 only; if Rat 2 then sniffed Rat 1 in return, we would score an interaction for Rat 2 as well).

Several dependent measures were used to characterize performance in the initial assessments of repetitive and motor behavior. In the Y-maze, we scored a repetition for each rat that explored the same arm twice and an alternation for each rat that explored both arms across trials (Markram et al., 2008). In the marble-burying task, we counted the number of marbles at least two-thirds submerged beneath bedding (Mehta et al., 2011). In the open-field test, we measured the duration of self-grooming and self-injury, as well as the frequency of rearing, by scoring video recordings of each session. Self-grooming was defined as the rat rubbing any body part with its paws or mouth for at least 1 s (Mohammadi et al., 2020). Self-injury was defined as any self-grooming that resulted in blood (self-injury never occurred during this assessment). Rearing was defined as any instance in which the rat stood on its hind legs, such that its body was vertical (Mohammadi et al., 2020). Finally, we measured general locomotion using activity tracking software to analyze each video (ToxTrac; Rodriguez et al., 2018). For each subject, the software measured the average speed of travel (mm/s) and total distance traveled (m). Additionally, the software automatically divided the arena into a grid of distinct zones and used it to calculate exploration rate (percentage of zones entered).

Because many of the dependent measures (duration of social interactions, duration of self-grooming and self-injury, and frequency of rearing) involved an observer collecting data from video recordings, multiple trained observers independently scored the videos. Each video was scored by one observer, and at least 80% of videos were scored by two or more observers. All observers were blind to each subject's sex and

group assignment. For data analysis, we used the average of each dependent measure across all observers for each video. To quantify the reliability of these data, we also assessed inter-observer agreement (IOA) for each video. IOA was calculated by dividing the total number of agreements across all dependent measures by the total number of agreements and disagreements, and then multiplying by 100 to yield a percentage of agreement. If IOA for any video was <70%, the observer received additional training, and the first author scored the video to resolve any disagreements. The average IOA for social-interaction videos was 85.2% (range 64.0% – 97.3%). The average IOA for open-field videos was 91.3% (range 77.7% – 99.0%).

In pretraining, we recorded the number of sessions required to reach criterion (responding on at least 80% of trials) for each lever. For analysis, we combined the number of sessions required to reach criterion on each lever (e.g., if a rat required 3 sessions on the left lever and 2 sessions on the right lever to reach criterion, then the number of sessions required to meet criterion would have been recorded as 5, even though that rat may have completed additional sessions to ensure equal exposure to each lever or because the other rat in the pair had not yet reached criterion). In addition, we measured the latency (s) to the first response on each lever. Given the wide range of variation in initial latencies across levers and rats, we used the latency for each lever for each rat, such that two latency values were analyzed for each rat.

In the reinforced behavioral variability task, our primary dependent measure was U-value, which is commonly used to characterize overall levels of sequence variability (Page & Neuringer, 1985). U-value ranges from 0, in which only one possible sequence

occurred, to 1, in which all possible sequences occurred equally frequently. U-value was calculated using Equation 1:

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

in which Rf_i is the relative frequency of each sequence and n is the total number of possible sequences, in this case 16.

A secondary dependent measure for the reinforced behavioral variability task was the proportion of sequences meeting the threshold contingency, another measure of variability. To calculate this measure, we divided the number of sequences that would have satisfied the threshold contingency by the total number of sequences per session. The proportion of sequences meeting the threshold contingency was calculated for all conditions and groups, even though the threshold contingency was only implemented for vary rats during the variability condition. Therefore, one would expect to see lower proportions when the threshold contingency was not in place (i.e., baseline and yoked conditions), indicative of lower levels of behavioral variability, and higher proportions when the threshold contingency was in place (i.e., vary condition only), indicative of higher levels of behavioral variability.

We conducted inferential statistics for offspring data using Graphpad Prism and an alpha level of .05. For the dependent measures from the initial assessments and pretraining, we conducted 2 (group – VPA/SAL) x 2 (sex) analyses of variance (ANOVAs), although an independent-samples *t*-test was conducted to assess weights on PND 8, because offspring sex had not yet been determined, and a 2 (group) x 5 (PND) ANOVA was conducted to assess eye-opening across days. For the reinforced behavioral variability task, we conducted 2 (group) x 2 (sex) x 2 (contingency – vary/yoked)

ANOVAs for the first and last sessions of each condition; however, because no significant effect of sex was observed, we have reported the results of 2 (group) x 2 (contingency) ANOVAs for simplicity. Parametric statistics were used for most dependent measures, because all assumptions regarding the data (e.g., normality) were met for those variables. Non-parametric statistics (Mann-Whitney U for main effects and Kruskall-Wallis H for potential interactions) were used for measures of time – duration of social interaction, duration of self-grooming, latency to first response – and U-value, as these measures are typically not normally distributed. For significant interactions, we conducted post-hoc multiple comparisons, using a Šidák correction (Dunn's correction for nonparametric statistics) to ensure familywise error rate of 0.05. All *p*-values for post-hoc comparisons have been adjusted using this correction. Because we found no significant effect of sex on our primary dependent variables, the figures below display group comparisons (VPA and SAL), with sexes collapsed. Means (*M*) and standard deviations (*SD*) are reported for all variables analyzed using parametric tests, and medians (*Med*) and interquartile ranges (*IQR*) are reported for those using nonparametric tests. Because of the small sample size of dams ($n = 2$ in each group), we only conducted inferential statistics for offspring data. We did not expect to observe behavioral changes in dams[23]; however, Table 5-1 contains data from the initial assessments and pretraining, and Figure 5-1 contains data from the reinforced behavioral variability task for the four dams.

[23] Although data for dams are not frequently reported, available data have shown that this level of VPA exposure during adulthood does not impact physiological or behavioral measures (e.g., Tomasiewicz et al., 2006; Vorhees, 1987).

Table 5-1.
Data from Initial Assessments and Pretraining for Dams.

	VPA A	VPA B	SAL A	SAL B
Social interaction (duration; s)	180.0 s	249.0 s	346.5 s	203.0 s
Y-maze	Alternation	Alternation	Alternation	Alternation
Marbles buried	7	6	11	17
Rearing (frequency)	244	202	110	226
Self-grooming (duration; s)	81.5 s	45.5 s	211.0 s	125.0 s
Average speed (mm/s)	24.34	15.92	17.99	23.67
Total distance (m)	46.75	30.98	36.74	46.80
Exploration rate	96.67%	93.33%	66.25%	90.00%
Pretraining (latency; s)	Left – 1.83 Right – 15.77	Left – 8.12 Right – 2.97	Left – 135.05 Right – 14.96	Left – 3.18 Right – 2.51
Pretraining (sessions to criterion)	Left – 1 Right – 2	Left – 2 Right – 1	Left – 1 Right – 2	Left – 2 Right – 1

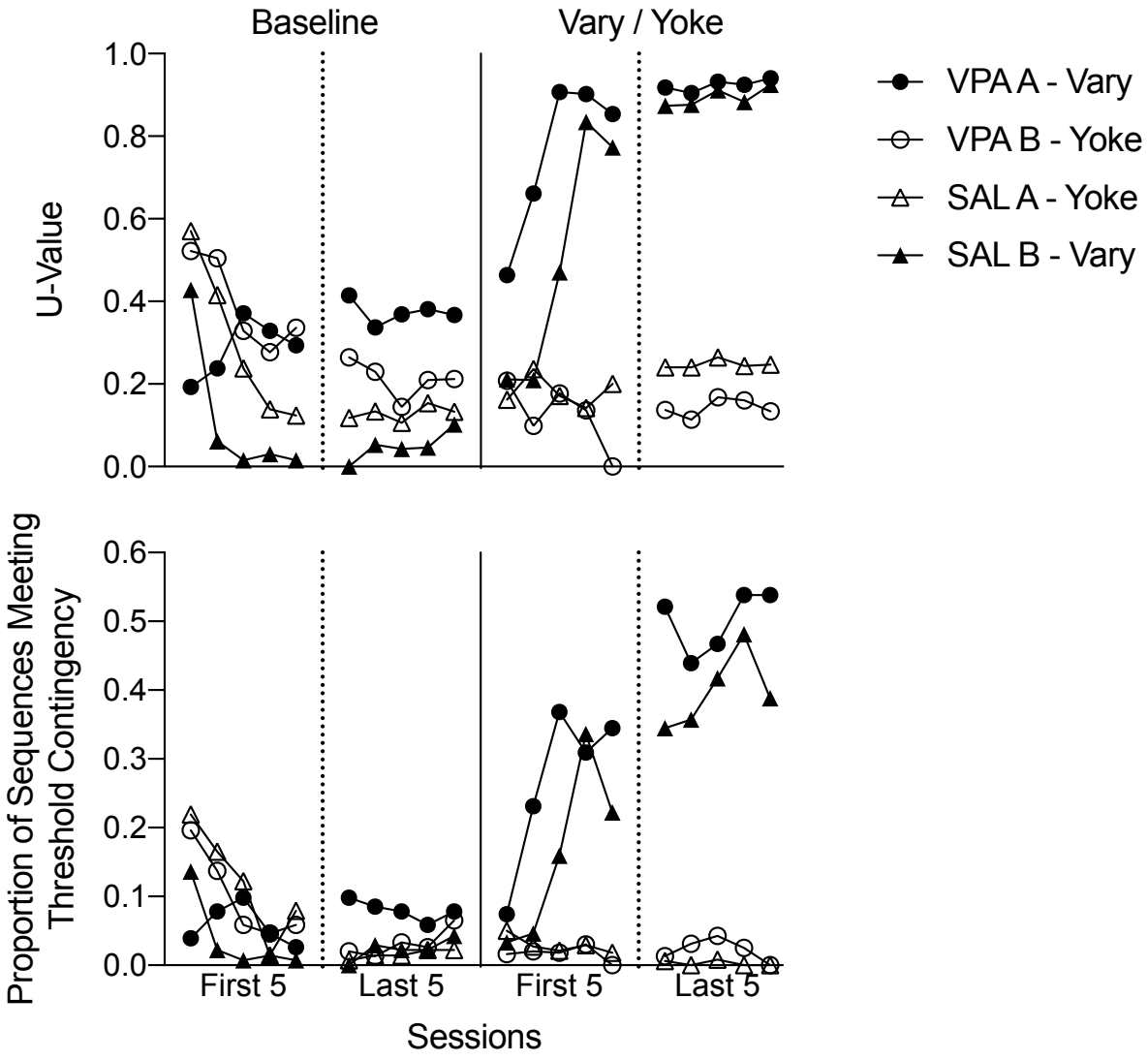
Note. Duration of social interactions (s) in the social-interaction assessment; repetition or alternation in the Y-maze; number of marbles buried in the marble-burying task; frequency of rearing, duration of self-grooming, average speed moved (mm/s), total distance traveled (m), and exploration rate (percentage of zones entered) in the open-field test; latency to engage in lever pressing (s) for the first time for each lever in pretraining; and number of sessions required to meet criterion (responding on at least 80% of trials) for each lever in pretraining. Data for the two VPA and two SAL dams are shown.

Results

Offspring Viability

Exposure to VPA in utero had an adverse effect on offspring viability. Table 5-2 shows VPA and SAL offspring weight at PND 8 and PND 21, as well as total offspring, total viable offspring (i.e., survived past PND 30), and any health abnormalities the offspring experienced. Offspring weight on PND 8 was significantly lower for VPA (M = 12.4 g, SD = 2.2) than SAL offspring (M = 18.6 g, SD = 1.8), $t(43) = 10.31$, $p < .0001$. Similarly, offspring weight on PND 21 was significantly lower for VPA (M = 37.5 g, SD = 5.5) than SAL offspring (M = 45.0 g, SD = 5.4), $F(1, 42) = 24.05$, $p < .0001$. As expected, males (M = 42.7 g, SD = 5.4) were generally heavier than females (M = 39.7 g,

Figure 5-1.
U-Value and Proportion of Sequences Meeting the Threshold Contingency Across Phases of the Reinforced Behavioral Variability Task for Dams.



Note. U-values (*top panel*) and proportion of sequences meeting the threshold contingency (*bottom panel*) from the first five and last five sessions of each phase are presented. Filled and open symbols represent responding for the Vary and Yoke dams, respectively. Circles and triangles represent responding for VPA and SAL dams, respectively.

Table 5-2.
Offspring Viability.

	VPA A		VPA B		SAL A		SAL B	
	Male	Female	Male	Female	Male	Female	Male	Female
Weight (g; PND 8)[a]	13.2 (8-17)		11.8 (7-14)		19.0 (16-22)		18.3 (15-20)	
Weight (g; PND 21)	43.0 (38-49)	37.0 (32-44)	38.0 (33-41)	33.4 (24-38)	53.0 (52-55)	48.3 (44-53)	42.4 (38-45)	39.2 (38-41)
Total offspring	5	5	6	7	3	7	7	5
Viable after PND 30	5	4	6	6	3	7	7	5
Health abnormalities	3[b]	0	2[c]	0	0	0	0	0

Note. Average (and range) weight (g) of all offspring on PND 8, average (and range) weight (g) of male and female offspring on PND 21, total number of male and female offspring born, number of male and female offspring that survived after PND 30, and number of male and female offspring that experienced health abnormalities for VPA dams A and B and SAL dams A and B.

[a] On PND 8, sex had not yet been determined for offspring, so weights for males and females are combined.
[b] Two males showed chromodacryorrhea (i.e., red tears) in one eye, and one male regularly had blood in his urine but experienced no other health complications.
[c] One male showed chromodacryorrhea in one eye, and one male engaged in self-injury (scratching his face) for several weeks.

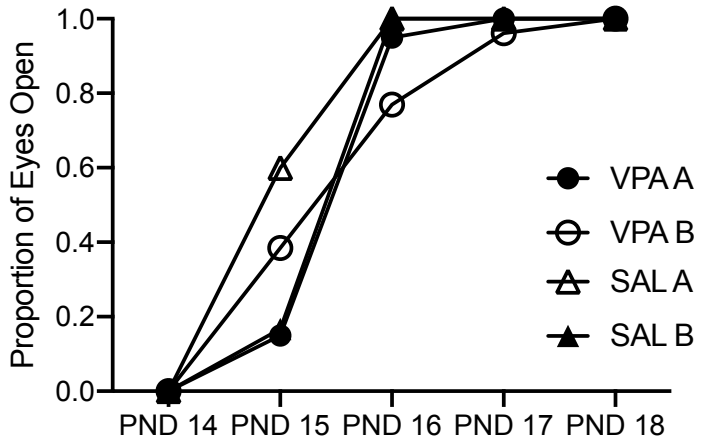
SD = 7.3) across both groups on PND 21, $F(1, 42) = 4.46$, $p = .0406$, but there was no interaction between sex and group, $F(1, 42) = 1.933$, $p = .1718$.

The effects of VPA on viability were not only seen for offspring weight; two of the VPA offspring did not survive after being weaned, whereas all SAL offspring survived to complete the experiment. Several health abnormalities were observed in VPA offspring as well. Three VPA rats displayed chromodacryorrhea (i.e., red tears). One VPA rat regularly had blood in his urine (he was examined by our veterinarian and was determined not to be in pain or distress), which persisted after a course of antibiotics, indicating that the blood was unlikely the result of a common infection. Finally, one VPA rat engaged in severe self-injury, which consisted of scratching his face. The resulting wound was treated daily with medicated ointment, but the behavior continued for several

weeks. The self-injury only ceased when we began removing the rat from the operant chamber immediately after his session was complete, instead of removing all of the rats when all sessions had finished as is standard practice. Interestingly, all of the VPA rats displaying any health abnormalities were males. No male or female SAL rats displayed any of these health abnormalities.

Despite these differences in offspring viability, we observed no significant delay in eye-opening for VPA rats compared to SAL rats. Beginning on PND 12, we recorded the number of eyes open for each pup daily. As shown in Figure 5-2, the proportion of eyes open per litter increased across days, $F(4, 10) = 60.98$, $p < .0001$. On PND 14, no pups' eyes were open across the two VPA litters and the two SAL litters, and all eyes were open by PND 18. There were no significant differences in proportion of eyes open between VPA and SAL rats on any day during this period, $F(1, 10) = 1.10$, $p = .3195$, and no interaction, $F(4, 10) = 0.33$, $p = .8509$.

Figure 5-2.
Proportion of Eyes Open Across Days.

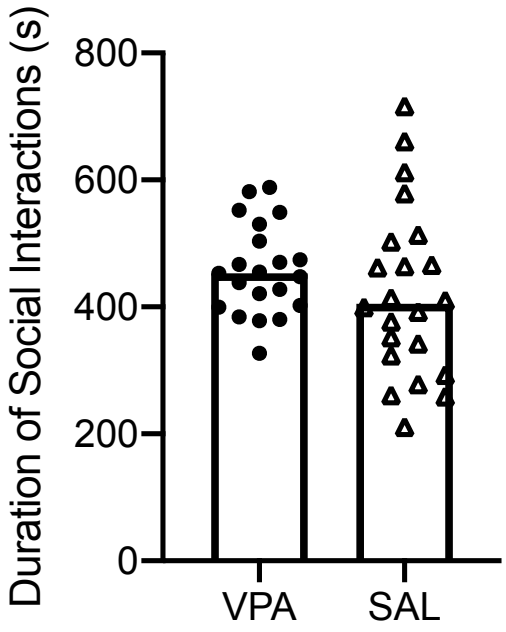


Note. Data points indicate the proportion of eyes open across all rat pups in a single litter. Circles and triangles show data for the two VPA litters and the two SAL litters, respectively.

Initial Assessments

In the first initial assessment, we found no significant differences in duration of social interaction across rats. As shown in Figure 5-3, VPA rats (*Med* = 453.00 s, *IQR* = 401.00 – 517.00) and SAL rats (*Med* = 404.80 s, *IQR* = 315.90 – 505.60) engaged in social interaction for a similar amount of time during this assessment, $U = 172.50$, $p = .1585$, although individual differences were greater for SAL rats than VPA rats. In addition, there were no significant differences in duration of social interaction between males (*Med* = 438.50 s, *IQR* = 388.30 – 488.80) and females (*Med* = 434.30 s, *IQR* = 338.30 – 535.10), $U = 220.00$, $p = .7959$. There was also no significant interaction between group and sex, $H = 2.78$, $p = .4268$. As shown in Table 5-1, the duration of social interaction was similar across dams exposed to both VPA and SAL.

Figure 5-3.
Duration of Social Interactions (s) in the Social Interaction Assessment.



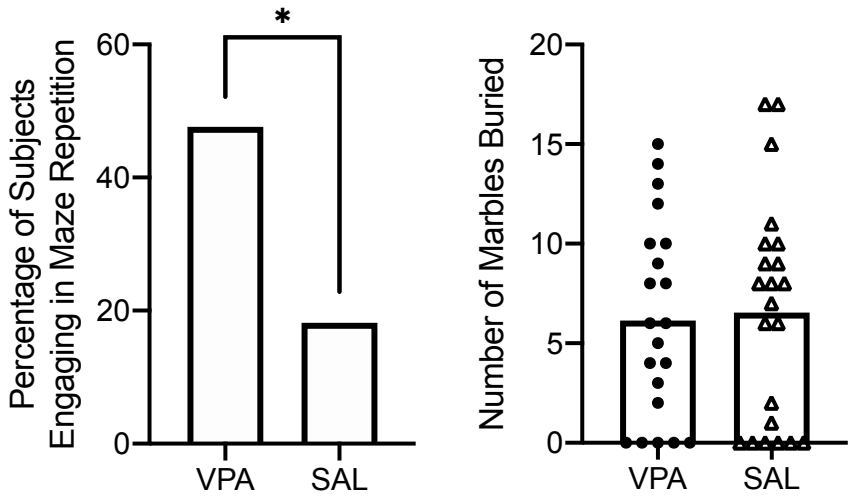
Note. Filled circles and open triangles represent individual subject data for VPA and SAL rats, respectively, and bars show the median for each group.

Rats exposed to VPA were more likely to behave repetitively in the Y-maze than SAL rats. A repetition was defined as entering the same arm of the maze twice (as opposed to exploring both arms). As shown in the left panel of Figure 5-4, 10 out of 21 VPA rats (47.6%) engaged in repetition, whereas only 4 out of 22 SAL rats (18.2%) engaged in a repetition, which was a significant difference, $F(1, 39) = 5.09$, $p = .0297$. There was no significant effect of sex in number of repetitions, $F(1, 39) = 1.89$, $p = 0.1766$, and there was no interaction between sex and group, $F(1, 39) = 1.09$, $p = 0.3020$. There were also no significant differences in the number of omissions between groups (VPA $M = 1.29$, $SD = 2.33$; SAL $M = 0.86$, $SD = 1.55$), $t(41) = 0.70$, $p = .4861$. As shown in Table 5-1, all four dams engaged in an alternation in the Y-maze, which is species-typical behavior.

There was no significant effect of VPA on the number of marbles buried in the marble-burying task. As shown in the right panel of Figure 5-4, the number of marbles buried was not significantly different for VPA rats ($M = 6.14$, $SD = 4.96$) and SAL rats ($M = 6.55$, $SD = 5.61$), $F(1, 39) = 0.02$, $p = .8881$. There was also no significant effect of sex (males $M = 5.43$, $SD = 4.88$; females $M = 7.23$, $SD = 5.54$) on the number of marbles buried, $F(1, 39) = 1.19$, $p = .2816$, and no significant interaction between sex and group, $F(1, 39) = 3.057$, $p = .0883$. As shown in Table 5-1, both SAL dams buried more marbles than both VPA dams.

In the open-field task, we measured instances of rearing, as well as time spent self-grooming, both of which are thought to be indicators of stereotypy. As shown in the left panel of Figure 5-5, the frequency of rearing during the assessment was higher for VPA rats ($M = 133.31$, $SD = 44.64$) than SAL rats ($M = 106.59$, $SD = 37.66$), $F(1, 39) =$

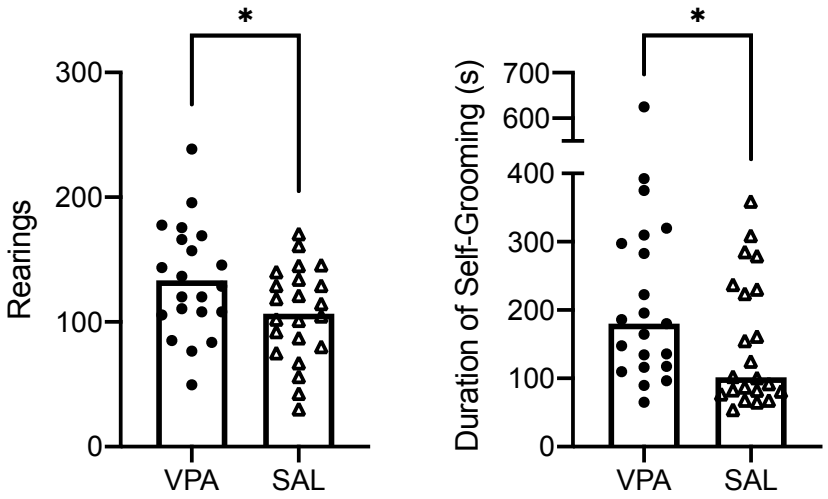
Figure 5-4.
Number of Subjects Engaging in Maze Repetition and Number of Marbles Buried.



Note. Percentage of subjects engaging in repetition for VPA and SAL rats in the Y-maze (*left panel*). Number of marbles buried for VPA and SAL rats in the marble-burying task (*right panel*). Filled circles and open triangles represent individual subject data for VPA and SAL rats, respectively, and bars show the mean for each group.

* $p < .05$

Figure 5-5.
Frequency of Rearing and Duration of Self-Grooming (s) in the Open-Field Test.



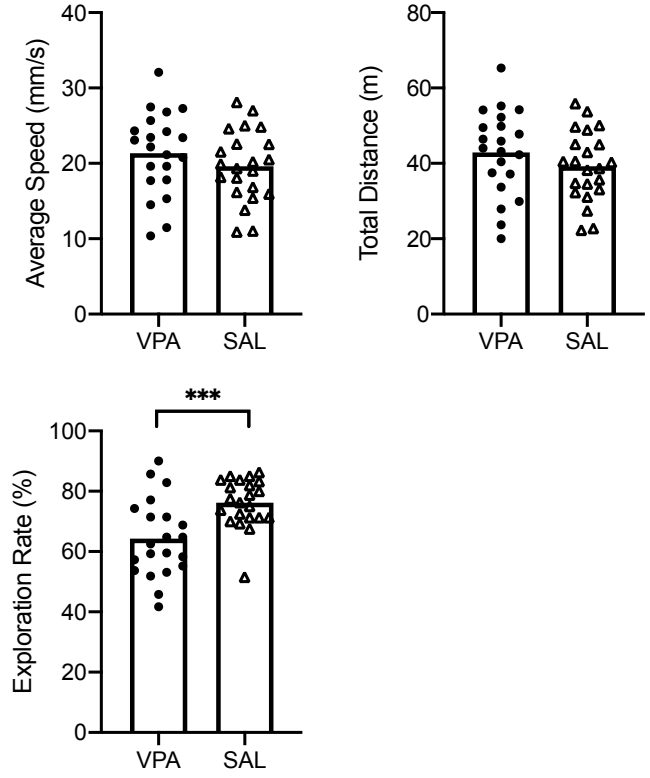
Note. Total instances of rearing during the open-field test (*left panel*). Duration of self-grooming (s) during the open-field test (*right panel*). For both panels, filled circles and open triangles represent individual subject data for VPA and SAL rats, respectively. Bars show the mean number of rearings and median duration of self-grooming across groups.

* $p < .05$

4.15, $p = .0485$. However, there were no significant differences in frequency of rearing between males ($M = 122.48$, $SD = 44.92$) and females ($M = 112.16$, $SD = 40.48$), $F(1, 39) = 1.118$, $p = .2968$, and no significant interaction, $F(1, 39) = 1.50$, $p = .2283$. The right panel of Figure 5-5 shows an increased duration of self-grooming in VPA rats (*Med* = 180.00 s, *IQR* = 116.80 – 303.80) compared to SAL rats (*Med* = 101.50 s, *IQR* = 80.00 – 232.10), $U = 144.50$, $p = .0352$. Self-grooming was similar for males (*Med* = 155.00 s, *IQR* = 98.50 – 258.00) and females (*Med* = 135.30 s, *IQR* = 82.88 – 288.10), $U = 213.00$, $p = .6695$, and there was no significant interaction, $H = 7.04$, $p = .0706$. As shown in Table 5-1, instances of rearing were relatively similar across VPA and SAL dams, but both SAL dams engaged in more self-grooming than both VPA dams.

In the open-field test, SAL rats tended to engage in more exploratory behavior than VPA rats, even though there were no differences in general locomotion. As shown in the top left panel of Figure 5-6, there were no significant differences in average speed of movement during the task across group (VPA $M = 21.35$ mm/s, $SD = 5.47$; SAL $M = 19.62$ mm/s, $SD = 4.73$), $F(1, 39) = 1.07$, $p = .3084$, or sex (males $M = 21.04$ mm/s, $SD = 5.25$; females $M = 19.92$, $SD = 5.04$), $F(1, 39) = 0.38$, $p = .5404$, and no significant interaction, $F(1, 39) = 1.295$, $p = .2621$. In addition, as shown in top right panel of Figure 5-6, there were no significant differences in total distance traveled across group (VPA $M = 42.88$ m, $SD = 11.35$; SAL $M = 39.26$ m, $SD = 9.26$), $F(1, 39) = 1.15$, $p = .2901$, or sex (males $M = 42.21$ m, $SD = 10.52$; females $M = 39.90$ m, $SD = 10.35$), $F(1, 39) = 0.40$, $p = .5317$, and no significant interaction, $F(1, 39) = 1.28$, $p = .2648$. Despite these non-significant differences in locomotor activity, there was a significantly higher exploration rate for SAL rats ($M = 76.0\%$, $SD = 8.07$) than VPA rats ($M = 64.0\%$, $SD = 12.87$), $F(1,$

Figure 5-6.
Average Speed (mm/s), Total Distance Traveled (m), and Exploration Rate (%) in the Open-Field Test.



Note. Average speed (mm/s) during the open-field test (*top left panel*). Total distance traveled (m) during the open-field test (*top right panel*). Exploration rate (percentage of zones entered) during the open-field test (*bottom panel*). For all panels, filled circles and open triangles represent individual subject data for VPA and SAL rats, respectively, and bars show the mean for each group.

*** $p < .001$

39) = 13.12, $p = .0008$, as shown in the bottom panel of Figure 5-6, although it is important to note the sizable individual differences, especially in VPA rats. There were no significant differences in exploration rate across sex (males $M = 71.0\%$, $SD = 13.57$; females $M = 70.0\%$, $SD = 10.94$), $F(1, 39) = 0.32$, $p = .5757$, and no significant interaction, $F(1, 39) = 0.00001$, $p = .9982$. As shown in Table 5-1, there were no major differences in average speed or total distance traveled across VPA and SAL dams, but one of the SAL dams engaged in much less exploration than the other three dams.

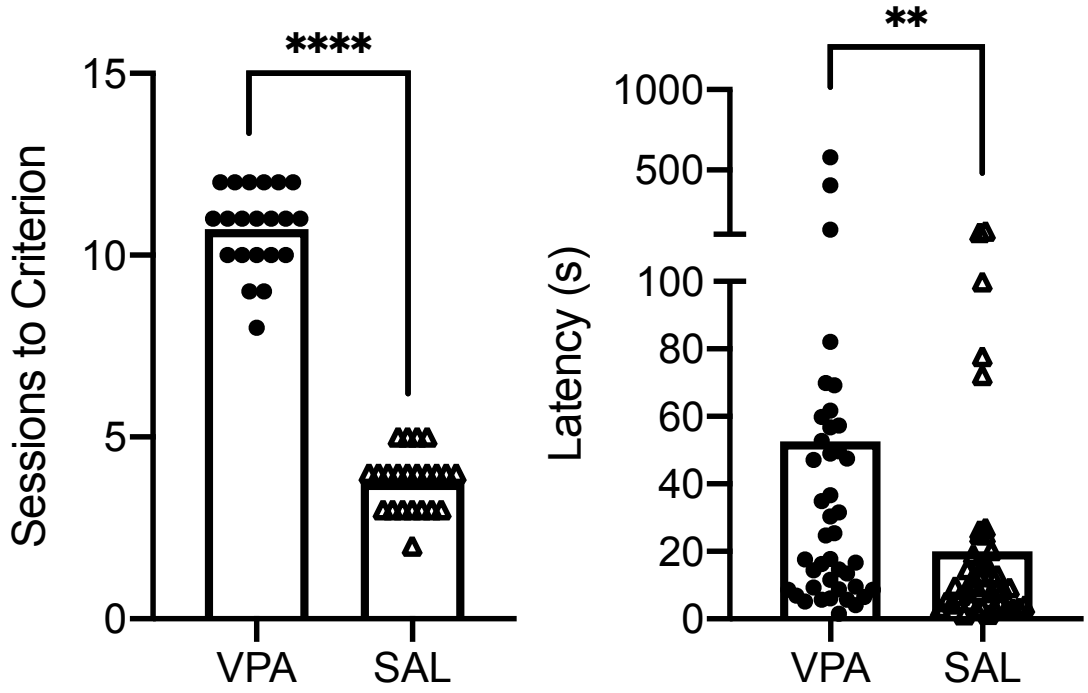
Pretraining

During pretraining, acquisition of lever pressing was significantly slower for VPA rats compared to SAL rats. We calculated the number of autoshaping sessions required to reach criterion (responding on 80% or more of trials) on each lever. As shown in the left panel of Figure 5-7, the number of sessions to criterion for both levers combined was significantly higher for VPA rats (M = 10.71; SD = 1.15) than SAL rats (M = 3.77, SD = 0.81), $F(1, 39) = 504.70$, $p < .00001$. There was no significant difference in sessions to criterion for males (M = 7.33, SD = 3.72) and females (M = 7.00, SD = 3.65), $F(1, 39) = 0.23$, $p = .6340$, and no interaction, $F(1, 39) = 0.002$, $p = .9612$. We also measured the latency to press each lever for the first time. As shown in the right panel of Figure 5-7, initial latencies for both levers were higher for VPA rats (Med = 21.25 s, IQR = 8.79 – 53.76) than SAL rats (Med = 9.44 s, IQR = 4.27 – 18.57), $U = 575.00$, $p = .0023$). Initial latencies were not significantly different for males (Med = 15.06 s, IQR = 7.06 – 50.38) and females (Med = 12.81 s, IQR = 5.17 – 25.29), $U = 772.50$, $p = .1923$. The Kruskall-Wallis H test to detect interactions was significant, $H = 10.31$, $p = .0161$; however, follow-up tests showed no significant interactions after correcting for multiple comparisons. Dams acquired lever pressing more rapidly than offspring; all four dams required only 3 total sessions to meet the criterion of responding on at least 80% of trials. Initial latencies were also generally lower for dams than offspring, but relatively similar for VPA and SAL dams.

Reinforced Behavioral Variability

As would be expected due to the probabilistic contingency, overall levels of behavioral variability, in terms of U-value, were relatively low across all rats during

Figure 5-7.
Sessions to Criterion in Pretraining and Latency (s) to First Lever Press.

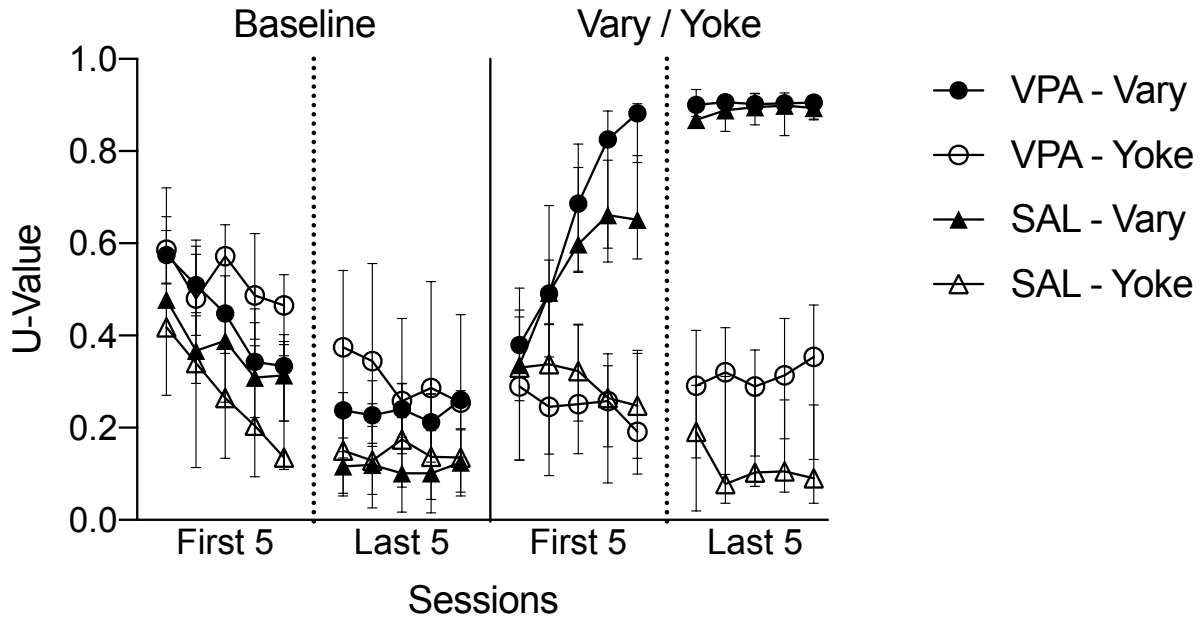


Note. Number of sessions required to meet criterion (responding on at least 80% of trials) on both levers during pretraining (*left panel*). Latency (s) to first lever press on each lever (*right panel*). Filled circles and open triangles represent individual subject data for VPA and SAL rats, respectively. Bars show the mean sessions to criterion and median latency across groups.

** p <.01
**** p < .0001

baseline. Figure 5-8 shows a steady decline in U-value from the first five sessions to the last five sessions of baseline. The top left and right panels of Figure 5-9 show individual subject U-values from the first and last session of baseline, respectively. In the first session of baseline, VPA rats (*Med* = 0.58, *IQR* = 0.51 – 0.66) had higher U-values than SAL rats (*Med* = 0.43, *IQR* = 0.31 – 0.63), U = 139.00, p = .0251, but there was no significant effect of contingency assignment (vary *Med* = 0.55, *IQR* = 0.42 – 0.64; yoked *Med* = 0.52, *IQR* = 0.34 – 0.63), U = 206.00, p = .5554, or interaction H = 6.589, p = .0862. By the last session of baseline, U-values had generally decreased for all rats, but

Figure 5-8.
Median U-Value Across Phases of the Reinforced Behavioral Variability Task.

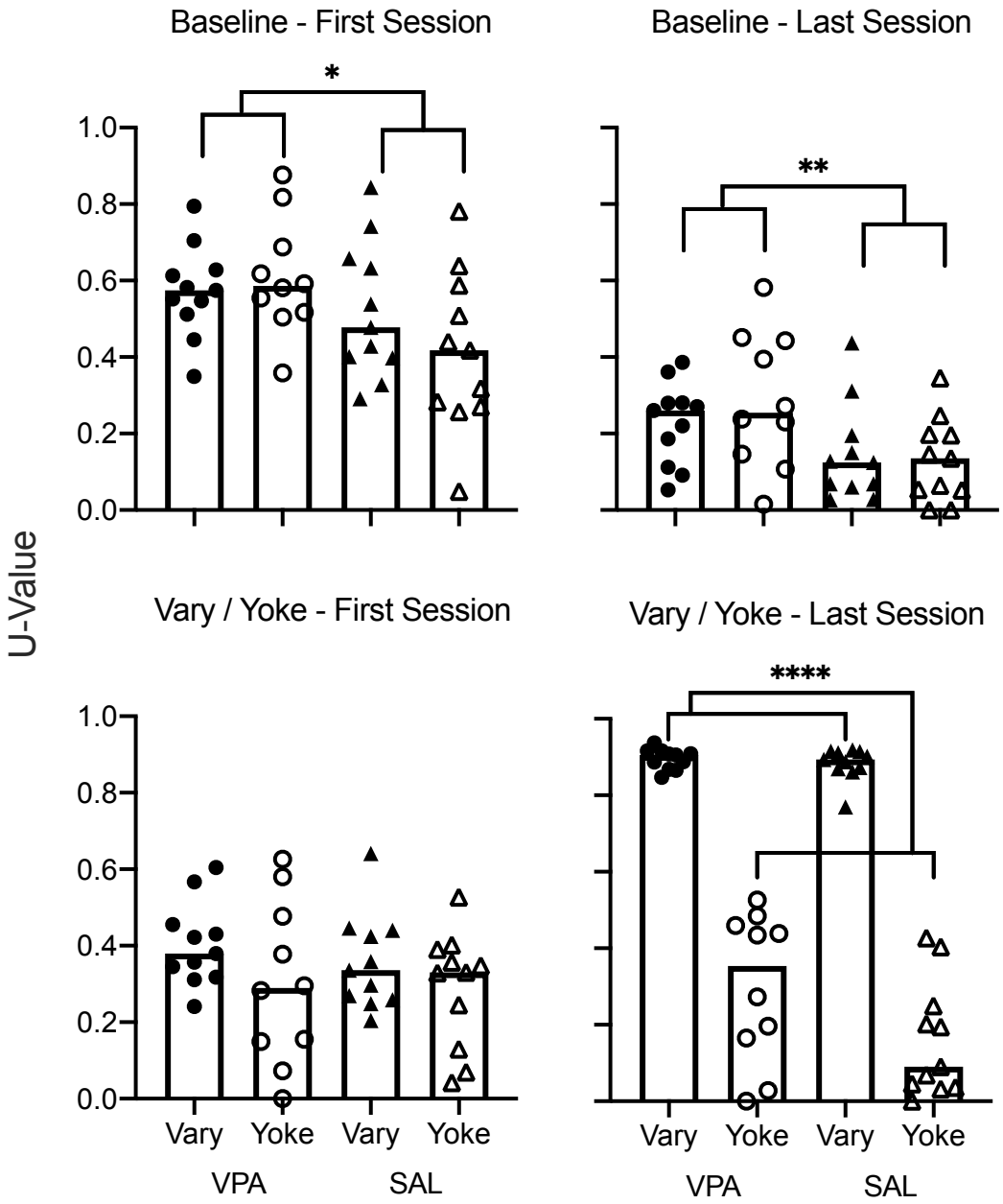


Note. Median U-values from the first five and last five sessions of each phase are presented. Filled and open symbols represent responding for the Vary and Yoke groups, respectively. Circles and triangles represent responding for VPA and SAL rats, respectively. Error bars display interquartile range.

VPA rats (*Med* = 0.26, *IQR* = 0.13 – 0.37) again had higher U-values than SAL rats (*M* = 0.13, *IQR* = 0.05 – 0.20), $U = 119.00$, $p = .0058$, with no effect of contingency (vary *Med* = 0.17, *IQR* = 0.07 – 0.28; yoked *Med* = 0.20, *IQR* = 0.06 – 0.31), $U = 226.00$, $p = .9086$, or interaction $H = 7.72$, $p = .0521$.

Supporting these results, the proportion of sequences meeting the threshold contingency was also low across all rats during baseline (see Figure 5-10). As shown in the top panels of Figure 5-11, there were minimal group or contingency differences. In the first session of baseline, there were no significant differences in the proportion of sequences meeting the threshold contingency between VPA (vary *M* = 0.19, *SD* = 0.07; yoked *M* = 0.23, *SD* = 0.07) and SAL rats (vary *M* = 0.19, *SD* = 0.12; yoked *M* = 0.13,

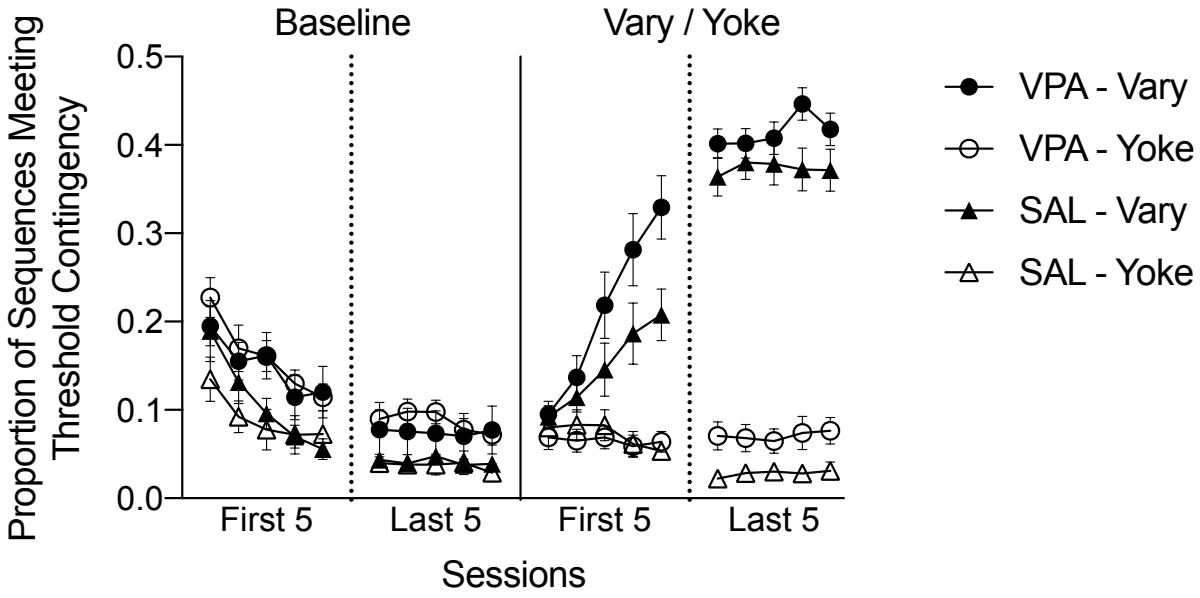
Figure 5-9.
U-Values from First and Last Sessions of Each Phase.



Note. U-values from the first and last session of each phase. Filled and open symbols represent individual subject data for the Vary and Yoke groups, respectively. Circles and triangles represent individual subject data for VPA and SAL rats, respectively. Bars show the median for each group.

* $p < .05$
** $p < .01$
**** $p < .0001$

Figure 5-10.
Mean Proportion of Sequences Meeting the Threshold Contingency Across Phases of the Reinforced Behavioral Variability Task.

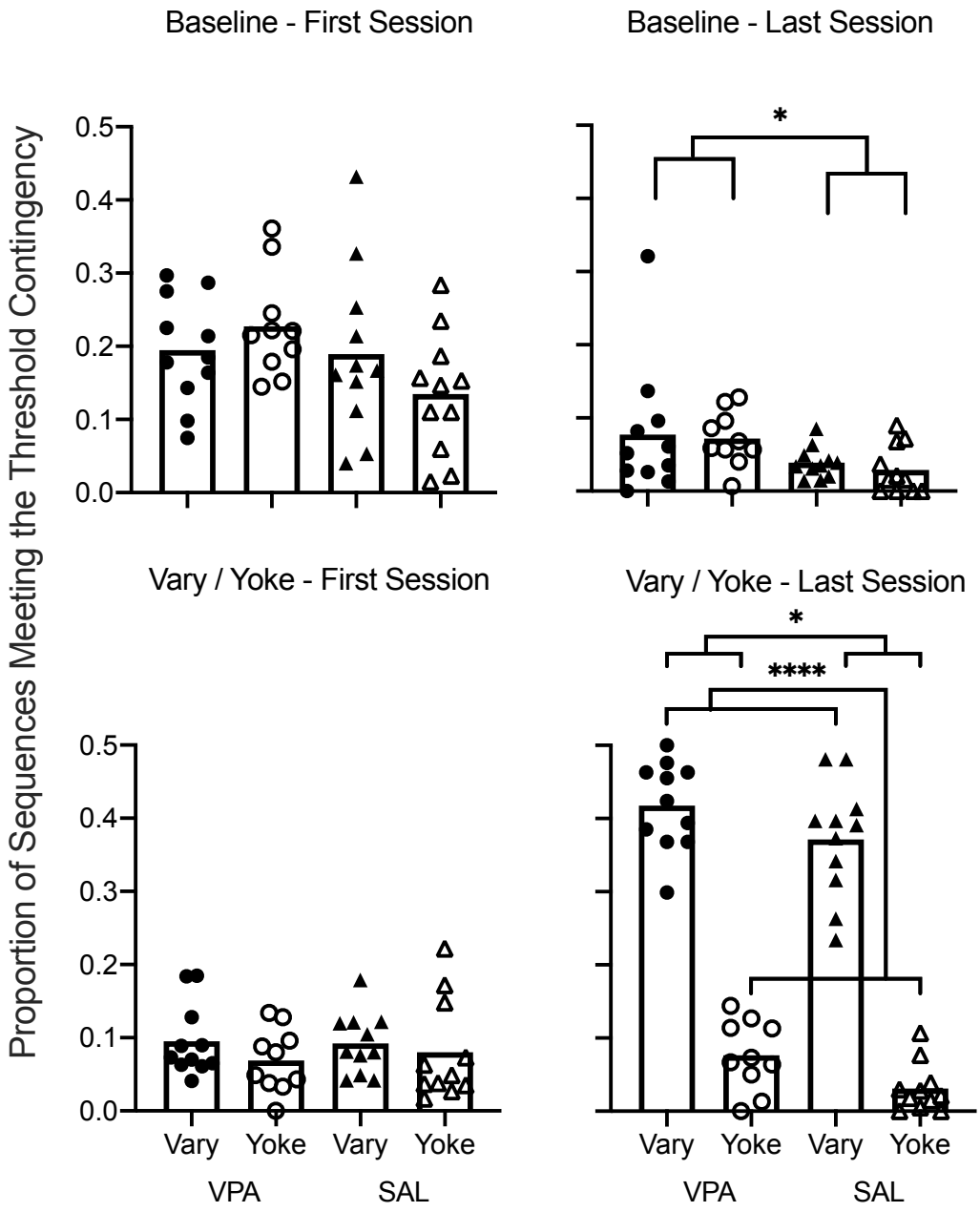


Note. Mean proportion of sequences meeting the threshold contingency from the first five and last five sessions of each phase are presented. Filled and open symbols represent responding for the Vary and Yoke groups, respectively. Circles and triangles represent responding for VPA and SAL rats, respectively. Error bars display standard error of the mean.

SD = 0.08), $F(1, 39) = 3.30$, $p = .0770$, no significant differences across contingencies, $F(1, 39) = 0.17$, $p = .6799$, and no significant interaction, $F(1, 39) = 2.65$, $p = .1117$. In the final session of baseline, the proportion of sequences meeting the threshold contingency was significantly higher for VPA rats (vary $M = 0.08$, $SD = 0.09$; yoked $M = 0.07$, $SD = 0.04$) compared with SAL rats (vary $M = 0.04$, $SD = 0.02$; yoked $M = 0.03$, $SD = 0.03$), $F(1, 39) = 6.38$, $p = .0157$. There was no significant effect of contingency, $F(1, 39) = 0.22$, $p = .6425$, and no significant interaction, $F(1, 39) = 0.02$, $p = .8931$.

In the next condition, half of the rats were required to respond on a variability contingency while the other half received yoked reinforcer rates, and all rats behaved

Figure 5-11.
Proportion of Sequences Meeting the Threshold Contingency from First and Last Sessions of Each Phase.



Note. Proportion of sequences meeting the threshold contingency from the first and last session of each phase. Filled and open symbols represent individual subject data for the Vary and Yoke groups, respectively. Circles and triangles represent individual subject data for VPA and SAL rats, respectively. Bars show the mean for each group.

* $p < .05$
**** $p < .0001$

accordingly. As shown in Figure 5-8, U-values rapidly increased for vary rats but remained low for yoked rats. This effect is also seen in the bottom panels of Figure 5-9, which display individual subject data from the first and last session of the condition. We observed no significant difference in U-value between VPA (*Med* = 0.36, *IQR* = 0.26 – 0.47) and SAL rats (*MED* = 0.33, *IQR* = 0.25 – 0.41), *U* = 202.00, *p* = .4926, no significant effect of contingency (vary *Med* = 0.36, *IQR* = 0.29 – 0.44; yoked *Med* = 0.33, *IQR* = 0.14 – 0.40), *U* = 166.00, *p* = .1178, and no significant interaction, *H* = 3.15, *p* = .3691. However, by the last session of the condition, there was a clear effect of contingency. U-values were significantly higher for vary rats (*Med* = 0.90, *IQR* = 0.87 – 0.91) than yoked rats (*Med* = 0.20, *IQR* = 0.04 – 0.43), *U* = 0, *p* < .0001. U-values were similar for VPA (*Med* = 0.85, *IQR* = 0.35 – 0.91) and SAL rats (*Med* = 0.60, *IQR* = 0.09 – 0.90), *U* = 197.50, *p* = .4232. Finally, there was a significant interaction, *H* = 32.19, *p* = <.0001. Specifically, the effect of contingency, i.e., higher levels of variability for vary rats compared to yoked rats, was evident within each group (VPA *p* = .0015; SAL *p* <.0001).

Again, the proportion of sequences meeting the threshold contingency supported these findings for the second condition. As shown in Figure 5-10 and the bottom panels of Figure 5-11, this measure increased steadily for vary rats and remained low for yoked rats. In the first session of the vary and yoked conditions, we observed no significant difference in the proportion of sequences meeting the threshold contingency between VPA (vary *M* = 0.10, *SD* = 0.05; yoked *M* = 0.07, *SD* = 0.04) and SAL rats (vary *M* = 0.09, *SD* = 0.04; yoked *M* = 0.08, *SD* = 0.07), *F*(1, 39) = 0.07, *p* = .7960, no significant effect of contingency, *F*(1, 39) = 1.49, *p* = .2296, and no significant interaction, *F*(1, 39)

= 0.20, p = .6600. In the final session, however, the proportion of sequences meeting the threshold contingency was significantly higher for VPA (vary M = 0.42, SD = 0.06; yoked M = 0.08, SD = 0.05) than SAL rats (vary M = 0.37, SD = 0.08; yoked M = 0.03, SD = 0.03), $F(1, 39) = 6.76$, p = .0131. Rats in the vary group also had a higher proportion of sequences meeting the threshold contingency than those in the yoked group, $F(1, 39) = 373.90$, $p < .0001$, but there was no significant interaction, $F(1, 39) = 0.0002$, p = .9888.

Finally, as shown in Figure 5-1, U-values and the proportion of sequences meeting the threshold contingency for dams were similar to those measures in offspring. In baseline, U-values and proportions of sequences meeting the threshold contingency were low to moderate throughout the phase. Conversely, in the second phase, U-values and proportions of sequences meeting the threshold contingency rose rapidly for vary dams and remained low for yoked dams. By the end of the phase, all rats were responding according to the contingencies in place, evidenced by the vary and yoked dams' exceptionally high and low U-values and proportions of sequences meeting the threshold contingency, respectively.

Discussion

The results of the present study provide limited support for the validity of the VPA rat model of ASD. In this experiment, we exposed pregnant rats to either VPA or SAL on the twelfth day of gestation. Then, we assessed some of the core symptoms of ASD – social interaction and restricted, repetitive behaviors – in the offspring. Based on previous research, we hypothesized that rats exposed to VPA in utero would present with impaired social interaction and excessive restrictive, repetitive behaviors. Consistent with

this hypothesis, we observed more repetitions in a maze, decreased exploration, more rearing, more self-grooming, and slower acquisition of lever pressing in VPA rats compared with SAL rats. In addition, VPA offspring were less viable than SAL rats, displaying several health abnormalities. Inconsistent with our hypothesis, we found no difference between VPA and SAL rats in social interaction or marbles buried. Unexpectedly, VPA rats behaved slightly more variably than SAL rats during the reinforced behavioral variability task, although it should be noted that the differences in U-value and the proportion of sequences meeting the threshold contingency were relatively minimal.

Exposure to VPA in utero adversely impacted offspring viability. On PND 8 and PND 21, VPA rats weighed significantly less than SAL rats, which is supported by the current literature (Schneider & Przewłocki, 2005). Schneider and Przewłocki also observed a delay in eye-opening, a finding which we did not replicate. However, our null effect of VPA on eye-opening is consistent with other research in this area (Reynolds et al., 2012). We also observed several health abnormalities in VPA rats, including chromodacryorrhea (also observed by Favre et al., 2013), severe self-injury, and premature death (two VPA rats did not survive past PND 30, whereas no SAL rats were lost). These findings indicate that VPA exposure may result in some unfavorable health outcomes, in addition to any adverse behavioral effects.

We observed no deficits in social interaction for VPA rats compared to SAL rats. This finding is at odds with the majority of the present literature. Although some researchers have observed no difference between VPA and SAL rodents in terms of social behavior (e.g., Narita et al., 2010; Schneider & Przewłocki, 2005), many other

researchers have shown impaired social interaction (e.g., Dufour-Rainfray et al., 2010; Kataoka et al., 2011; Kim et al., 2011; Markram et al., 2008; Mohammadi et al., 2020; Schneider et al., 2008). It should be noted that a variety of social-interaction assessments have been used in the literature. Because behavioral variability, not social interaction, was the main purpose of the present study, we selected one of the simplest social-interaction assessments available, the social-interaction open-field assessment. Our test involved placing the experimental rat in an arena with a stranger rat and measuring the total time the experimental rat spent engaging in social interactions. However, other assessments have focused on play behavior, sniffing, and social grooming. One other assessment that has been used to investigate social behavior in rodents is the three-chamber social-interaction test (e.g., Dufour-Rainfray et al., 2010; Kim et al., 2011; Roullet et al., 2013). In this assessment, rats are placed in a three-chambered apparatus. The experimental rat is placed in one chamber, and the other two chambers contain either another rat or nothing. VPA rats have been shown to spend more time in an empty chamber than a chamber with another rat, which is interpreted as a deficit in social behavior (e.g., Dufour-Rainfray et al., 2010). The three-chamber and open-field social-interaction assessments are quite different from each other and may well be measuring distinct aspects of social behavior. The validity of these and similar assessments of social interaction has been called into question, and the development of new and improved procedures is a critical future direction, outside the scope of the present study (Crawley, 2004).

Some limited evidence from the current experiment supported the finding that VPA rats are more likely to engage in restricted and repetitive behaviors and less likely to

engage in exploratory behaviors. In the Y-maze used in the present study, VPA rats were significantly more likely to make a repetition (i.e., enter the same arm on two consecutive trials), supporting prior research (e.g., Markram et al., 2008). Control rats have shown a tendency to alternate (i.e., enter two different arms on two consecutive trials), which is perhaps a manifestation of innate exploratory behavior. For example, Markram et al. found that only 24% of untreated rats engaged in repetition, and in the present study, only 18% of SAL rats engaged in repetition, both well below chance. Conversely, VPA rats were significantly more likely to engage in repetition; 51% (Markram et al., 2008) and 48% (present study) of VPA rats entered the same arm twice. In other words, VPA rats were less likely to engage in species-typical exploratory behavior and more likely to respond repetitively.

Excessive stereotypy and a disinclination to explore were also observed for VPA rats in the open-field test. For each rat, we recorded the number of times the rat engaged in rearing (i.e., any instance in which the rat stood on its hind legs, such that its body was vertical), the amount of time spent self-grooming, and exploration rate (percentage of arena entered), three measures of behavioral stereotypy. We observed a significantly higher frequency of rearing, an increased duration of self-grooming, and a decreased exploration rate in VPA rats compared to SAL rats. These findings replicated previous research showing increased vertical locomotor activities (i.e., rearing; Mohammadi et al., 2020) and increased exhibition of stereotypic tendencies in the form of self-grooming (e.g., Gandal et al., 2010; Mehta et al., 2011; Wagner et al., 2006) in VPA rats compared to SAL rats. Additionally, the decreased exploration rate in our study was observed despite no difference in general activity (distance traveled and average speed), which

indicates that VPA may impact repetitive behavior selectively, without altering overall motor function.

Although increased repetitive behavior was observed for VPA rats in the Y-maze and in some aspects of the open-field test, not all measures of repetitive behavior revealed the same effect. For example, VPA rats and SAL rats buried the same number of marbles on average in the marble-burying task. Previous research has reported that VPA-treated animals buried more marbles than controls (e.g., Mehta et al., 2011; Wagner et al., 2006). One potential reason for the discrepant findings is that all prior studies were conducted with VPA mice, as opposed to rats, as in the present study. Anecdotally, the rats in our study did not seem to be specifically burying the marbles. Instead, rats either did not engage with the marbles or bedding, or they simply dug in the bedding without regard to the marbles. The marbles became buried as a result of the digging, but the rats did not seem to be attending to the marbles themselves (i.e., the rats did not touch the marbles except in passing). It is possible that the marble-burying task is not the most appropriate measure of stereotypy in rats. Although the marble-burying task has been used in rats in studies unrelated to VPA (e.g., Schneider & Popik, 2007), differences in these cases were typically observed after multiple tests. Furthermore, the marble-burying task is not always described as an index of stereotypy. Schneider and Popik stated that increased burying could be taken as a measure of anxiety or impulsivity. Given that the marble-burying task has primarily been conducted in VPA mice, not rats, the anecdotal observations of digging unrelated to the marbles in the present study, and the potential need for repeated testing, our null results do not necessarily invalidate the VPA rat model of ASD. Further research should be conducted to address these concerns.

Further group differences were observed during operant training. During autoshaping, we continued running sessions with a pair of rats until both rats pressed the extended lever on at least 80% of trials for both levers. VPA rats required significantly more sessions to individually reach this criterion than SAL rats. In addition, VPA rats had a higher latency to respond for the first time on each lever. One possible explanation for these results is that there was a significant size difference across rats when beginning operant training. Throughout development, we observed that VPA rats weighed significantly less than SAL rats; thus, it may have been more difficult for VPA rats to depress the levers with sufficient force to complete responses reliably, which is why more training sessions were required. Another potential interpretation is that overall learning may have been impaired in VPA rats, as opposed to behavioral variability. It is possible that VPA exposure resulted in a decreased sensitivity to environmental consequences, such that even training lever presses was a challenge. Although not considered one of the core deficits of ASD, many individuals with ASD are diagnosed with comorbid intellectual and developmental disabilities and experience slower learning (LoVullo & Matson, 2009). One potential reason for impaired learning is that individuals with ASD seem to be less sensitive to environmental consequences. This interpretation has been supported in the literature (e.g., Fisher et al., 2014), including a decreased sensitivity to pain in individuals with ASD (see Moore, 2015, for a review) and VPA rats (e.g., Schneider & Przewłocki, 2005). Therefore, when presented with reinforcement contingencies, the behavior of these individuals may be slow to correspond to those contingencies, resulting in global behavioral deficits. This hypothesis is limited, however,

because we observed no delay in adjusting to the introduction of the variability contingency for VPA rats.

Based on previous research and the results from our initial assessments, we expected that VPA rats would behave less variably than SAL rats in a reinforced behavioral variability task. Individuals with ASD behave less variably than control participants in reinforced behavioral variability tasks (Miller & Neuringer, 2000). If the VPA rat model of ASD is valid, similar results should be seen across individuals with ASD and VPA rats. However, we observed either no effect or an effect in the opposite direction throughout our reinforced behavioral variability task. In the first and last sessions of baseline, U-values for VPA rats were significantly higher than those for SAL rats. This effect was directly opposed to our predictions based on the previous literature. For the VPA rat to be a valid model of ASD, the rats should behave similarly in a reinforced behavioral variability task to humans with ASD. The finding that VPA rats behaved more variably in the reinforced behavioral variability task than SAL rats severely limits its potential use as an animal model of ASD. Further research will be necessary to determine the replicability of this effect, especially given the substantial within-subjects variance in this experiment.

If the unexpected finding of increased levels of variability for VPA rats in the reinforced behavioral variability task is replicated in future research, there are a number of potential explanations. For example, it is possible that we would have achieved different results using different procedural details (e.g., manipulating the stringency of the variability criterion; implementing other variability schedules, such as a lag schedule; manipulating the response length of each sequence or the effort required to make a

response; adding discriminative stimuli to indicate a change in conditions; including more within-subjects comparisons by reversing the contingencies; etc.). Based on the current data, it is unclear what effects we would predict for each of these manipulations, and future research should be conducted to investigate further.

This study is not the first to generate these kinds of unexpected data. Arnold and Newland (2018) used a reinforced behavioral variability task to assess stereotypy in the BALB/c mouse model of ASD. Contrary to the hypothesis that animal models of ASD will behave overly repetitively in all cases, Arnold and Newland found that BALB/c mice behaved less variably than controls during baseline but more variably when a variability contingency was in place. This result was interpreted as an increased sensitivity to consequences in BALB/c mice. Unlike this study, our results showed increased levels of variability during baseline. Therefore, one conceivable explanation for the increased levels of variability we observed is that individuals with ASD, and possibly VPA rats (unlike BALB/c mice), tend to be less sensitive to environmental consequences. With no variability contingency in place (i.e., baseline, yoked), the most efficient way to respond is to behave as repetitively as possible. Repetitive responses tend to be less effortful and can occur more rapidly, and do not impact the probability of reinforcement. Therefore, most organisms quickly learn to behave stereotypically in these situations. However, the VPA rats did not adjust their behavior to the extent that would have been expected, perhaps because their behavior was generally less sensitive to the contingency of reinforcement. Evidence against this theory is that VPA rats responded quickly to the introduction of the variability contingency, similar to SAL rats. The question then becomes why the VPA rats' behavior was relatively insensitive to consequences in the

baseline and yoked conditions, but apparently quite sensitive to consequences with a variability contingency in place. There may be fundamental differences between contingencies that permit any response, such as baseline and yoked, and contingencies that require a specific type of responding, such as a variability contingency.

In fact, one possibility is that responding on a variability contingency is not necessarily indicative of behavioral variability in the way we have been conceptualizing it. We have been working under the assumption that behavioral variability is an operant, in that it is sensitive to consequences and controlled by antecedents (see Neuringer, 2002, for a review). In other words, organisms learn to vary their behavior, possibly even to behave semi-randomly, when responding on these contingencies. This type of learned variability may not be opposite or even related to behavioral stereotypy. The processes governing learned, or operant, variability may differ from those that produce abnormal stereotypy in individuals with ASD.

However, there are other theories of how variability contingencies produce variable behavior, in addition to the theory that behavioral variability is an operant. For example, the behavioral variability observed in variability tasks may be a byproduct, or artifact, of the specific procedural details. We may be inadvertently reinforcing some other aspect of behavior (e.g., switching between levers; Machado, 1997), which results in variability. Variability may also be induced by cycles of extinction and reinforcement (e.g., Holth, 2012) or may be the result of negative frequency-dependent selection (i.e., constantly reinforcing the least frequent sequences, resulting in a wide distribution of responses; Barba, 2014; Machado & Tonneau, 2012). If behavioral variability arises in variability tasks due to one of these explanations, then the task may not have been

informative regarding assessment of learned variable behavior in the VPA rat model of ASD. We hypothesized that VPA rats would behave more repetitively on the variability task because of a tendency to engage in excessive stereotypy or difficulty learning to vary, similar to humans with ASD. If variability is a byproduct of our procedures, however, individual differences in behavioral variability or stereotypy may not manifest in this task. More basic research is needed to understand reinforced behavioral variability before we can draw any definitive conclusions about its implications for variability in clinical populations.

Finally, one possible interpretation of our results is that the VPA rat model simply does not effectively characterize some critical behavioral aspects of ASD. Regardless of the similarities in symptomology in some assessments, VPA rats seem to behave more variably than controls in an operant task, unlike humans with ASD (e.g., Miller & Neuringer, 2000). If VPA rats tend to respond more variably than individuals with ASD, then future research should focus on exploring novel animal models that better represent all of the complex features of ASD. The translational goal of discovering interventions that may improve the quality of life for individuals with ASD by testing those interventions with an animal model can only be accomplished after an accurate model is identified. A variety of animal models of ASD have been developed (e.g., Lewis et al., 2007) and are relatively untested, especially using operant tasks like reinforced behavioral variability.

In the present experiment, no statistically significant sex differences emerged for any of our primary dependent measures. It is well documented that male children are at least three times more likely to be diagnosed with ASD than female children (e.g.,

Loomes et al., 2017; although there is a question of whether this effect is due to physiological sex differences or a gender bias in diagnosis). Therefore, we would have expected to see similar sex differences in an animal model of ASD. Sex differences in VPA rats have been apparent in some, but not all, of previous research, but observed differences tended to be on a neural, as opposed to behavioral, level. For example, Weinstein-Fudim et al. (2019) reported sex differences in gene expression after prenatal VPA exposure. Additionally, Raza et al. (2015) found sex differences in neuroanatomical pathology but not behavioral measures. Perhaps consistent with these findings, VPA male rats in the present experiment experienced some health abnormalities (e.g., chromodacryorrhea), whereas these problems did not occur for VPA females or SAL rats. It is possible that VPA physiologically affected males more so than females, even though we did not observe behavioral changes. Based on the present findings and the existing literature, it seems that VPA may have a sex-specific impact on physiologic development, in that males are more affected than females, but this difference does not necessarily extend to behavioral measures.

The present experiment did have some limitations. First, our sample size was smaller than anticipated. Although a post-hoc power analysis revealed that our obtained sample size of $n = 43$ offspring was sufficient to detect a medium to large effect size ($d = 0.44$), future research using larger sample sizes would increase statistical power. A second limitation is that we determined VPA and SAL assignment by cohort, as opposed to random assignment, even though all other assignments (pair-housing and matching) were randomly determined. Future research should include random assignment for all factors.

The results of the current study provide limited support for the VPA rat model of ASD. Compared to SAL rats, VPA rats showed increased repetitions in the Y-maze, decreased exploration rates in an open field (despite no difference in overall activity), increased rearing, and increased self-grooming, replicating prior research. However, we found no difference between VPA and SAL rats in social interaction or marbles buried, which is inconsistent with previous research. Finally, we also observed the novel findings of slower acquisition of lever pressing, and, surprisingly, slightly higher levels of behavioral variability throughout the reinforced behavioral variability task in VPA rats. Our results do not definitively support nor eliminate the VPA rat as a potential model of ASD; therefore, further investigation of the validity of the VPA rat model of ASD is warranted. If the VPA rat model of ASD is valid, there are a number of interesting future directions to pursue. First, it would be useful to test these rats in other behavioral tasks that may more accurately reflect the deficits observed in humans (e.g., other operant tasks). Additionally, this model should be compared to other existing animal models of ASD. There are a number of genetic and environmental rodent models that are worth considering (e.g., Crawley, 2012; Erdoğan et al., 2017; Ey et al., 2011). The existence of both genetic and environmental animal models of ASD points to the wide variance in (and lack of understanding of) the etiology of the disorder.

Finally, an ultimate goal of this research would be to develop interventions that mitigate the symptoms of ASD. If we can establish a strong animal model of ASD, then we can test various interventions to determine which are most promising before attempting to implement them clinically. For example, the adverse effects of VPA exposure have been reversed using various medications in rats (e.g., Kim et al., 2014,

2017). Additionally, Favre et al. (2015) showed that a predictable, enriched environment prevented the development of abnormal social and emotional (e.g., fear conditioning, anxiety) behavior, although such mitigation was not observed in a repetition task (i.e., Y-maze). More research is needed to test the potentially beneficial effects of physiological and environmental manipulations on social and stereotyped behavior in VPA rats and other animal models of ASD.

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CHAPTER 6

GENERAL DISCUSSION

The four studies discussed in this dissertation illuminate the importance of translational research on reinforced behavioral variability. Our studies demonstrated persistence and relapse of reinforced behavioral variability in pigeons and humans, assessed choice for reinforced behavioral variability in children with autism spectrum disorder (ASD), and investigated reinforced behavioral variability in a rat model of ASD. Our results have important theoretical and clinical implications for understanding reinforced behavioral variability and its relation to ASD.

Study One:

Persistence and Relapse of Reinforced Behavioral Variability in Pigeons

Our first set of basic experiments provided evidence for relapse of reinforced behavioral variability in pigeons, using rapid reacquisition, reinstatement, and resurgence paradigms (Galizio et al., 2018; Chapter 2). Despite previous research indicating that reinforced behavioral variability is not readily disrupted by environmental changes (e.g., Abreu-Rodrigues et al., 2004; Cohen et al., 1990; Crow, 1988; Doughty & Lattal, 2001; McElroy & Neuringer, 1990; McKinley et al., 1989; Morris, 1990; Odum et al., 2006; Pesek-Cotton et al., 2011; Wagner & Neuringer, 2006; Ward et al., 2006), our findings showed a selective reduction in levels of behavioral variability as a result of the removal of food reinforcement (i.e., extinction). Behavioral variability subsequently increased when the contingencies were restored (i.e., rapid reacquisition; Experiment 1), when food was delivered response-independently (i.e., reinstatement; Experiment 2), and when food was removed for repetitive responding (i.e., resurgence; Experiment 3).

These findings have important theoretical implications. Given that relapse is an important characteristic of operant behavior, the evidence that reinforced behavioral variability is susceptible to relapse supports the conceptualization of variability as an operant (e.g., Neuringer, 2002). However, it is important to note that relapse is not unique to operant behavior (e.g., Bouton, 2002), and the relapse of reinforced behavioral variability does not rule out other potential explanations. For example, if behavioral variability is an artifact of the intermittent reinforcement imposed by variability contingencies (as has been proposed by Holth, 2012), then the high levels of behavioral variability observed in relapse preparations could have been induced by extinction. Alternatively, reinforced behavioral variability may be produced as a result of negative frequency-dependent selection, in which sequences are cyclically reinforced and extinguished based on their relative frequencies (i.e., the balance hypothesis; Barba, 2015; Machado & Tonneau, 2012). During extinction, the relative frequencies of each sequence would gradually fall to near-zero levels, but certain environmental manipulations (e.g., restoration of the contingencies [reacquisition], response-independent reinforcer deliveries [reinstatement], and extinction of an alternative response [resurgence]) could cause relative frequencies of each sequence to return to pre-extinction levels. The balance hypothesis could also account for the greater persistence of reinforced behavioral variability compared to repetition observed in previous research (see Doughty & Lattal, 2001).

The finding that reinforced behavioral variability is susceptible to relapse is potentially useful in developing interventions to promote variability in individuals with ASD. If variability is likely to recur under certain conditions, then learned variability may

be more resilient to treatment challenges (e.g., treatment infidelity). More research is needed, however, to determine the best practices for ensuring that reinforced behavioral variability will be maintained in applied settings.

Study Two:

An Investigation of Resurgence of Reinforced Behavioral Variability in Humans

The second basic study provided some evidence of resurgence of reinforced behavioral variability in college students (Galizio et al., under review; Chapter 3). Although the variability task we used reliably produced and maintained variable behavior (Ross & Neuringer, 2002), it can be difficult to distinguish between resurgence of reinforced behavioral variability and other phenomena. We employed the use of a cluster analysis to identify four main patterns of responding, or classes. Data from participants in the first class supported the finding of *resurgence* of reinforced behavioral variability. Data from participants in the second class were most likely the result of the participants engaging in *rule-governed behavior*, and not always behaving in line with the contingencies in place. Data from participants in the third class were indicative of *extinction-induced response variability*, as opposed to the recurrence of learned variability. Data from participants in the final class were mixed; this class was designated as *uncategorized*.

These data could add to our understanding of reinforced behavioral variability. Data from the resurgence class support the interpretation of variability as an operant (Neuringer, 2002), although, as in Study 1, other explanations cannot be ruled out. Data from the extinction-induced response variability class point to the interpretation of

variability as a byproduct (e.g., Holth, 2012) but also do not rule out other theories, such as variability as an operant. Further research is needed to better test these hypotheses.

Finally, data from the rule-governed behavior and uncategorized classes elucidate some of the difficulties involved when working with humans. There are many unknown and uncontrollable factors affecting the behavior of humans. For example, instructions have been shown to influence behavioral variability in humans (e.g., Souza et al., 2012), so it is highly likely that participants were engaging in covert verbal behavior (e.g., rule-following based on the task instructions or based on self-imposed rules) during the task. Anytime reinforced behavioral variability is applied to humans, especially humans with advanced verbal behavioral repertoires, there is a risk that they are not responding to the actual contingencies in place, an important consideration for application.

Study Three:

Choice for Reinforced Behavioral Variability in Children with Autism Spectrum Disorder

Our third study was an applied replication and extension of the literature on choice and behavioral variability (Galizio et al., 2020; Chapter 4). After being taught to play variably and repetitively in the presence of different stimuli, children with ASD were offered a choice between playing variably or playing repetitively. Although one participant selected both options equally, indicating indifference, the other two participants showed a slight preference for playing variably. These results contradicted our hypothesis that individuals with ASD would prefer repetition, due to their apparent symptomology. This finding has important implications for theory and practice.

Consistent with findings with pigeons (e.g., Abreu-Rodrigues et al., 2005) and college students (e.g., Abreu-Rodrigues et al., 2007), Study 3 showed that, after being taught to behave variably using a lag schedule, some individuals with ASD also display a slight preference for reinforcement of behavioral variability over repetition. These results indicate that some individuals with ASD may behave repetitively, not necessarily because they prefer to, but because they have not yet learned how to behave variably. At the least, our data do not support the interpretation that individuals with ASD prefer to behave repetitively when they are able to behave both variably and repetitively.

In terms of informing clinical interventions, the finding that some individuals with ASD prefer variation is useful in designing treatments. If individuals with ASD are simply taught to behave variably, they may choose to do so without any additional training, which means that we should be implementing lag schedules more frequently to provide individuals with ASD the choice to behave variably. For individuals who show indifference or who might choose repetition more frequently, other strategies could be employed to shift preference to variability. For example, one could increase the rate, magnitude, or quality of reinforcement provided for playing variably, or the variability or repetition requirements could be altered to make variable play less effortful. Also critical to future research are comparisons to typically developing individuals. Before proceeding too far with variability interventions for children with ASD, we need a better understanding about how much behavioral variability is typical in, expected of, and preferred by typically developing children.

Study Four:

Reinforced Behavioral Variability in the Valproate Rat Model of Autism Spectrum Disorder

The final study was a translational investigation of reinforced behavioral variability in the valproate (VPA) rat model of ASD. In order for this model to be considered valid, similar symptoms to humans with ASD (e.g., excessive stereotypy) should be observed. We decided to test the VPA rat model for excessive stereotypy in a variety of tasks, including reinforced behavioral variability. Consistent with previous research, we found that rats exposed to VPA in utero tended to engage in more repetitive maze completion (Markram et al., 2008), decreased exploration in an open field (Mehta et al., 2011), increased rearing (Mohammadi et al., 2020), and increased self-grooming (Mehta et al., 2011), compared to controls, all of which are behavioral markers of stereotypy. We also observed that VPA rats acquired lever pressing more slowly than controls, which could model the intellectual and developmental delays sometimes observed in children with ASD (LoVullo & Matson, 2009). These data point to the validity of the VPA rat model of ASD.

However, we also observed evidence that VPA rats behaved inconsistently with individuals with ASD. In contrast with prior research, we observed no difference in the number of marbles buried, another potential indicator of stereotypy, by VPA rats compared to controls (Mehta et al., 2011). Finally, the results from the reinforced behavioral variability assessment were unexpected and inconsistent with our hypothesis that the VPA rat serves as a model for ASD. During baseline, with no variability contingency in place, VPA rats behaved *more* variably than controls, and with a

variability contingency in place, levels of variability were similar across groups. These data are the opposite of what would be expected, based on the findings from reinforced behavioral variability tasks in humans with ASD (Miller & Neuringer, 2000). Therefore, the validity of the VPA rat model of ASD is limited.

One future direction for translational work could be focused on developing and testing the VPA rat model, as well as other animal models, of ASD. A large number of animal models of ASD have been proposed and have yet to be fully explored (Lewis et al., 2007). Neuroscientists and geneticists should continue to design empirically based models (i.e., modifications should be based on our current understanding of the etiology of ASD in humans). Behavioral scientists should continue to test the validity of these models in a variety of paradigms, especially complex operant procedures, such as the reinforced behavioral variability task, to determine whether the core symptoms of ASD – deficits in social interaction and communication and excessive stereotypy – are manifested.

Conclusions

In conclusion, this series of studies showed evidence for persistence and relapse of reinforced behavioral variability in pigeons (Study 1; Galizio et al., 2018; Chapter 2) and humans (Study 2; Galizio et al., under review; Chapter 3), a slight preference for reinforced behavioral variability in children with ASD (Study 3; Galizio et al., 2020; Chapter 4), and limited evidence for the validity of the VPA rat model of ASD (Study 4; Chapter 5). Further research on reinforced behavioral variability is needed in several directions. First, the theoretical underpinnings of reinforced behavioral variability must be investigated in the basic laboratory setting, with human and/or nonhuman animal

subjects. In a tightly controlled laboratory environment, variables that may play a role in understanding variability can be isolated and manipulated. If we understand how and why variability occurs, we can better utilize variability procedures as a tool to improve lives. A second direction of future research must be in applying procedures to reinforce behavioral variability in clinical settings. Teaching behavioral variability may improve the quality of life for individuals with ASD or other disorders. Finally, translational research on reinforced behavioral variability is needed to bridge the gap between basic and applied research in the area. Productive translational research should be bidirectional, involving conducting basic research with clear and immediate applied implications or conducting applied research in more tightly controlled settings so as to isolate variables and refine current interventions.

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Appendix C:

Appendix to Chapter 3

Cluster analysis has already been used in a variety of fields, including psychology and biology (e.g., Bonomini et al., 2015; Borgen & Barnett, 1987; Clatworthy et al., 2005; Na et al., 2010; Rousseeuw, 1987), and the field of behavior analysis could also benefit from this technique. In the present study, cluster analysis was useful in understanding the heterogeneity in our data. This section provides a more detailed discussion of the application of this technique in the present study.

K-means cluster analysis is an algorithm that divides the data into *k* clusters, or classes, based on similarity (Foreman, 2014). First, for data with *n* dimensions, the algorithm randomly assigns *k* centroids, points in *n*-dimensional space. Second, each data point is assigned to the class corresponding to the nearest centroid in terms of Euclidean distance. Third, the algorithm calculates the average in each dimension of each cluster's data points and places a new centroid at that averaged point. Then the algorithm returns to the second step, reassigning each data point to one of the new centroids. The algorithm repeats this process until a specified number of iterations has elapsed or until an iteration occurs during which no data point changes its class membership, at which point the algorithm is said to have converged. Ideally, the centroids will move less and less with each iteration as the classes become more defined.

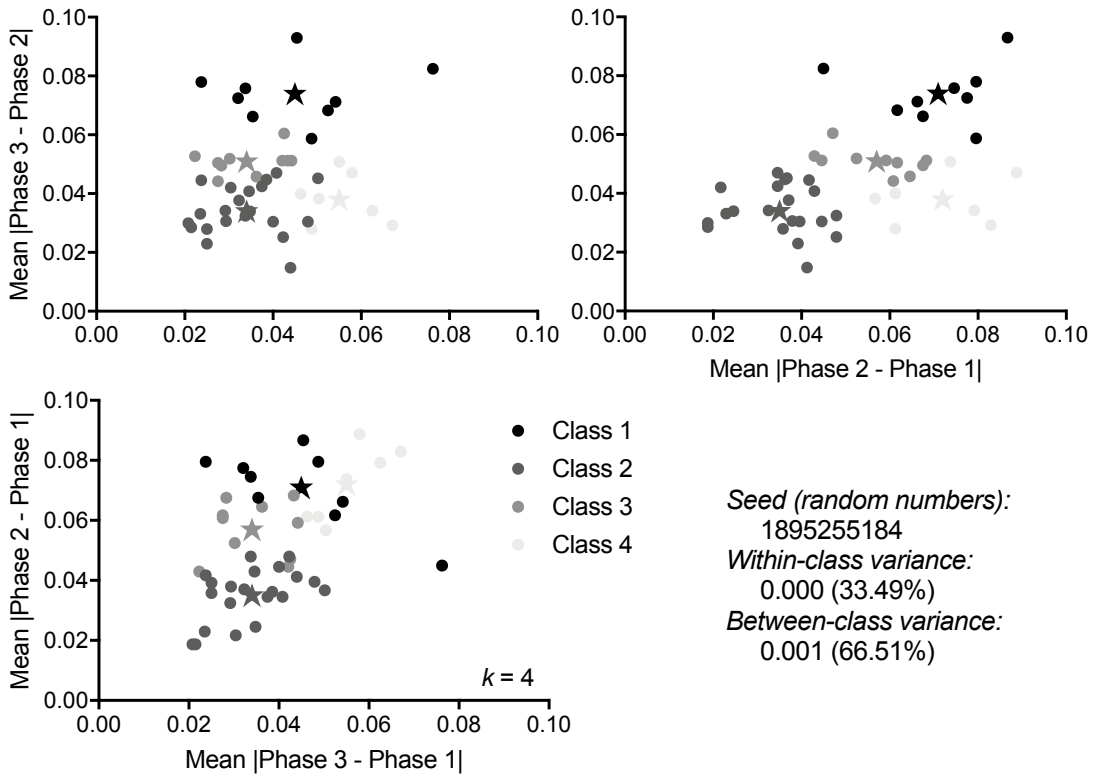
In the present study, we conducted a *k*-means cluster analysis using absolute mean difference scores derived from relative frequency distributions (see Chapter 3 Results). Specifically, relative frequencies were calculated for each category of each dimension, size and location, across phases for each participant. Next, difference scores for the target

dimension were calculated by subtracting the relative frequency of one category in one phase from the relative frequency of the same category in another phase. Absolute difference scores for the target dimension were then averaged within a single participant for each pair of phases. Three absolute mean difference scores were obtained for each participant (the average difference between baseline and alternative, between alternative and extinction, and between baseline and extinction). These scores were plotted on a three-dimensional scatterplot. A cluster analysis was used to categorize similar patterns, based on those absolute mean differences. The analysis was conducted using the XL Stat add-in for Microsoft Excel with *k* clusters.

The effectiveness of a *k*-means cluster analysis depends upon a careful selection of *k* by the experimenter (Müller & Guido, 2017). Although, for a given dataset, the algorithm may converge for a wide range of *k* values, testing dozens of *k* values will increase the Type I family-wise error rate. Therefore, the experimenter should have a theoretical basis for choosing a small range of *k* values to test. After conducting the cluster analysis with each *k* value, the experimenter can identify the strongest *k* value by comparing each *k* value's ratio of between-class variance to within-class variance. Between-class variance is a measure of distance from each data point to the nearest centroid belonging to another class. Within-class variance is a measure of distance from each data point to its class centroid. For the present study, visual inspection of relative frequency distributions revealed 3-4 apparent patterns, informed by theoretical interpretations. To confirm these observations, we tested *k* values of 3 (resurgence, rule-governed behavior, and extinction-induced response variability) and 4 (resurgence, rule-governed behavior, extinction-induced response variability, and other). For $k = 3$, the

between-class variance was 57.43% of the total and within-class variance was 42.47% (ratio = 1.36). For $k = 4$, the between-class variance was 66.51% and within-class variance was 33.29% (ratio = 1.99). The higher ratio for $k = 4$ indicated a stronger result, so only data from the 4-means cluster analysis are presented in Figure A1.

Figure A1.
Scatterplot of Absolute Mean Differences Across Phases.



Note. Scatterplots showing absolute mean differences across Phases 1 (baseline), 2 (alternative), and 3 (extinction). In each panel, the black circles represent data for participants assigned to Class 1 (resurgence). The dark grey, medium grey, and light grey circles represent data for participants assigned to Class 2 (rule-governed behavior), Class 3 (extinction-induced response variability), and Class 4 (uncategorized), respectively. The stars of each color represent the class centroids, according to the cluster analysis. The bottom right panel shows the seed representing the random iteration used in the present analysis, as well as the percentage of within- and between-class variance. An interactive three-dimensional graph displaying the same data can be found at the following link: https://plot.ly/~annie.galizio/2/.

Figure A1 shows scatterplots with absolute mean differences compared across phases with colors representing *k*=4 classes. The top left panel shows absolute mean differences for the second phase, alternative, and the third phase, extinction, as a function of absolute mean differences for the first phase, baseline, and the third phase, extinction. The top right panel shows absolute mean differences for the second phase, alternative, and the third phase, extinction, as a function of absolute mean differences for the first phase, baseline, and the second phase, alternative. The bottom left panel shows absolute mean differences for the first phase, baseline, and the second phase, alternative, as a function of absolute mean differences for the first phase, baseline, and the third phase, extinction. In each panel, the data points in each class are grouped around the corresponding class centroids (represented by stars). In general, the data points in each class are closer to the corresponding class centroid than other class centroids, indicating strong class membership. An interactive three-dimensional graph displaying the same data can be found at the following link: https://plot.ly/~annie.galizio/2/.

Table A1 shows the centroids for each class, with which theoretical interpretations can be made. The centroids for Class 1 were consistent with resurgence; the absolute mean difference was high between the first phase, baseline, and the second phase, alternative and between the second phase, alternative, and the third phase, extinction, but lower between the first phase, baseline, and the third phase, extinction. The centroids for Class 2 were consistent with rule-governed behavior; all centroids were similar and relatively low. The centroids for Class 3 were consistent with extinction-induced response variability; absolute mean differences were relatively moderate across all phases. Tables A2 and A3 show the distance between class centroids, and the class

Table A1.
Class Centroids.

	Class centroids		
	Phase 2 – Phase 1	Phase 3 – Phase 2	Phase 3 – Phase 1
Class 1 (Resurgence)	0.071	0.074	0.045
Class 2 (Rule-Governed Behavior)	0.035	0.034	0.034
Class 3 (Extinction-Induced Response Variability)	0.057	0.051	0.034
Class 4 (Uncategorized)	0.072	0.038	0.055

Note. Class centroids for the absolute mean differences between Phases 1 (baseline), 2 (alternative), and 3 (extinction).

Table A2.
Distance Between Class Centroids.

	Distance between class centroids		
	Class 2 (Rule-Governed Behavior)	Class 3 (Extinction-Induced Response Variability)	Class 4 (Uncategorized)
Class 1 (Resurgence)	0.055	0.029	0.037
Class 2 (Rule-Governed Behavior)	-	0.027	0.043
Class 3 (Extinction-Induced Response Variability)	-	-	0.029

assignments and distances to class centroid for each participant, respectively. The distance to the class centroid for each participant is indicative of the strength of the cluster assignment; a lower distance is representative of a stronger assignment.

Table A3.
Class Assignments.

Class	Participant	Distance to centroid
Class 1 (Resurgence)	22	0.014
	28	0.025
	36	0.012
	41	0.011
	47	0.018
	57	0.042
	66	0.013
	70	0.023
	72	0.013
Class 2 (Rule-Governed Behavior)	23	0.016
	25	0.011
	26	0.015
	29	0.011
	32	0.010
	37	0.006
	38	0.012
	39	0.005
	40	0.009
	43	0.012
	44	0.021
	45	0.016
	49	0.016
	55	0.023
	58	0.013
	59	0.021
	61	0.020
	62	0.015
	64	0.016
	67	0.004
	69	0.018
Class 3 (Extinction-Induced Response Variability)	24	0.012
	27	0.006
	33	0.010
	34	0.008
	35	0.014
	42	0.009
	60	0.010
	63	0.016
	65	0.019
	71	0.015

Table A3 (continued).
Class Assignments.

Class	Participant	Distance to centroid
Class 4 (Uncategorized)	30	0.013
	50	0.011
	51	0.016
	52	0.016
	54	0.018
	56	0.019
	68	0.014

Note. Class assignments and distance to respective class centroid for each participant.

Table A4 shows the number and percentage of participants assigned to each class, as well as the average, minimum, and maximum distance to the class centroid for each class, and a theoretical description of each class. The most common cluster, which contained almost half of participants, was Class 2, rule-governed behavior. Classes 1 and 3, resurgence and extinction-induced response variability, respectively, contained a similar number of participants, close to twenty percent. Only seven participants were classified in the final cluster, uncategorized, which represented miscellaneous other types of responding. The average distance to the centroid was similar for all classes, indicating that the cluster assignments were strong.

Table A4.
Class Descriptions and Participants.

	Number of participants	Percentage of participants	Average distance to centroid (range)	Description
Class 1	9	19.15%	0.019 (0.011-0.042)	Resurgence
Class 2	21	44.68%	0.014 (0.004-0.023)	Rule-governed behavior
Class 3	10	21.28%	0.012 (0.006-0.019)	Extinction-induced response variability
Class 4	7	14.89%	0.015 (0.011-0.019)	Uncategorized

Note. Number and percentage of participants assigned to each class; average, minimum, and maximum distance to the class centroid for each class; and theoretical description for each class.

We also conducted a supplemental exploratory analysis to compare the proportion of responses that received point deliveries across the clusters. Specifically, the proportions of responses that received points were compared across the first two phases (baseline and alternative) as well as the class as determined through the *k*-means cluster analysis. Based on an examination of the Q-Q plot, the distribution of proportion of responses that received points was sufficiently normal that we decided to conduct a mixed-effects ANOVA. Overall, there was no difference in proportion of rectangles receiving points across the phases (i.e., main effect of phase; $F(1, 43) = 0.15$, $p = .697$) nor was there a difference in the proportion of responses receiving points across class (i.e., main effect of cluster; $F(3, 43) = 1.61$, $p = .198$). There was, however, a significant interaction of phase and class membership on the proportion of responses that received points ($F(3, 43) = 5.114$, $p = .004$).

To more closely examine the interaction between phase and cluster membership on the proportion of responses receiving points we conducted post-hoc pairwise comparisons for each cluster. Table A5 includes the comparisons of the proportion of responses that received points between the baseline and alternate phases for each cluster. The proportion of responses that received points was significantly higher in the baseline phase than the alternative phase for Class 2 ($MD = 18.4$, $p < .001$). This is consistent with an interpretation that Class 2 participants were engaging in rule-governed behavior and therefore saw decreased reinforcer rates in the alternative phase of the experiment. For Class 4, the proportion of responses than received points was significantly lower in baseline than in the alternative phase ($MD = -16.3$, $p = .014$). There was no difference across phases for either Classes 1 or 2.

Table A5.
Post-Hoc Comparisons in Proportion of Points Earned Between Phases per Class.

	Mean Difference	*p*	D
Class 1	-6.56	.410	-0.24
Class 2	18.40	<.001	0.82
Class 3	-1.40	.840	-0.05
Class 4	-16.30	.014	-1.07

Note: Mean differences are proportion of responses receiving points in baseline phase minus proportion of responses receiving points in alternate phase. Effect size is Cohen's D.

Appendix D:

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CURRICULUM VITAE

ANN GALIZIO

Contact Information

Department of Psychology
Utah State University
2810 Old Main Hill
Logan, UT 84322-2810

Email: annie.galizio@gmail.com
Cell: (910) 617-3802
Office: (435) 797-5553

Education

2020 (expected)	Behavior Analysis Utah State University Second-Year Project: The relation between reinforced behavioral variability, delay discounting, and working memory Dissertation: A translational investigation of reinforced behavioral variability: Implications for promoting behavioral variability in individuals with autism Supervisor: Amy Odum, PhD	PhD
2014	Psychology *(minors in Neuroscience and Spanish)* College of Charleston Honors College, *Summa Cum Laude* Bachelor's Essay: Mechanisms underlying reinforced behavioral variability Supervisor: Adam Doughty, PhD	BS

Certifications

2020 (expected)	Board Certified Behavior Analyst, Doctoral Level Behavior Analyst Certification Board	BCBA-D

Academic Positions

2020-present (expected)	Assistant Professor Department of Psychology Western New England University

Research Experience

2016-2019	Graduate Research Assistant Department of Special Education and Rehabilitation Utah State University Supervisor: Tom Higbee, PhD, BCBA-D
2014-2020	Graduate Research Assistant and Lab Manager Department of Psychology Utah State University Supervisor: Amy Odum, PhD
2012-2014	Undergraduate Research Assistant Department of Psychology College of Charleston Supervisor: Adam Doughty, PhD
2012	Undergraduate Research Assistant Department of Psychology College of Charleston Supervisor: Mark Hurd, PhD
2011	Undergraduate Research Assistant Department of Psychology University of North Carolina Wilmington Supervisors: Mark Galizio, PhD, and Katherine Bruce, PhD
2011	Undergraduate Research Assistant Department of Psychology College of Charleston Supervisor: Sarah Robertson, PhD
2010-2013	Undergraduate Research Assistant Department of Psychology College of Charleston Supervisor: Jen Wright, PhD

Clinical Experience

2017-2019	Case Manager Autism Support Services: Education, Research, and Training (ASSERT) Utah State University Supervisor: Tom Higbee, PhD, BCBA-D

2016-2017	Lead Instructor Autism Support Services: Education, Research, and Training (ASSERT) Utah State University Supervisor: Kassidy Reinert, MS, BCBA
2015-2016	Instructor Autism Support Services: Education, Research, and Training (ASSERT) Utah State University Supervisor: Kassidy Reinert, MS, BCBA
2013-2014	Line Therapist Carolina Coast Behavioral Services Charleston, SC Supervisor: Shannon Doughty, PhD
2011	Clinical Case Manager National Crime Victims Research and Treatment Center Medical University of South Carolina, Charleston, SC Supervisor: Alyssa Rheingold, PhD
2010-2014	Volunteer Phone Counselor 2-1-1 Crisis Hotline Trident United Way, North Charleston, SC Supervisor: Sonia Donnelly, MBA
2008-2010	Volunteer Patient Advocate Tileston Mental Health Clinic Wilmington, NC Supervisor: Antonio Puente, PhD

Teaching Experience

2017	Graduate Teaching Assistant *Concepts and Principles of Behavior Analysis in Education* Department of Special Education and Rehabilitation Utah State University Supervisor: Tom Higbee, PhD, BCBA-D
2016-2020	Graduate Instructor *Analysis of Behavior: Advanced (online)* – 7 semesters *Analysis of Behavior: Advanced (face-to-face)* – 4 semesters Department of Psychology Utah State University Supervisor: Amy Odum, PhD

2015-2020	Graduate Research Supervisor *Undergraduate Apprenticeship* – 10 semesters Department of Psychology Utah State University Supervisor: Amy Odum, PhD

Editorial Service

2015-present	Editorial Assistant Journal of the Experimental Analysis of Behavior Society for the Experimental Analysis of Behavior Supervisors: Amy Odum, PhD *(Editor-in-Chief Aug 2015 – Aug 2019)*, and Mark Galizio, PhD *(Editor-in-Chief Aug 2019 – present)*

Reviews Completed:

2019	Journal of the Experimental Analysis of Behavior
2018	Basic and Applied Social Psychology
2018	Journal of the Experimental Analysis of Behavior
2018	Behavioural Processes
2016	Pharmacology, Biochemistry, and Behavior
2016	Pharmacology, Biochemistry, and Behavior
2016	Basic and Applied Social Psychology

Other Professional Service

Feb 2017 – present	Assistant Coordinator Winter Conference on Learning & Behavior Supervisor: Amy Odum, PhD *(Convener)*

Manuscripts in Progress

Contreras, B. P., Higbee, T. S., **Galizio, A.**, Pellegrino, A., Becerra, L., & Heaps, A. (in preparation). Promoting generalization of varied play behavior with children with autism spectrum disorder.

DeHart, W. B., Friedel, J. E., Berry, M. S., Frye, C. C. J., **Galizio, A.**, & Odum, A. L. (under review). Comparison of delay discounting of different outcomes in cigarette smokers, smokeless tobacco users, e-cigarette users, and non-tobacco users. *Journal of the Experimental Analysis of Behavior.*

Friedel, J. E., **Galizio, A.**, Frye, C. C. J., DeHart, W. B., & Odum, A. L. (in preparation). Assessment of a rapid method to obtain indifference points: Measures of delay discounting obtained from a visual analogue scale and a survey.

Galizio, A., Friedel, J. E., & Odum, A. L. (under review). An investigation of resurgence of reinforced behavioral variability in humans. *Journal of the Experimental Analysis of Behavior*.

Publications

Galizio, A., Higbee, T. S., & Odum, A. L. (2020). Choice for reinforced behavioral variability in children with autism spectrum disorder. *Journal of the Experimental Analysis of Behavior*, *113*(3), 495–514. https://doi.org/10.1002/jeab.591

Odum, A. L., Becker, R. J., Haynes, J. M., **Galizio, A.**, Frye, C. C. J., Downey, H., Friedel, J. E., & Perez, D. M. (2020). Delay discounting of different outcomes: Review and theory. *Journal of the Experimental Analysis of Behavior*, *113*(3), 657–679. https://doi.org/10.1002/jeab.589

Friedel, J. E., **Galizio, A.**, Berry, M. S., Sweeney, M. M., & Odum, A. L. (2019). An alternative approach to relapse analysis: Using Monte Carlo methods and proportional rates of response. *Journal of the Experimental Analysis of Behavior*, *111*(2), 289–308. https://doi.org/10.1002/jeab.489

Frye, C. C. J., **Galizio, A.**, Haynes, J. M., DeHart, W. B., & Odum, A. L. (2019). The effect of nicotine and nicotine+monoamine oxidase inhibitor on the value of alcohol. *Behavioural Pharmacology*, *30*(4), 363–369. https://doi.org/10.1097/FBP.0000000000000438

Wright, J. C., Reinhold, E., **Galizio, A.**, & DiBartolo, M. (2019). Judge no evil, see no evil: Do people's moral choices influence to whom they visually attend? In *Methodological Advances in Experimental Philosophy* (pp. 101–130). Bloomsbury Academic.

DeHart, W. B., Friedel, J. E., Frye, C. C. J., **Galizio, A.**, & Odum, A. L. (2018). The effects of outcome unit framing on delay discounting. *Journal of the Experimental Analysis of Behavior*, *110*(3), 412–429. https://doi.org/10.1002/jeab.469

Frye, C. C. J., Rung, J. M., Nall, R. W., **Galizio, A.**, Haynes, J. M., & Odum, A. L. (2018). Continuous nicotine exposure does not affect resurgence of alcohol seeking in rats. *PLOS ONE*, *13*(8), e0202230. https://doi.org/10.1371/journal.pone.0202230

Galizio, A., Frye, C. C. J., Haynes, J. M., Friedel, J. E., Smith, B. M., & Odum, A. L. (2018). Persistence and relapse of reinforced behavioral variability. *Journal of the Experimental Analysis of Behavior*, *109*(1), 210–237. https://doi.org/10.1002/jeab.309

Galizio, A., Doughty, A. H., Williams, D. C., & Saunders, K. J. (2017). Understanding behavior under nonverbal transitive-inference procedures: Stimulus-control-topography analyses. *Behavioural Processes*, *140*, 202–215. https://doi.org/10.1016/j.beproc.2017.05.010

Frye, C. C. J., **Galizio, A.**, Friedel, J. E., DeHart, W. B., & Odum, A. L. (2016). Measuring delay discounting in humans using an adjusting amount task. *Journal of Visualized Experiments*, *107*, 53584. https://doi.org/10.3791/53584

Doughty, A. H., & **Galizio, A.** (2015). Reinforced behavioral variability: Working towards an understanding of its behavioral mechanisms. *Journal of the Experimental Analysis of Behavior*, *104*(3), 252–273. https://doi.org/10.1002/jeab.171

Robertson, S. M. C., Swickert, R. J., Connelly, K., & **Galizio, A.** (2015). Physiological reactivity during autobiographical narratives in older adults: The roles of depression and anxiety. *Aging & Mental Health*, *19*(8), 689–697. https://doi.org/10.1080/13607863.2014.962010

Symposia and Paper Sessions

Galizio, A., Higbee, T. S., Peck, S., Becerra, L., Hinnenkamp, J. E., & Odum, A. L. (2020, May). Choice for variability in children with autism. *Symposium: The effects of lag schedules and teacher presentation rates on academic, play, and social behavior of children with autism. Oral presentation at the Annual Convention of the Association for Behavior Analysis International, Online.* Presenting author.

Morrissey, K., **Galizio, A.**, Haynes, J. M., Towse, C., Perez, D., & Odum, A. L. (2020, May). Generalization of variability training across responses in rats. *Symposium: To vary or not to vary: Advances in behavioral variability research. Oral presentation at the Annual Convention of the Association for Behavior Analysis International, Online.*

Galizio, A., Higbee, T. S., Peck, S., Becerra, L., Hinnenkamp, J. E., & Odum, A. L. (2020, Mar). Choice for variability in children with autism. *Oral presentation at the Winter Conference on Animal Learning and Behavior, Logan, UT.* Presenting author.

Morrissey, K., **Galizio, A.**, Haynes, J. M., Towse, C., Perez, D., & Odum, A. L. (2020, Mar). Generalization of variability training across responses in rats. *Oral presentation at the Winter Conference on Animal Learning and Behavior, Logan, UT.*

Towse, C., Haynes, J. M., **Galizio, A.**, Frye, C. C. J., & Odum, A. L. (2020, Mar). Delay discounting of food and water in rats shows trait characteristics. *Oral presentation at the Winter Conference on Animal Learning and Behavior, Logan, UT.*

Odum, A. L., Haynes, J. M., **Galizio, A.**, Downey, H., & Perez, D. (2019, Nov). Why do we disregard delayed outcomes? *Invited presentation at the Annual Meeting of the Georgia Association for Behavior Analysis, Athens, GA.*

Odum, A. L., Haynes, J. M., **Galizio, A.**, Downey, H., & Perez, D. (2019, Oct). Delay discounting: Why do we do things we regret? *Keynote address at the Annual Meeting of the Mexican Association for Behavior Analysis, Mexico City, MX.*

Odum, A. L., Haynes, J. M., **Galizio, A.**, Downey, H., & Perez, D. (2019, Oct). Why do we disregard delayed consequences? *Invited presentation at the Annual Meeting of the Nevada Association for Behavior Analysis, Reno, NV.*

Galizio, A. & Odum, A. L. (2019, May). Investigating generalization of reinforced variability in rats. *Symposium: Recent basic and applied research on reinforced behavioral variability. Oral presentation at the Annual Convention of the Association for Behavior Analysis International, Chicago, IL.* Presenting author.

Odum, A. L., Bevins, R. A., Galizio, M., Serang, S., Whitmore, S. A., Frye, C. C. J., DeHart, W. B., **Galizio, A.**, Friedel, J. E., Haynes, J. M., Berry, M. S., & Becker, R. J. (2019, Feb). The relation between delay discounting and e-cigarette use: Human and rat studies. *Oral presentation at the Winter Conference on Learning and Behavior, Logan, UT.*

Contreras, B. P., Higbee, T. S., **Galizio, A.**, Pellegrino, A., Becerra, L. A., & Heaps, A. (2018, May). Promoting generalization of varied play behavior with children with autism. *Symposium: Play with me! Evaluations of the use of script training and lag schedules to establish play behaviors and social interactions in children with autism. Oral presentation at the Annual Convention of the Association for Behavior Analysis International, San Diego, CA.*

Galizio, A. & Odum, A. L. (2018, May). Resurgence of reinforced behavioral variability in humans. *Oral presentation at the Experimental Analysis of Human Behavior Special Interest Group Business Meeting at the Annual Convention of the Association for Behavior Analysis International, San Diego, CA.* Presenting author.

Galizio, A., Haynes, J. M., Frye, C. C. J., & Odum, A. L. (2018, May). Spontaneous recovery of reinforced behavioral variability. *Symposium: Behavioral variability: Reinforcement and induction. Oral presentation at the Annual Convention of the Association for Behavior Analysis International, San Diego, CA.* Presenting author.

Galizio, A. & Odum, A. L. (2018, Feb). Resurgence of reinforced behavioral variability in humans. *Oral presentation at the Winter Conference on Animal Learning and Behavior, Logan, UT.* Presenting author.

Haynes, J. M., Frye, C. C. J., **Galizio, A.**, Nall, R. W., Rung, J. M., & Odum, A. L. (2018, Feb). Effects of continuous nicotine administration on alcohol relapse. *Oral presentation at the Winter Conference on Animal Learning and Behavior, Logan, UT.*

Odum, A. L., Frye, C. C. J., Haynes, J. M., **Galizio, A.**, & Rung, J. M. (2018, Feb). Delay discounting: person, context, and change. *Oral presentation at the Winter Conference on Animal Learning and Behavior, Logan, UT.*

Stuart, I., Frye, C. C. J., **Galizio, A.**, & Odum, A. L. (2018, Feb). The effects of nicotine on maladaptive alcohol drinking. *Oral presentation at the Winter Conference on Animal Learning and Behavior, Logan, UT.*

Odum, A. L., DeHart, W. B., Friedel, J. E., Frye, C. C. J., **Galizio, A.**, & Haynes, J. M. (2017, May). Delay discounting of alcohol and nicotine use. *Oral presentation at the Annual Meeting of the Research Society on Alcoholism, Denver, CO.*

DeHart, W. B., Frye, C. C. J., **Galizio, A.**, Haynes, J. M., & Odum, A. L. (2017, May). Delay discounting of non-monetary outcomes: The effects of different magnitudes and delay distributions. *Symposium: Delay Discounting in Health with a Focus on Food and Exercise. Oral presentation at the Annual Convention of the Association for Behavior Analysis International, Denver, CO.*

Frye, C. C. J., **Galizio, A.**, Haynes, J. M., & Odum, A. L. (2017, May). Examining the magnitude effect in humans and pigeons: It is all about the contrast. *Symposium: Explorations of the Magnitude Effect Across Species and Domains. Oral presentation at the Annual Convention of the Association for Behavior Analysis International, Denver, CO.*

Galizio, A., Frye, C. C. J., Friedel, J. E., Haynes, J. M., & Odum, A. L. (2017, May). Persistence and relapse of reinforced behavioral variability. *Symposium: Reinforced Behavioral Variability: Basic Research, Applications, and Theoretical Implications. Oral presentation at the Annual Convention of the Association for Behavior Analysis International, Denver, CO.* Presenting author.

Galizio, A., Frye, C. C. J., Haynes, J. M., & Odum, A. L. (2017, May). The relation between timing, delay discounting, and discriminating contingencies in rats. *Oral presentation at the Annual Meeting of the Society for the Quantitative Analysis of Behavior, Denver, CO.* Presenting author.

Odum, A. L. & **Galizio, A.** (2017, Mar). Women in EAB: Representation in the Journal of the Experimental Analysis of Behavior. *Oral presentation at the Women in Behavior Analysis convention in Nashville, TN.*

Galizio, A. & Odum, A. L. (2017, Feb). The effects of nicotine on performance in a titrating delayed matching-to-sample task in pigeons. *Oral presentation at the Winter Conference on Animal Learning and Behavior, Park City, UT.* Presenting author.

Odum, A. L., DeHart, W. B., Friedel, J. E., **Galizio, A.**, & Frye, C. C. J. (2016, Jan). Organismic and environmental influences on delay discounting: Evidence for a general process. *Keynote address at the Winter Conference on Animal Learning and Behavior, Winter Park, CO.*

Galizio, A. & Doughty, A. H. (2014, May). Behavioral mechanisms underlying reinforced behavioral variability. *Symposium: Behavioral variability: Its fundamental importance and relation to other phenomena. Oral presentation at the Annual Convention of the Association for Behavior Analysis International, Chicago, IL*. Presenting author.

DiBartolo, M., **Galizio, A.,** Reinhold, E., & Wright, J. C. (2012, May). Judge no evil, see no evil: A case for motivated moral attention. *Oral presentation at the Experiments on Ethical Dilemmas workshop, London, UK.* Presenting author.

Poster Presentations

Haynes, J. M., Frye, C. C. J., **Galizio, A.**, Becker, R. J., Perez, D., & Odum, A. L. (2019, May). Defecting during the delay: Delay maintenance in rats. *Poster presented at the Annual Meeting of the Society for the Quantitative Analysis of Behavior, Chicago, IL.*

Galizio, A., Frye, C. C. J., Haynes, J. M., Friedel, J. E., & Odum, A. L. (2019, Feb). Effects of *d*-amphetamine and nicotine on remembering and motivation in pigeons. *Poster presented at the California Association for Behavior Analysis Annual Western Regional Conference on Behavior Analysis, Long Beach, CA*. Presenting author.

Galizio, A., Frye, C. C. J., Haynes, J. M., Friedel, J. E., & Odum, A. L. (2018, Nov). Effects of *d*-amphetamine and nicotine on remembering and motivation in pigeons. *Poster presented at the Substance Use and Addiction Conference, Washington, DC.* Presenting author.

Swanson, K. W., **Galizio, A.**, Haynes, J. M., Frye, C. C. J., & Odum, A. L. (2018, May). Spontaneous recovery of operant variability. *Poster presented at the Annual Meeting of the Society for the Quantitative Analysis of Behavior, San Diego, CA.*

Friedel, J. E., DeHart, W. B., Frye, C. C. J., **Galizio, A.**, Haynes, J. M., & Odum, A. L. (2017, May). Comparing the quality of hyperbolic delay discounting models across various amounts of differing outcomes. *Poster presented at the Annual Meeting of the Society for the Quantitative Analysis of Behavior, Denver, CO.*

Galizio, A., Frye, C. C. J., Haynes, J. M. (2017, May). The relation between timing, delay discounting, and discriminating contingencies in rats. *Poster presented at the Annual Meeting of the Society for the Quantitative Analysis of Behavior, Denver, CO.* Presenting author.

Haynes, J. M., Frye, C. C. J., **Galizio, A.**, & Odum, A. L. (2017, May). Effects of nicotine and nicotine with MAOI on alcohol valuation. *Poster presented at the Annual Meeting of the Society for the Quantitative Analysis of Behavior, Denver, CO.*

Friedel, J. E., **Galizio, A.**, & Odum, A. L. (2016, May). Mental accounting and delay discounting. *Poster presented at the Annual Convention of the Association for Behavior Analysis International, Chicago, IL.*

Galizio, A., Frye, C. C. J., Friedel, J. E., DeHart, W. B., & Odum, A. L. (2016, May). Timing and delay discounting. *Poster presented at the Annual Convention of the Association for Behavior Analysis International, Chicago, IL*. Presenting author.

DeHart, W. B., Frye, C. C. J., Friedel, J. E., **Galizio, A.**, & Odum, A. L. (2016, May). Delay discounting of different outcomes by smokers, smokeless tobacco users, e-cigarette users, and non-users. *Poster presented at the Annual Meeting of the Society for the Quantitative Analysis of Behavior, Chicago, IL.*

Frye, C. C. J., **Galizio, A.**, Friedel, J. E., DeHart, W. B., & Odum, A. L. (2016, May). The magnitude effect in delay discounting research: It's all about the contrast. *Poster presented at the Annual Meeting of the Society for the Quantitative Analysis of Behavior, Chicago, IL.*

Galizio, A., Smith, S. A., Friedel, J. E., Frye, C. C. J., & Odum, A. L. (2016, May). Effects of nicotine on performance in a titrating delayed matching-to-sample task in pigeons. *Poster presented at the Annual Meeting of the Society for the Quantitative Analysis of Behavior, Chicago, IL.* Presenting author.

Frye, C. C. J., Friedel, J. E., **Galizio, A.**, & Odum, A. L. (2015, May). Resurgence of operant variability. *Poster presented at the Annual Convention of the Association for Behavior Analysis International, San Antonio, TX.*

Galizio, A., Friedel, J. E., Smith, B. M., Frye, C. C. J., McIntyre, S., & Odum, A. L. (2015, May). Reinforced behavioral variability is resistant to change under extinction and reinstatement. *Poster presented at the Annual Convention of the Association for Behavior Analysis International, San Antonio, TX.* Presenting author.

Friedel, J. E., DeHart, W. B., Frye, C. C. J., **Galizio, A.**, & Odum, A. L. (2015, May). Impulsivity and tobacco use: Discounting of qualitatively different outcomes in non-smokers, cigarette smokers, and smokeless tobacco users. *Poster presented at the Annual Meeting of the Society for the Quantitative Analysis of Behavior, San Antonio, TX*.

Galizio, A., Friedel, J. E., Hudgins, C. D., Nelson, S. A., Vaidya, M., & Odum, A. L. (2015, May). Effects of *d*-amphetamine on performance in a titrating delayed matching-to-sample task in pigeons. *Poster presented at the Annual Meeting of the Society for the Quantitative Analysis of Behavior, San Antonio, TX*. Presenting author.

Galizio, A. & Doughty, A. H. (2014, May). Behavioral mechanisms underlying reinforced behavioral variability. *Poster presented at the Annual Meeting of the Society for the Quantitative Analysis of Behavior, Chicago, IL.* Presenting author.

Galizio, A. & Doughty, A. H. (2014, Mar). Behavioral and neural mechanisms underlying reinforced behavioral variability. *Poster presented at the Annual Meeting of the Symposium for Young Neuroscientists And Professors of the Southeast, Asheville, NC.* Presenting author.

Ruscio, M., **Galizio, A.**, & Lench, D. (2013, Nov). Neuroscience Seminar in Germany. *Poster presented at the Annual Provost's Study Abroad Dinner, College of Charleston, Charleston, SC.* Presenting author.

Galizio, A. & Doughty, A. H. (2013, Oct). Reinforced behavioral variability: Direct reinforcement or other processes? *Poster presented at the Annual Meeting of the Southeastern Association for Behavior Analysis, Myrtle Beach, SC.* Presenting author.

Jackson, C., **Galizio, A.**, & Doughty, A. H. (2013, Oct). Effects of inter-response and inter-trial interval durations on reinforced behavioral variability. *Poster presented at the Annual Meeting of the Southeastern Association for Behavior Analysis, Myrtle Beach, SC.*

Galizio, A., Doughty, A. H., Williams, D. C., Saunders, K. J., & Kresselman, A. L. (2013, Oct). Behavior under non-verbal transitive-inference procedures: Transitivity without awareness, value transfer, or stimulus control topography? *Poster presented at the International Convention of the Association for Behavior Analysis International, Mérida, México*. Presenting author.

Galizio, A., Doughty, A. H., Williams, D. C., Saunders, K. J., & Kresselman, A. L. (2013, May). Behavior under non-verbal transitive-inference procedures: Transitivity without awareness, value transfer, or stimulus control? *Poster presented at the Annual Convention of the Association for Behavior Analysis International, Minneapolis, MN*. Presenting author.

Galizio, A., Doughty, A. H., Williams, D. C., Saunders, K. J., & Kresselman, A. L. (2012, Oct). Behavior under non-verbal transitive-inference procedures: Transitivity without awareness, value transfer, or stimulus control? *Poster presented at the Annual Meeting of the Southeastern Association for Behavior Analysis, Columbia, SC*. Presenting author.

Deal, M., April, L. B., Eure, R., **Galizio, A.,** Hawkey, A., Hausman, C., Jacobs, K., Timms, M. & Galizio, M. (2011, Oct). Drug effects on incrementing non-matching to sample in rats. *Poster presented at the Annual Meeting of the Southeastern Association for Behavior Analysis, Charlotte, NC.*

Wright, J. C., Thomason, L., Sweeney, S., Reinhold, E., **Galizio, A.,** Silver, E., DiBartolo, M., Milz, A., & Grandjean, P. (2011, May). The role of cognitive resources in determining our moral intuitions: Are we all liberals at heart? *Poster presented at the Association for Psychological Sciences Convention, Washington, DC.*

Research Grant Applications

2019-2020	Graduate Student Translational Research Grant (awarded $4999) Society for the Experimental Analysis of Behavior "Investigating operant variability in the valproate rat model of autism"
2018-2019	Autism Early Intervention Clinics (awarded $9000) "The effects of antipsychotic medications on performance on a titrating delayed matching-to-sample task in pigeons"
2018-2019	Graduate Research and Creative Opportunities (GRCO) Grant (awarded $1000) Utah State University "Generalization of reinforced behavioral variability in rats"

2018-2019	Psi Chi Graduate Student Research Grant (awarded $1500) Psi Chi National Psychology Honors Society "Generalization of reinforced behavioral variability in rats"
2018	Innovative Student Research Grant (not awarded) Society for the Advancement of Behavior Analysis "Generalization of reinforced behavioral variability across response topographies in rats"
2017	Graduate Research and Creative Opportunities (GRCO) Grant (not awarded) Utah State University "Generalization of reinforced behavioral variability in rats"
2013	Psi Chi Summer Research Grant (awarded $5000) Psi Chi National Psychology Honors Society "Mechanisms underlying reinforced behavioral variability in pigeons"
2013	Summer Undergraduate Research with Faculty (SURF) Grant (awarded $6500) The Undergraduate Research and Creative Activities Program College of Charleston, Charleston, SC "Mechanisms underlying reinforced behavioral variability in pigeons"

Honors, Awards, and Scholarships

2019	Psychology Department Student Spotlight Department of Psychology Utah State University, Logan, UT
2018	Paper Competition Winner ($160) Experimental Analysis of Human Behavior Special Interest Group Association for Behavior Analysis International
2018	Graduate Enhancement Award ($4000) Office of Research and Graduate Studies Utah State University, Logan, UT
2018	Graduate Student Travel Award ($300) Department of Psychology Utah State University, Logan, UT
2017	Graduate Student Travel Award ($500) Office of Research and Graduate Studies and Department of Psychology

	Utah State University, Logan, UT
2016	Senior Student Presenter Grant ($150) Society for the Advancement of Behavior Analysis Association for Behavior Analysis International
2016-2017	Exceptional Student Group Cambridge Center for Behavioral Studies
2016	Ray Alvord Scholarship ($1000) Department of Psychology Utah State University, Logan, UT
2016	Graduate Student Travel Award ($600) Office of Research and Graduate Studies and Department of Psychology Utah State University, Logan, UT
2015	Graduate Student Travel Award ($600) Office of Research and Graduate Studies and Department of Psychology Utah State University, Logan, UT
2014	Departmental Honors Department of Psychology College of Charleston, Charleston, SC
2014	Outstanding Student Award Department of Psychology College of Charleston, Charleston, SC
2014	HSS Scholars Award Department of Psychology, School of Humanities and Social Sciences College of Charleston, Charleston, SC
2014	Global Scholar College of Charleston, Charleston, SC
2013	Bischoff Memorial Competitive Merit Scholarship ($3000) Department of Psychology College of Charleston, Charleston, SC
2013	Research Presentation Grant ($750) The Undergraduate Research and Creative Activities Program College of Charleston, Charleston, SC
2013	Omicron Delta Kappa Leadership Honors Society

College of Charleston, Charleston, SC

2012 Phi Eta Sigma Outstanding Student Scholarship ($500)
Phi Eta Sigma Honors Society
College of Charleston, Charleston, SC

2012-2013 Honors Committee
Student representative
Honors College
College of Charleston, Charleston, SC

2012 Phi Kappa Phi Study Abroad Grant ($1000)
Phi Kappa Phi Honors Society

2012 Phi Kappa Phi Honors Society
College of Charleston, Charleston, SC

2012 Sigma Delta Pi National Collegiate Hispanic Honors Society
College of Charleston, Charleston, SC

2012 William Aiken Fellow Summer Enrichment Grant ($3000)
William Aiken Fellows Society
College of Charleston, Charleston, SC

2012 Study Abroad Scholarship ($1000)
School of Humanities and Social Sciences
College of Charleston, Charleston, SC

2012 Research Presentation Grant ($500)
The Undergraduate Research and Creative Activities Program
College of Charleston, Charleston, SC

2011 Phi Eta Sigma Honors Society
College of Charleston, Charleston, SC

2011 Psi Chi Psychology Honors Society
College of Charleston, Charleston, SC

2011 William Aiken Fellows Society
College of Charleston, Charleston, SC

2011-2014 Psychology Advising Committee
Student representative
Department of Psychology
College of Charleston, Charleston, SC

2010-2014	Highly Distinguished Honor Student Honors College College of Charleston, Charleston, SC

Relevant Trainings

LGBTQIA+ Allies On Campus Training
Department of Psychology
Utah State University

Cultural Competence Training
Utah State University

Getting Started as a Successful Proposal Writer and Academician
Office of Research and Graduate Studies
Utah State University

Acceptance and Commitment Therapy (ACT) Workshop Series
Utah State University

Collaborative Institutional Training Initiative (CITI) Training
Social and Behavioral Research
Lab Animal Research
Responsible Conduct of Research

Education Abroad

Jul – Aug 2012	Spanish Conversation and Reading Strategies in Chile University of North Carolina at Wilmington, Wilmington, NC Pontificia Universidad Católica de Valparaíso (PUCV), Valparaíso, Chile Instructor: Valerie Rider, PhD
May – Jun 2012	Neuroscience Seminar in Germany College of Charleston, Charleston, SC Charite University, Berlin, Germany Ludwig Maximilians Universitat, Munich, Germany Instructors: Mike Ruscio, PhD, and Christopher Korey, PhD

Languages Spoken

Spanish, *intermediate level*

References

Amy Odum, PhD
Amy.Odum@usu.edu
(435) 797-5578

Additional references available upon request