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EXTENSIONS OF BEHAVIORAL MOMENTUM THEORY TO CONDITIONS  
WITH CHANGING REINFORCER RATES

by

Andrew R. Craig

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

of

DOCTOR OF PHILOSOPHY

in

Psychology

Approved:

---

Timothy A. Shahan, Ph.D.  
Major Professor

---

Amy L. Odum, Ph.D.  
Committee Member

---

Gregory J. Madden, Ph.D.  
Committee Member

---

Timothy A. Slocum, Ph.D.  
Committee Member

---

Kerry E. Jordan, Ph.D.  
Committee Member

---

Mark R. McLellan, Ph.D.  
Vice President for Research and  
Dean of the School of Graduate Studies

UTAH STATE UNIVERSITY  
Logan, Utah

2017

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## ABSTRACT

Extension of Behavioral Momentum Theory to Conditions with Changing  
Reinforcer Rates

by

Andrew R. Craig, Doctor of Philosophy

Utah State University, 2017

Major Professor: Timothy A. Shahan, Ph.D.  
Department: Psychology

Behavioral momentum theory states that resistance to change of operant behavior is governed by the Pavlovian stimulus-reinforcer relation in a given discriminative-stimulus situation. That is, higher reinforcer rates in the presence of a discriminative stimulus result in a stronger stimulus-reinforcer relation and, thereby, greater resistance to change. Within the momentum-based quantitative framework of resistance to change, the construct relating persistence to pre-disruption reinforcer rates is termed “behavioral mass.” All research on which momentum theory is based has examined resistance to change following prolonged exposure to stable reinforcer rates in multiple schedules of reinforcement. Thus, at present little is known about the time frame over which behavioral mass accumulates or the manner by which newly experienced stimulus-reinforcer relations are incorporated into mass when these rates change. The experiments described in this dissertation aimed to clarify these facets of the construct. Chapters 1 and

2 provide a detailed overview behavioral momentum theory and resistance to change. Topics discussed include quantitative models of resistance to change, clinical implications of resistance-to-change research, some notable limitations of behavioral momentum theory, and extensions of the theory to account for diverse behavioral outcomes. A recently published study is presented in Chapter 3 that aimed to determine how resistance to change and behavioral mass of pigeons' key pecking adapts in the face of stimulus-reinforcer relations that change across time during baseline. Results suggest that resistance to change is a function of recently experienced stimulus-reinforcer relations and that behavioral mass depends most heavily on these recent experiences. The experiment described in Chapter 4 extended the findings reported in Chapter 3 by examining whether behavioral mass changes during operant extinction. Pre-exposure to extinction in an alternative multiple-schedule component decreased resistance to extinction of target-component key pecking relative to conditions without pre-exposure to extinction. Between-condition differences in extinction were well accounted for quantitatively by either variation in behavioral mass or changes in the magnitude of factors that are assumed to disrupt responding during extinction. Chapter 5 offers an integrative discussion of this research and emphasizes theoretical implications, practical applications, and areas for future research.

(211 pages)

## PUBLIC ABSTRACT

Extension of Behavioral Momentum Theory to Conditions with Changing  
Reinforcer Rates

Andrew R. Craig

Behavior is more likely to persist when disrupted in some way in the presence of stimuli correlated with frequent delivery of reward than in the presence of stimuli correlated with infrequent rewards. In laboratory investigations, the correlation between reward rates and specific stimuli are almost always held constant before testing for persistence. In the real world, however, how often rewards are encountered is likely to vary substantially over time. The major goal of the work described in this dissertation was to explore effects of reward rates that change over time on persistence of behavior in controlled laboratory settings using pigeon subjects. The first study demonstrated that persistence is more strongly influenced by rates of reward that were experienced recently than by rates of reward that were experienced in the distant past. The second study demonstrated that removing rewards for behavior in one context can subsequently reduce persistence of behavior maintained in another correlated context. Together, results from these studies provide initial insights into how persistence is affected by environments that change over time. They also underscore potentially important shortcomings of our current understanding of factors that cause behavior to persist.

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Cheers to my loving friends and family, particularly to my mother and stepfather, Sharon and Henry Rock, and my brother, Arthur Craig.

Andrew R. Craig

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# **CHAPTER 1**

## **INTRODUCTION**

### **Resistance to Change**

Our everyday behavior often is faced with challenges. A doctoral student writing a dissertation document might become distracted from this task by friends, social media, or other sources. Likewise, a smoker might be discouraged from lighting a cigarette by his or her significant other, family, or social stigma. Regardless of the behavior in question or the means by which that behavior is challenged, a likely outcome is that behavior will persist to some degree despite challenges that deter it. The extent to which operant behavior persists in the face of disruption relative to the rate at which it occurred in the absence of disruption is referred to as “resistance to change.” Given that resistance to change is a fundamental component of behavior in the real world, it is important to understand the environmental factors that affect it and the underlying behavioral mechanisms that cause it.

One variable that reliably has been shown to influence response persistence is the rate at which reinforcers are delivered prior to disruption. More specifically, when resistance to change is examined using multiple schedules of reinforcement, multiple-schedule components associated with relatively high-rate reinforcement tend to produce behavior that is more resistant to change than components associated with relatively low-rate reinforcement. Nevin (1974) conducted an early series of experiments that demonstrated this dependency. In his Experiment 1, pigeons pecked keys for food

reinforcement in a two-component multiple schedule. One component was associated with a red key light, the other component was associated with a green key light, and key pecking produced food three times as frequently in the presence of the red key than in the presence of the green key. Component presentations were separated by inter-component intervals (ICIs) during which the chamber was dark and response keys were inoperative. After responding stabilized in both multiple-schedule components, key pecking was disrupted in two different ways. First, food was presented at various frequencies during ICIs. Second, food presentations were suspended (i.e., key pecking was placed on extinction) in both multiple-schedule components. In the case of both disruptors, Nevin observed greater resistance to change of key pecking in the red-key component (i.e., the component associated with higher rate reinforcement) than in the green-key component. The positive dependency between resistance to change of responding in multiple schedules and baseline reinforcer rates is robust—it has been demonstrated in a number of species other than pigeons including humans (e.g., Ahearn, Clark, Gardenier, Chung, & Dube, 2003; Cohen, 1996; Mace et al., 1990, 2010), rats (e.g., Blackman, 1968; Pyszczynski & Shahan, 2011), and goldfish (Igaki & Sakagami, 2004) using a variety of disruptors.

In light of the generality of this effect, much empirical work has been dedicated to determining the behavioral processes linking resistance to change and baseline reinforcer rates within multiple schedules. For example, increasing the rate of response-dependent reinforcement within a discriminative-stimulus situation increases the frequency of pairings between responses and reinforcers (i.e., strengthens the operant response-

reinforcer contingency) while simultaneously increasing the Pavlovian relation between the multiple-schedule component stimuli and reinforcer deliveries. Thus, under these circumstances, either the response-reinforcer relation or stimulus-reinforcer relation (or both) could contribute to resistance to change.

Nevin, Tota, Torquato, and Shull (1990) conducted a series of experiments to explore which of these relations determined response persistence. In their first experiment, pigeons pecked keys for food reinforcement in a two-component multiple schedule. In Component A, food for key pecking was delivered according to a variable-interval (VI) 60-s (60 reinforcers/hr) schedule. In Component B, three reinforcement situations were introduced across conditions. In the first condition, contingencies of reinforcement were the same as in Component A (i.e., food was delivered for key pecking according to a VI 60-s schedule). In the second condition, response-dependent food continued to be available according to a VI 60-s schedule, and response-independent food was delivered concurrently according to either a variable-time (VT) 30- or 15-s schedule (for a total of 180 and 300 VI + VT reinforcers per hr, respectively). In the third condition, VI and VT food were delivered concurrently such that their combined rate was equal to Component-A reinforcer rates (60 reinforcer/hr; i.e., VI 180 s plus VT 90 s or VI 300 s plus VT 75 s).

The rationale for the study was that adding response-independent reinforcement into Component B should weaken the response-reinforcer relation relative to Component A because only some portion of reinforcers were delivered contingently on key pecking in Component B. Response-independent food, however, should contribute to the

Pavlovian stimulus-reinforcer relation in Component B. Thus, if the response-reinforcer relation governed resistance to change, one would anticipate less persistence in Component B than in Component A when some Component-B reinforcers were delivered independently of key pecking. Conversely, if the Pavlovian stimulus-reinforcer relation governed resistance to change, persistence should be greater in Component B when the rate of VI + VT reinforcement in that component was higher than the rate of VI reinforcement in Component A. The results of this experiment supported the latter of these conclusions. Adding VT food in Component B produced lower rates of key pecking than in Component A during baseline. Resistance of key pecking to both pre-session feeding and extinction, however, was higher in Component B when the combined rates of VI and VT reinforcement were higher than rates of VI reinforcement in Component A.

Nevin et al.'s (1990) result subsequently has been replicated both in pigeons and in other species (e.g., Ahearn et al., 2003; Grimes & Shull, 2001; Podlesnik & Shahan, 2009, 2010; Pyszczynski & Shahan, 2011; Shahan & Burke, 2004), providing strong support for the generality of this finding. Further, a second study in this paper demonstrated that provision of extra reinforcers in a multiple-schedule component *contingently on a second response* can increase resistance to change of target behavior in that component (see also Mace et al., 2010; Podlesnik, Bai, & Elliffe, 2012). Thus, resistance to change appears to be independent of the response-reinforcer relation (though a few notable exceptions have been reported; see Aló, Abreu-Rodrigues, Souza, & Cançado, 2015; K. A. Lattal, 1989; Nevin, Grace, Holland, & McLean, 2001; Shull & Grimes, 2006). Instead, the contribution of reinforcers within a discriminative-stimulus



situation to the Pavlovian stimulus-reinforcer relation, regardless of the type or source of those reinforcers, appears to govern resistance to change.

### **Behavioral Momentum Theory**

Behavioral momentum theory (Nevin, Mandell, & Atak, 1983) offers a formalized approach to understanding how variables in an organism's reinforcement history affect resistance to change and is predicated on the positive relation between baseline reinforcer rates and resistance to change in multiple schedules detailed above. According to momentum theory, response rate and resistance to change are two separable aspects of operant behavior (for review, Nevin, 1992a; 2002; Nevin & Grace, 2000). On the one hand, response rate is governed by the relation between responding and delivery of reinforcers made contingent on the response. Resistance to change, on the other hand, describes the degree to which behavior persists when faced with a disruptor and is related to two factors. First, resistance to change is directly related to the magnitude of the disruptor. Second, resistance is inversely related to a mass-like quality of behavior that is determined by the Pavlovian relation between discriminative stimuli and the reinforcers delivered in their presence. In its simplest form, behavioral momentum theory is described by the following equation:

$$\log \left( \frac{B_x}{B_o} \right) = \frac{-x}{m}. \quad (1)$$

The left side of Equation 1 is log-transformed proportion-of-baseline response rates during disruption. The right side of the equation represents those factors that affect response persistence and can be broken into two more general terms. The numerator

represents the magnitude of the disruptive factor applied to ongoing behavior ( $x$ ), and the denominator represents the mass-like quality of behavior, engendered by the Pavlovian stimulus-reinforcer relation established during baseline, that promotes response persistence. Based on parametric analyses of resistance to change, Grace and Nevin (1997) characterized  $m$  in Equation 2 as a power function of baseline reinforcer rates within a multiple schedule component (see also Nevin, 1992a, 2002). Thus, the term  $m$  in Equation 1 may be replaced with a more specific characterization of behavioral mass,  $r^b$ , where  $r$  is baseline reinforcer rates within a multiple-schedule component (in reinforcers delivered per hr) and  $b$  is a sensitivity parameter.

When modeling resistance to change, it is important that the disruptors that are applied to behavior maintained by different rates of reinforcement in the components of a multiple schedule are either equal or that differences in the magnitudes of the disruptors are clearly and quantitatively defined. Nevin and Grace (2000) suggested disruptors like pre-session feeding or delivery of free reinforcers during the ICIs of a multiple schedule suppress responding in a way that is independent of reinforcer rates within multiple-schedule components and dependent only on the magnitude of the disruptor applied (see, Nevin, 1974; Nevin et al., 1983; see also Nevin, 1992a; 2002, for review).

Mathematically, persistence in the face of these disruptors may be expressed as:

$$\log \left( \frac{B_x}{B_o} \right) = \frac{-kx}{r^b} . \quad (2)$$

where  $x$  is the magnitude of the disruptor (i.e., amount prefed or frequency of ICI food in the animal laboratory) and  $k$  is a scaling parameter such that a one-unit increase in  $x$  does not necessarily represent a one-unit increase in disruption.

When extinction is applied as a disruptor, the contingencies of reinforcement that previously maintained responding in the components of a multiple schedule are removed. Because suspending high- and low-rate reinforcement is likely to produce unequal disruptive impacts on responding (for discussion, see Baum, 2012; Gallistel, 2012), Nevin and Grace (2000; see also Nevin & Shahan, 2011) expanded the numerator of Equation 2 to describe the specific disruptive effects of extinction as follows:

$$\log\left(\frac{B_t}{B_o}\right) = \frac{-t(c + d\Delta r)}{r^b}. \quad (3)$$

The parameter  $t$  is time in extinction (measured in sessions),  $c$  is the disruptive impact on responding of suspending the response-reinforcer contingency, and  $d\Delta r$  represents generalization decrement. Here,  $\Delta r$  is the change in reinforcer rates between baseline and extinction (in reinforcers omitted per hr) and  $d$  is a scaling parameter. The model asserts that the disruptive impacts of  $c$  and  $d\Delta r$  are separate and additive because operant extinction may progress, albeit more slowly, if the operant response-reinforcer contingency is suspended in the absence of generalization decrement (i.e., by delivering response-independent reinforcement during extinction at the same rate that response-dependent reinforcement was delivered during baseline; Koegel, & Rincover, 1977; Nevin, McLean, & Grace, 2001; Rescorla & Skucy, 1969).

### **Open Questions Regarding Behavioral Mass**

Behavioral mass is the major construct within momentum theory that relates reinforcer rates in a given discriminative context to resistance to change of behavior within that context. Despite the theoretical and practical implications of this construct,

and notwithstanding a tradition of studying resistance to change from the perspective of behavioral momentum theory that has spanned several decades (since Nevin et al., 1983), there remain several unanswered questions regarding the nature of behavioral mass. Two of these uncertainties are reviewed below.

First, it is important to acknowledge that the studies on which behavioral momentum theory and its quantitative models are based have examined response persistence under a relatively restricted set of circumstances. An archetypal resistance-to-change procedure proceeds as follows. Responding first is established in the components of a multiple schedule. Then, reinforcement conditions are held constant until behavior in the various components stabilizes. Finally, a disruptor is applied to ongoing behavior in all multiple-schedule components to assess resistance to change (for review, see Nevin, 1992a, 2002, 2012; Nevin & Grace, 2000; Nevin & Shahan, 2011). Because baseline reinforcement schedules almost always are held constant for a prolonged period of time in the study of resistance to change (for an exception, see Craig & Shahan, 2016b), it remains unclear how long a stimulus-reinforcer relation must be in effect for that relation to affect resistance to change. Put another way, it is uncertain over what time frame behavioral mass accumulates given a stimulus-reinforcer relation. As a consequence, it also is uncertain whether, and if so how, behavioral mass might change in the face of stimulus-reinforcer relations that change over time.

Another area for research regarding behavioral mass is associated with the augmented model of extinction (Equation 3). This equation suggests that a Pavlovian stimulus-reinforcer relation that is formed during baseline remains intact during

extinction (see Nevin & Grace, 2000; Nevin & Shahan, 2011, for review). Put another way, behavioral mass ( $r^b$  in the denominator of the equation) does not change with extinction experiences, however extensive those experiences might be. Instead, decreases in responding during extinction are attributed to the growth of disruptive factors (suspending the response-reinforcer contingency,  $c$ , and generalization decrement,  $d\Delta r$ , in the numerator) with time in extinction,  $t$ . This assertion is counterintuitive—it is difficult to believe, for example, that the strength of a response that was reinforced for one week would not change if reinforcement were suspended for several decades. Because of the way that extinction performance has been quantitatively characterized by behavioral momentum theory, however, no existing multiple-schedule extinction data may be used to determine whether or not behavioral mass stays the same given extinction experiences. If Equation 3 were fitted to extent data, decreases in responding would be captured by variations in disruptor terms, not variations in behavioral mass.

### **Applied Relevance**

One major goal of applied behavior analysis is to promote socially significant behavior change in human populations (Cooper, Heron, & Heward, 2007) either through increasing the frequency of socially desirable behavior or decreasing the frequency of socially inappropriate behavior. Whatever the goal of a behavioral intervention, the behavior that is targeted for treatment almost certainly has some extensive, preexisting history of reinforcement. Further, reinforcement-based treatments often are used to promote positive behavior change (for review, see Higgins & Petry, 1999; Jessel, &

Ingvarsson, 2016; Petscher, Rey, & Bailey, 2009; Stitzer & Petry, 2015), and these treatments necessarily entail manipulating the reinforcement history associated with a target behavior.

A basic understanding of how historical variables affect response persistence thus could be informative for at least two reasons. First, it could help to clarify how pre-intervention reinforcement conditions associated with behavior that is targeted for treatment affect resistance to treatment contingencies. Second, such an understanding could help to identify likely effects on future persistence of target behavior that result from reinforcement-based treatments themselves (for discussion, see Mace et al., 2010; Nevin et al., 2016; Nevin & Shahan, 2011; Nevin & Wacker, 2013; Podlesnik et al., 2012; Pritchard, Hoerger, Mace, Penney, & Harris, 2014). The momentum-based framework for understanding resistance to change described above offers a straightforward method for not only comprehending but also predicting these effects.

It also is worthwhile to mention that an emphasis recently has been placed on translating principles of behavioral momentum theory into clinical applications. These principles have been used to clarify the effects of treatment parameters on persistence of problem behavior during, and susceptibility of problem behavior to relapse following, treatment in humans (e.g., Fuhrman, Fisher, & Greer, 2016; Mace et al., 2010; Nevin et al., 2016; Pritchard et al., 2014; Sweeney et al., 2014; Wacker et al., 2011). Further, basic-research studies (e.g., Craig & Shahan, 2016a; Nevin et al., 2016; Podlesnik, Bai, & Elliffe, 2012; Sweeney et al., 2014; Sweeney & Shahan, 2013) have sought to more thoroughly explore effects of clinically relevant treatment factors on suppression and

relapse of non-human animals' behavior from the perspective of behavioral momentum theory. Thus, clearly defining how the momentum-based framework describes resistance to change under diverse situations could inform future applications of behavioral momentum theory to practice. Further, such endeavors hold the potential to aid in development of novel strategies for treating problematic behavior in clinical populations.

### **Purpose**

The purpose of the work reported in this dissertation is to investigate resistance to change in the face of stimulus-reinforcer relations that change across time. From the perspective of behavioral momentum theory, this work aimed to examine more thoroughly the temporal dynamics of behavioral mass. A thorough historical analysis of resistance to change and behavioral momentum theory is described in Chapter 2. The purpose of this chapter is to create a detailed context from which to evaluate the theoretical and practical foundations of momentum theory and to describe limitations to the theory and its extensions to more complex behavioral outcomes. Chapter 3 presents data from a recently published study that aimed to determine effects of changing stimulus-reinforcer relations over time on subsequent resistance to change. Data from an extension of this experiment are described in Chapter 4. The purpose of this study was to determine if behavioral mass changes during operant extinction. Chapter 5 presents an integrative discussion of the results from Chapters 3 and 4. Emphasis is placed on theoretical and practical implications of these findings and areas for future research and theoretical development.

## CHAPTER 2

### AN ANALYSIS OF BEHAVIORAL MOMENTUM THEORY<sup>1</sup>

#### Introduction

Persistence is an important dimension of behavior for both theoretical and practical reasons. Persistence of behavior, in itself, is neither good nor bad. If the behavior in question were completing math problems in a third-grade classroom, then persistence would be a desirable attribute. If the behavior in question were cigarette smoking, then persistence would be an undesirable attribute. The context and function of the behavior will determine whether the individual, her family, and others concerned would *wish* it to continue. Basic learning factors, though, will determine whether it *will* continue, and for how long, and in the face of what challenges.

Nevin (1974) conducted a groundbreaking experiment on the basic processes that contribute to the persistence of behavior (this experiment will be described briefly here, and in more detail later in the chapter). He used pigeons pecking lit disks (conventionally called “keys”) to earn food as his subjects, and a sound-and light-attenuated chamber (a so-called “Skinner box” or “operant chamber”) as his setting, but the findings have long since been shown to have broad applicability. In Nevin’s experiment, the pigeons could peck the key when it was lit either of two colors. When the key was lit one color (the

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<sup>1</sup> Chapter 2 of this dissertation was adapted from “Behavioral momentum and resistance to change,” by A. R. Craig, A. L. Odum, & J. A. Nevin, 2014, *The Wiley Blackwell handbook of classical and operant conditioning* (pp. 249-274), with permissions from John Wiley & Sons Publishing and J. A. Nevin. A copy of the corresponding license agreement and permission-to-use letter may be found in Appendices A and B, respectively.



“rich” component of the reinforcement schedule), they could earn relatively more food (which served as the reinforcer). When the key was lit another color (the “lean” component of the schedule), they could earn relatively less food. Nevin employed various ways to make one component richer than the other, as well as various ways of challenging and disrupting the performance engendered by the schedule. The result was the same: Behavior maintained by a richer schedule of reinforcement was more resistant to change than behavior maintained by a leaner schedule of reinforcement.

These basic findings, along with findings from a number of related studies (see Nevin, 1992a; Nevin & Grace, 2000, for review), led Nevin and his colleagues to draw parallels between the resistance to disruption of voluntary (i.e., “operant”) behavior and Newton’s second law of motion (see Nevin et al., 1983). Newton’s second law states that when some outside force acts on a moving object, the resulting change in the velocity of the object will be directly related to the magnitude of the force that is applied, and inversely related to the mass of the object (Newton, 1686). That is, larger external forces tend to slow down an object more quickly, and heavier objects are harder to slow down. Objects that are more massive, then, are more resistant to changes in the velocity. Building on the metaphor between behavior and Newton’s second law of motion, Nevin et al. (1983) suggested that the rate of responding (i.e., the number of responses emitted by an organism across some period of time) in a given situation might be analogous to the velocity of a moving object. Based on the observation that behavior that is maintained by higher reinforcer rates generally is more resistant to change (i.e., more persistent in the face of disruption) than behavior that is maintained by lower reinforcer rates, Nevin et al.

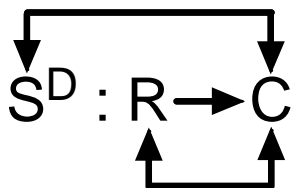
(1983) continued this metaphor by suggesting that behavior also possesses a mass-like quality that contributes to resistance to change, and that reinforcer deliveries in a stimulus situation contribute to this “behavioral mass.” Nevin and colleagues called this metaphor “behavioral momentum theory.”

The overarching goal of this chapter is to provide a general review of behavioral persistence from the perspective of behavioral momentum theory. In the following sections, we first will describe the basic theoretical underpinnings of behavioral momentum, the procedures that historically have been used to investigate behavioral persistence, and some general findings from the resistance-to-change literature. Second, we will detail some conceptually problematic findings that are not well captured by the metaphor offered by Nevin et al. (1983). Finally, we will discuss recent extensions of momentum theory to more complex behavioral phenomena.

### **Behavioral Momentum Theory: An Overview**

As it currently is understood, behavioral momentum theory contends that response rate and resistance to change are two separate aspects of operant behavior. Further, distinct relations between reinforcers and (1) the responses that produce them and (2) the stimuli in the presence of which they are delivered contribute to response rate and resistance to change (Nevin, 1992a). The separability of these relations can be illustrated by considering the operant three-term contingency (Skinner, 1938; for an illustration, see Figure 2.1).

## Resistance to Change



## Response Rate

*Figure 2.1.* The operant three-term contingency. Here,  $S^D$  represents a discriminative stimulus,  $R$  is a response in the presence of the  $S^D$ , and  $C$  is the delivery of a consequence. The response-consequence and stimulus-consequence relations are outlined with indication to which aspect of operant behavior these contingencies are thought to contribute.

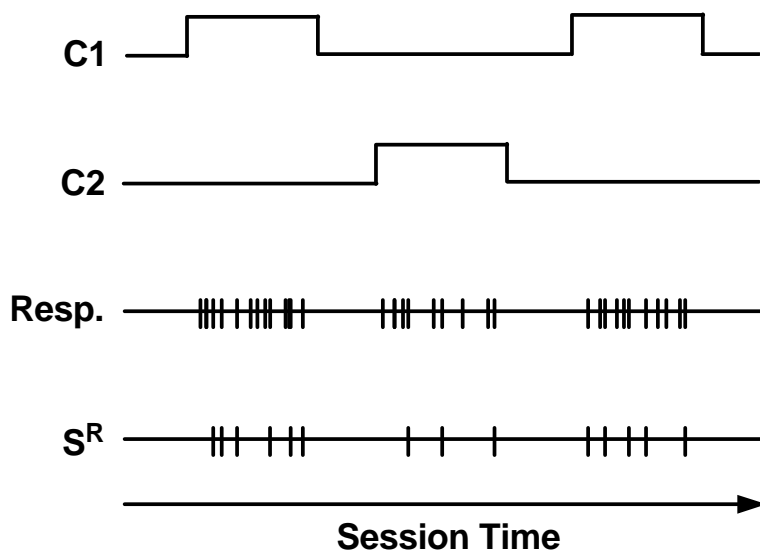
According to the three-term contingency, a discriminative stimulus ( $S^D$ , in Figure 2.1) in the organism's environment sets the occasion for a response ( $R$ ), and dependent on that response, a consequence ( $C$ ), in the context of this chapter, a reinforcer, might be delivered. One can derive a number of two-term contingencies from the overall three-term contingency. The first contingency, that between the response and the reinforcer, governs the rate at which responding occurs in the stimulus situation. The second contingency, that between the discriminative stimulus and the presence of reinforcers, also called the Pavlovian stimulus-reinforcer relation, contributes to resistance to change independently of the response-reinforcer relation.

In this section, we will provide an overview of the foundational work underlying behavioral momentum theory. First, we will discuss the methods that traditionally have been used to study behavioral persistence. We then will present some findings that support both the basic predictions and theoretical underpinnings of behavioral momentum.

### **Traditional Methods for Studying Behavioral Persistence**

When a single behavior is trained and subsequently disrupted, the decrease in behavior that occurs may tell the observer little about the factors that influence resistance to change. Indeed, determining the functional relation between an independent variable (in this case, reinforcer rate) and a dependent variable (here, resistance to change) requires that contrasts between the effects of different levels of the independent variable on the dependent variable be examined (see Baron & Perone, 1998, for further discussion). To clarify the contribution of reinforcers to behavioral persistence, comparisons must be made between behavior that is maintained in the presence of two or more stimuli that are associated with different reinforcer frequencies or magnitudes (see Nevin, 1974; Nevin et al., 1983). This arrangement, known as a multiple schedule (Ferster & Skinner, 1957), provides a useful tool for studying resistance to change.

In the multiple-schedule paradigm, two or more separate discriminative stimuli, each of which is associated with a distinct schedule of reinforcement, alternate successively within an experiment; each stimulus and its associated schedule of reinforcement defines a multiple-schedule component (see Figure 2.2 for a schematic depiction of a basic two-component multiple-schedule preparation; see also Nevin & Grace, 2000). In the case of a pigeon in an operant chamber, these separate components are signaled by different key colors. The pigeon's pecking the response key when it is lit one color (C1, in Figure 2.1) might produce food relatively frequently, while pecking the key while it is lit another color (C2) might produce food relatively infrequently.



*Figure 2.2.* A schematic representation of a two-component multiple schedule. ‘C1’ represents the first component, and ‘C2’ represents the second. Raised bars are periods during which the stimuli correlated with each component are present. Note that C1 and C2 components are separated by periods of blackout (inter-component intervals). Adapted from Nevin and Grace (2000).

In resistance-to-change research, variable-interval (VI) schedules, arranging between 3:1 and 12:1 reinforcer-rate ratios between the rich and lean components, respectively, historically have been the preferred rule by which reinforcers are delivered within multiple schedules (for reviews, see Nevin, 1992a; Nevin & Grace, 2000). The rate at which responding produces reinforcers according to VI schedules tends to be fairly constant despite potential variations in rate of responding, thereby ensuring that obtained reinforcer rates closely approximate the reinforcer rates that are programmed by the experimenter (see Nevin et al., 2001, for detailed discussion). This is an important consideration, given that baseline reinforcer rates typically are the major independent variables in momentum studies.

Another important detail of the multiple-schedule preparation is that the distinct

components of the schedule usually are separated by brief (e.g., 30-s) inter-component intervals (ICIs), periods of blackout during which the operandum is unavailable. Inter-component intervals tend to decrease interactions between the components of the multiple schedule, such as those that produce behavioral-contrast effects in response rate (see Nevin, 1992b, for discussion). Intercomponent intervals, therefore, help to ensure that the separate components of the multiple schedule represent distinct stimulus situations.

The meaningful comparison in resistance-to-change research is between the relative contributions of different rates of reinforcement to behavioral persistence. The multiple schedule allows for such comparisons to be arranged both within subjects and within a single experimental condition. This feature limits the need to conduct lengthy, multi-phase or between-groups experiments (for a discussion of other relative advantages of within-subject designs, see Baron & Perone, 1998). Further, because disruptors can be applied to various stimulus situations of the multiple schedule within the same session, this paradigm eliminates any potential confounds that might be associated with exposing subjects to conditions of disruption multiple times. For example, repeated exposure to extinction, a commonly used disruptor in which responding no longer produces reinforcers, might change the discriminability of nonreinforcement and thereby affect data from subsequent extinction tests (see Baum, 2012).

Once stable responding is achieved in the various components of the multiple schedule, resistance to change may be assessed by applying a disruptor to all of the multiple-schedule components within a session. In the animal laboratory, such disruptors

as operant extinction, providing hungry animals with some portion of their daily ration of food prior to sessions (conventionally, “pre-feeding”), and the presentation of response-independent food during ICIs traditionally have been used (e.g., Harper, 1996; Nevin, 1974, 2012; Nevin & Grace, 2000).

One can classify disruptors by whether they alter the motivation of the organism to respond for reinforcers or change the baseline contingencies under which the organism responded (see Nevin & Grace, 2000, for review). On one hand, pre-feeding and the presentation of free, ICI food may be classified as “external disruptors.” These disruptors alter the motivation of the organism to respond for reinforcement while the internal workings of the experimental situation, like reinforcer availability for performing some behavior, remain intact. External disruptors tend to result in decreases in behavior that are proportional to the magnitude of the disruptor. For example, if a hungry pigeon is pre-fed prior to a session in which it typically would respond for food, the decrease in behavior that is observed during the session generally is greater when they are given more food than when they are given less food (cf., Nevin, 1992b; Nevin et al., 1990). Extinction, on the other hand, is an internal disruptor. It alters the response-reinforcer relation that previously maintained responding. Because the baseline contingencies necessarily are altered during extinction, behavior typically decreases across time with continued exposure to extinction contingencies (see Nevin, 2012, for review).

Aside from the methodological considerations just reviewed, thought also must be given to the manner in which data are analyzed when studying behavioral persistence. One challenge for studying the effects of reinforcer rate on resistance to change is that

different reinforcer rates tend to maintain different rates of responding. More specifically, higher reinforcer rates typically produce higher response rates. This finding is ubiquitous in behavioral psychology (see Shull, 2005, for review). Describing the resistance to change of one behavior relative to that of another behavior might be difficult if the two behaviors occurred at different rates prior to disruption. For example, if behavior in one multiple-schedule component occurs at a higher rate (e.g., 100 responses per min) than behavior in the other component (e.g., 50 responses per min), disruption potentially could decrease responding in both components by a similar *absolute* amount (e.g., a decrease of 25 responses per min). The *relative* change in responding produced by disruption, however, actually would be larger in the component that occasioned lower response rates. In this example, behavior in the component with lower rates would be reduced by 50%, whereas behavior in the component with the higher rates would be reduced by only 25%. From the perspective of behavioral momentum theory, then, absolute response rate in the face of disruption might not be the ideal measure of resistance to change. A standardized unit of measurement is advantageous.

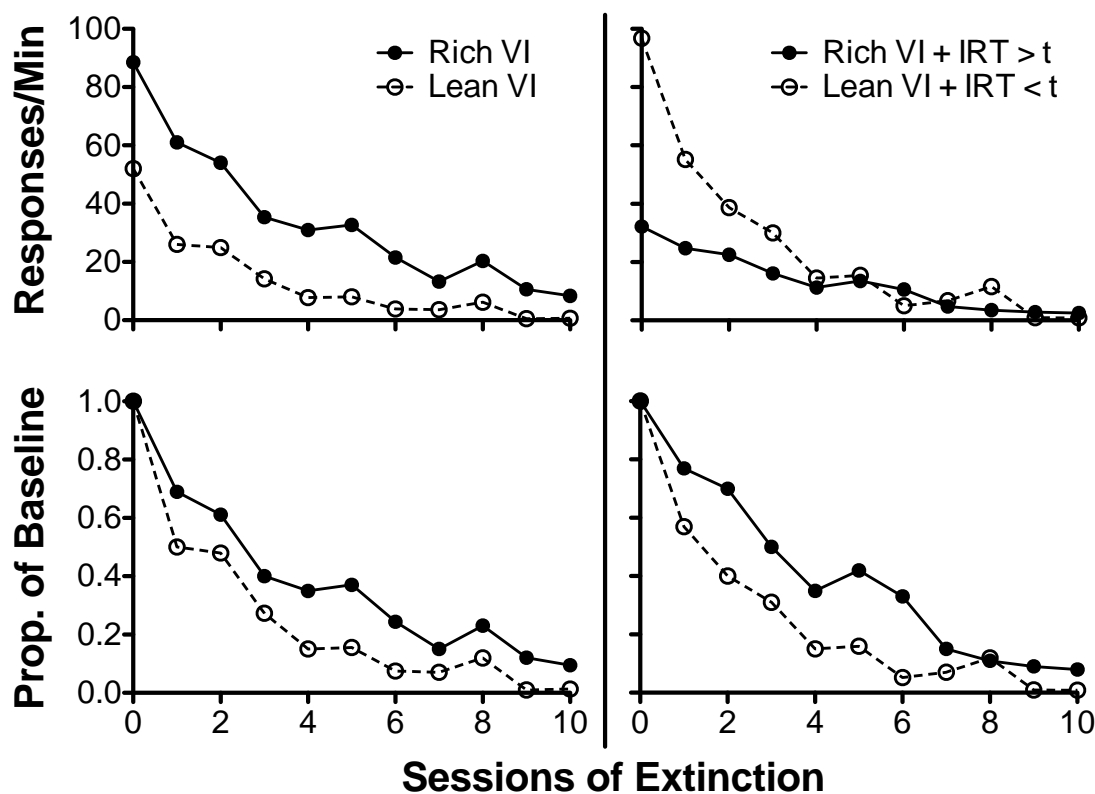
Converting absolute rates of responding during disruption to proportion-of-baseline response rates helps to address the issue present when comparing decreases in behavior between different stimulus situations in which behavior occurred at different rates (see Nevin et al., 1983). Proportion-of-baseline rates of responding typically are calculated by dividing the rate of responding in a given session of disruption by the average rate of responding obtained in the last few sessions during baseline. This measure can range from zero when no responses occurred during that session of disruption to one



when responding occurred at exactly the same rate during that session of disruption as it had during the final sessions of baseline. Occasionally, responding briefly will increase in frequency relative to baseline when disruption is applied, resulting in a proportion-of-baseline value that is greater than one. A common example of this is the extinction burst (e.g., Lerman, Iwata, & Wallace, 1999). This effect, though, is usually transient.

Proportion-of-baseline response rates describes the frequency at which behavior is occurring now (during disruption) *relative to how fast it was, then* (during baseline).

Figure 2.3 presents hypothetical extinction data from two multiple-schedule situations to illustrate the advantages of this measure of resistance to change. These data were modeled after those reported by Nevin's (1974) Experiment 5 (to be discussed later). The left panel depicts extinction data from a typical rich-VI/lean-VI multiple schedule in which responding occurred more frequently in the rich component than in the lean component during baseline. The right panel depicts extinction data from a rich-VI/lean-VI multiple schedule in which additional constraints were placed on the form of responding that was eligible for reinforcement. Here, inter-response times (IRTs) had to be greater than ( $IRT > t$ ) or less than ( $IRT < t$ ) some specified duration (these schedule arrangements also are referred to as differential reinforcement of low rate [DRL] and high rate [DRH] behavior, respectively; Ferster & Skinner, 1957). With these additional constraints, behavior occurred more frequently in the *lean* component during baseline despite its producing reinforcers less frequently in this stimulus situation. Comparing data from the bottom graphs to those from the top graphs, it is easier to determine the persistence of behavior in the rich-schedule component relative to that of behavior in the



*Figure 2.3.* Hypothetical extinction data demonstrating the utility of proportion of baseline as a measure of resistance to change. The left panels represent data from a typical rich/lean multiple schedule using variable-interval (VI) schedules, while the right panel represents data from a rich/lean multiple schedule with VI schedules in which additional constraints on responding were arranged. Here, the response that earned reinforcement had to have occurred following either a relatively long inter-response time ( $IRT > t$ ) or a relatively short IRT ( $IRT < t$ ) in the rich and lean components, respectively. The top graphs depict absolute response rates in the rich and lean components of a multiple schedules, and the bottom graphs depicts proportion-of-baseline rates for the same data.

lean-schedule component when the data are represented as proportion of baseline. Indeed, in the case of the right panel, converting responding across days of extinction to proportion of baseline reveals greater persistence in the rich-schedule component that might not have been apparent otherwise. The advantages of converting response-rate data from conditions of disruption to proportion of baseline are clear: Doing so provides a

quantitative measure of responding in the face of disruption that is robust with respect to variations in baseline response rates.

### **Some Representative Findings**

Now that we have discussed the methods that traditionally have been used to study behavioral persistence, we will describe some general findings from studies that have used these methods and variations on them. Many data sets have supported the notion that reinforcers contribute to behavioral persistence in the face of disruption (see Nevin, 1992b, 2012; Nevin & Grace, 2000, for reviews). As described briefly above, Nevin (1974) conducted an example of this work demonstrating that higher reinforcer rates yielded more persistent behavior. In his Experiments 1 and 2, pigeons pecked keys for food in a two-component multiple schedule. In the rich component, food was available three times as often as in the lean component. After responding had stabilized in both components of the multiple schedule, behavior was disrupted either by presenting response-independent (VT) food at various frequencies during ICIs (Experiment 1) or by extinction (Experiment 2). In both experiments, key pecking in the component associated with the richer schedule of reinforcement was more resistant to disruption than was key pecking in the component associated with the leaner schedule. Further, in Experiment 1, larger amounts of ICI food resulted in more disruption in both components.

The positive relation between reinforcer presentations during baseline and resistance to change is not limited to the *frequency* with which reinforcers are delivered. Resistance to change also is affected by the *amount* of each reinforcer that is delivered (i.e., variations in reinforcer magnitude). Shettleworth and Nevin (1965) offered an early

demonstration of this effect. Here, pigeons pecked keys for food in a two-component multiple schedule in which both components arranged food according to VI 120-s schedules (providing on average 30 reinforcers per hr). The critical difference between the components was that one component delivered 1 s of access to food while the other component delivered 9 s of access. When resistance to extinction was assessed following baseline, behavior in the component associated with 9-s hopper presentations was more persistent than behavior in the component associated with 1-s hopper presentations. Nevin (1974, Experiment 3) subsequently replicated these findings using a different disruptor. Here, pigeons responded under a multiple VI 60-s VI 60-s schedule in which the components differed in the reinforcer magnitudes that they arranged. Reinforcers consisted of 2.5 s of access to food in one component and 7.5 s of access in the other. Across different phases of disruption, different frequencies of response-independent (VT) food were introduced into the dark-key periods that separated the components of the multiple schedule. Resistance to change was greater in the component that was associated with 7.5 s of access to food and higher frequencies of free ICI food resulted in more disruption to behavior in both multiple-schedule components. The findings just reviewed provide support for the general observation that higher reinforcer rates and/or magnitudes during baseline produce behavior that is more persistent in the face of disruption. These general findings have been demonstrated in a number of species other than pigeons, including rats (e.g., Blackman, 1968; Grimes & Shull, 2001; Shahan & Burke, 2004), goldfish (Igaki & Sakagami, 2004), and different human populations (Cohen, 1996; Mace et al., 1990, 2010). Furthermore, as will be noted in detail below, these observations hold

with a variety of different reinforcers and settings.

In addition to the generality of the basic empirical findings associated with behavioral momentum theory, various studies have provided support for the conceptual underpinnings of the theory as well. As previously noted, behavioral momentum theory states that baseline response rate (velocity) and resistance to change (related to a mass-like aspect of behavior) are independent dimensions of discriminated operant behavior. We now consider the support for the conjecture that the response-reinforcer relation governs response rate while the Pavlovian stimulus-reinforcer relation governs resistance to change (refer to Figure 2.1).

### **The Stimulus-Reinforcer Relation: Support for Momentum Theory**

When all of the reinforcers that are delivered in the presence of a discriminative stimulus are dependent on a response, increasing the reinforcer rate strengthens both the stimulus-reinforcer and the response-reinforcer relations. Under most circumstances, one would expect that adding more reinforcers to a multiple-schedule component should result in higher rates of responding *and* behavior that is more resistant to change. How, then, might one tease apart these aspects of behavior to empirically test whether response rate and resistance to change depend on two separate relations?

Possibly the most straightforward method for answering the question just posed is by manipulating either the stimulus-reinforcer or the response-reinforcer relation independently of the other. Nevin et al. (1990) conducted a series of experiments that elegantly addressed this issue by strengthening the stimulus-reinforcer relation

independently of the response-reinforcer relation. In their first experiment, pigeons pecked keys for food in a two-component multiple schedule. One component, signaled by a green key, arranged food according to a VI 60-s schedule. In the other component, signaled by a red key, food was available according to the same VI schedule, *but additional food also was given independently of responding* according to VT schedules. The addition of this extra food had two effects. First, because responding produced only a portion of the food in the VI+VT component, the relation between responding and reinforcer deliveries was weakened to some extent. Second, the Pavlovian stimulus-reinforcer relation in that component was strengthened because more food was delivered in the presence of the discriminative stimulus. Therefore, Nevin et al. predicted that response rates would be lower (due to the weaker response-reinforcer relation), but resistance to change would be higher (due to the stronger stimulus-reinforcer relation), in the component with added VT food. This prediction was exactly what was observed: Response rates in the red-key component tended to be lower than in the green-key component during baseline. When resistance to change was assessed by either pre-feeding or extinction, however, behavior was more persistent in the component with the added food than in the other, VI-only, component.

In a second, admittedly complex, experiment, Nevin et al. (1990) asked whether adding food to a stimulus context *dependent on an alternative response* would increase the resistance to change of a target behavior. Here, Nevin et al. arranged a three-component multiple-concurrent schedule of reinforcement. In all of the components, two response keys, each of which was associated with different contingencies, were available

simultaneously to the pigeons. In Component A, the two response keys were illuminated green. Food was delivered according to a VI 240-s schedule (15 reinforcers per hr) for a target response on one key while food was delivered concurrently according to a VI 80-s schedule (45 reinforcers per hr) for an alternative response on a second key. In Component A, therefore, there were 60 possible reinforcers per hr. In Component B, two red response keys were available. The target response key again delivered food according to a VI 240-s schedule (15 reinforcers per hr) while responding on the alternative response key had no consequences (i.e., extinction; 0 reinforcers per hr). In Component B, therefore, there were 15 possible reinforcers per hr. In Component C, two white response keys were available, and responding on the target key produced food according to a VI 60-s schedule (60 reinforcers per hr) while responding on the alternative response key was on extinction (0 reinforcers per hr), thus providing the same reinforcer rate as the sum of rates in Component A (60 reinforcers per hr). Baseline response rates on the target key in Component A (the component with additional food for alternative responding) were lower than in Components B and C with no alternative reinforcement. Resistance to both pre-feeding and extinction of target responding, however, was greater in Component A than in component B, which arranged the same rate of response-dependent food for the target response, and about the same as in Component C, which arranged the same overall reinforcer rate. In summary, the findings of Nevin et al. demonstrate that increasing the rate of reinforcement in a stimulus situation increases behavioral persistence, even when some reinforcers are delivered independently of responding or dependent on another response. In other words, behavioral persistence is independent of the source of

reinforcers in the situation, but instead depends simply on the sum total of reinforcers in the situation.

Other experiments subsequently have replicated and extended the results reported by Nevin et al. (1990). For example, Mace et al. (1990; Experiment 2) delivered edibles to adults with intellectual disabilities for sorting different colors of dinnerware. These differently colored stimuli served to distinguish the separate components of a multiple schedule. The same rate of response-dependent edible presentations was delivered for sorting in both components, but in the presence of one color of dinnerware, response-independent edibles also were delivered. Resistance to change was assessed by distracting the participants with access to a video program during the sorting task. The adults sorted at a lower rate, but also sorted more persistently, in the component with added reinforcement.

Recent studies have extended the findings of Nevin et al. (1990) and Mace et al. (1990) to situations where qualitatively different reinforcers concurrently are delivered in a discriminative-stimulus situation. For example, Grimes and Shull (2001) demonstrated that sweetened condensed milk, when delivered independently of responding in one component of a multiple schedule, decreased the lever-press response rates of rats but increased resistance to extinction of behavior that was maintained by food. Shahan and Burke (2004) replicated these results with drug reinforcement by demonstrating that adding response-independent food deliveries into one component of a two-component multiple schedule increased the persistence of alcohol-maintained responding in rats. Together, these results suggest that, so long as reinforcers are delivered in the presence of



a discriminative stimulus, they may increase the stimulus-reinforcer relation and thereby increase resistance to change, even when those reinforcers that are delivered independently of responding are different from those produced by responding.

Above, we discussed the effects of augmenting the stimulus-reinforcer relation, alone, on resistance to change. Another approach to studying the separable nature of response rate and resistance to change is to place the response-reinforcer relation into opposition with the stimulus-reinforcer relation. Nevin (1974, Experiment 5) investigated exactly this arrangement. In this experiment, pigeons responded under a multiple VI 60-s VI 180-s schedule of reinforcement. Across conditions, additional constraints were added to the underlying VI schedules such that, when an interval elapsed, the IRTs between two consecutive responses had to be either less than or greater than 3 s (IRT < 3 s and IRT > 3 s contingencies, respectively) to earn a reinforcer. If separate reinforcer relations governed response rates and resistance to change, Nevin reasoned that behavioral persistence in the separate multiple-schedule components should be positively related to baseline reinforcer rates, regardless of the additional constraints (i.e., IRT < 3 s or IRT > 3 s) placed on responding. This is precisely what Nevin observed. The IRT < 3-s and IRT > 3-s arrangements produced high-and low-rate responding, respectively. When responding was disrupted by either free ICI food presentations or by extinction, however, behavior maintained in the context that was associated with the VI 60-s schedule consistently was more resistant to disruption than behavior maintained in the context associated with the VI 180-s schedule (see Figure 2.3 for an illustration of this finding using hypothetical data).

Nevin (1992b) offered a third approach demonstrating the dependency of resistance to change on the Pavlovian stimulus-reinforcer relation. The relation between reinforcers and a target discriminative stimulus, by definition, reflects the reinforcer rate in the presence of that stimulus *relative to the reinforcer rate in the absence of that stimulus* (i.e., in the context within which the target stimulus appears; see Rescorla, 1968). This definition of the stimulus-reinforcer relation suggests that resistance to change should be governed both by the absolute reinforcer rate in a given multiple-schedule component and by the reinforcer rate in that component *relative to the reinforcer rate in other components in the experimental session*. Put more simply, resistance to change should be susceptible to behavioral-contrast effects. Nevin demonstrated precisely this effect. In his experiment, pigeons pecked keys for food in a multiple schedule in various conditions. In all of these conditions, responding in the presence of a red key was reinforced according to a VI 60-s schedule (60 reinforcers per hr). Responding in the presence of the other, green, key was reinforced according to either a VI 12-s (300 reinforcers per hr) or a VI 360-s (10 reinforcers per hr) schedule across conditions. When food was delivered in the green-key component according to the VI 12-s schedule, the food rate in the red-key component was relatively lean, and when the green-key component delivered VI 360-s food, the food rate in the red-key component was relatively rich. Following baseline, resistance to both pre-feeding and extinction was assessed.

The critical comparison in this experiment was between the resistances to change of responding in the red-key component, which was always associated with VI 60-s food,

across conditions. Nevin (1992b) reported a behavioral-contrast effect in resistance to change between conditions in that responding in the red-key component was more persistent when the green-key component arranged VI 360-s food than when it arranged VI 12-s food. In other words, resistance to change depended on the reinforcer rate in the constant red-key component *relative* to the reinforcer rate in the alternative green-key component.

In summary, when either the response-reinforcer relation or the stimulus-reinforcer relation is manipulated alone (or the two relations are placed in opposition of one another), separate effects on response rate and resistance to change might be observed. Therefore, in terms of momentum theory, resistance to change generally is a function of the relative reinforcer rate that is delivered in the presence of a discriminative stimulus, and this relation largely is independent of the response-reinforcer relation. In the cases just discussed, this relation was independent of the source of reinforcers (i.e., whether or not reinforcers were delivered dependently on responding; Grimes & Shull, 2001; Nevin et al., 1990; Shahan & Burke, 2004), the type of reinforcers (Grimes & Shull, 2001; Shahan & Burke, 2004), and the rate at which responding was maintained during baseline (Nevin, 1974, Experiment 5). Further, resistance to change can be affected by manipulating the relative rates of reinforcer presentations between a component and its surrounding context (Nevin, 1992b).

These results demonstrate the broad applicability of the simple metaphor offered by behavioral momentum theory. This metaphor accurately describes the general finding that higher relative reinforcer rates (or amounts) produce behavior that is more resistant

to disruption, independently of baseline response rates. There are, however, a number of findings that might be considered problematic for behavioral momentum theory. While these findings might not have implications for most situations outside of the laboratory, they provide insights into the accuracy of the fundamental metaphor of behavioral momentum. In the following section, we will describe some of these challenges.

### **Challenges to Behavioral Momentum Theory**

Behavioral momentum theory proposes that the resistance to change of response rate in the presence of a stimulus situation depends directly on the reinforcer rate or amount signaled by that stimulus after extended training (i.e., the Pavlovian stimulus-reinforcer relation), regardless of whether all reinforcers are dependent on the target response. Although several lines of evidence support that proposition, as described above, there are some challenges to its generality. Much as Newtonian physics works well under most conditions that would be encountered in daily life but might fail to predict what happens under extreme conditions (like the physics of objects approaching the speed of light or of objects on the molecular scale; see Feynman, 1994), these challenges to behavioral momentum theory might pose little difficulty and have few implications in many applied and clinical situations. Ultimately, however, these problems suggest that behavioral momentum theory might profitably be replaced or supplemented by a theory that more accurately captures a wider range of situations and outcomes. The main areas in which discrepancies have emerged are different response-reinforcer relations, extreme differences in reinforcer rates, and single schedules of reinforcement.

### **Different Response-Reinforcer Relations**

If resistance to change depends on stimulus-reinforcer relations, there should be no difference in resistance to change between multiple-schedule components when stimulus-reinforcer relations are the same. To the contrary, several studies have found that when obtained reinforcer rates are matched between components but response-reinforcer relations differ between components, high response rates are generally *less* resistant to disruption than low response rates. A study by Blackman (1968) provides an early example. Rats were trained in multiple schedules with identical VI schedules of food reinforcement but with different constraints on response rate in the components. For example, in Component A, Rat 1 obtained reinforcers on a schedule that reinforced only those responses occurring within 0.2 s of the previous response ( $IRT < t$ , or DRH), and in Component B, only those responses that were spaced between 1.5 and 3.0 s were reinforced (a pacing schedule). As a result, response rates in Component A were about double those in Component B, even though obtained reinforcer rates were essentially identical. When a 1-min tone signaling an unavoidable shock was presented in the middle of each 8-min component, responding was suppressed much more in Component A (high-rate  $IRT < t$ ) than in Component B (low-rate pacing). These results should be contrasted with those obtained by Nevin (1974, Experiment 5) discussed above. In his experiment, Nevin arranged similar constraints on response rates in a two-component multiple schedule that arranged *different* reinforcer rates. Nevin's experiment, unlike Blackman's, provided support for behavioral momentum.

The finding that relatively low response rates are more resistant to change in

multiple schedules has been confirmed in subsequent experiments. For example, K. A. Lattal (1989) had pigeons respond on VI schedules with fixed-ratio (FR) or IRT > t (DRL) contingencies that produced different response rates in components with equated reinforcer rates. When responding was disrupted by introducing food during ICIs, response rate decreased less in the DRL component than in the FR component. Similarly, Nevin et al. (2001, Experiment 2) evaluated resistance to change with VI versus variable-ratio (VR) schedules, where the VR value was adjusted every few sessions so that higher-rate VR responding yielded the same obtained reinforcer rate as that in the VI component. Lower-rate VI responding was less disrupted by ICI food, extinction, and ICI food plus extinction, than higher-rate VR responding. The common feature of these studies is that when reinforcer rates were the same in two multiple-schedule components, resistance to change was greater in the component with the lower response rate.

Another area of research on the effect of response-reinforcer contingencies on resistance to change also reveals a relation between response rate and persistence, but in the opposite direction as described above. When reinforcers are presented immediately after eligible responses, the rate of responding is usually higher than when unsignaled delays intervene between responses and reinforcers (see K. A. Lattal, 2010, for review). Bell (1999) and Grace, Schwendiman, and Nevin (1998) confirmed this result in components of multiple schedules with obtained reinforcer rates equated between components, and then compared resistance to prefeeding, ICI food, and extinction between components. Both studies obtained greater resistance to change in the component that arranged immediate reinforcers. The results not only challenge the role of

Pavlovian factors (stimulus-reinforcer relations) in determining resistance to change, because reinforcer rates were equated between components, but also question the generality of the findings cited above that low response rates are more resistant to change than high response rates.

In summary, differential stimulus-reinforcer relations between the component stimuli in multiple schedules evidently are not necessary to produce differential resistance to change. Resistance to change may be influenced by contingencies that generate different response rates in the absence of differences in reinforcer rates. The critical differences, however, between response-reinforcer relations that selectively reinforce higher or lower response rates and those that involve reinforcer delays remain obscure. Both procedures affect response rate, but in one case (pacing contingencies), lower response rates are more persistent, and in the other case (delaying reinforcers), lower response rates are less persistent. Both lines of research show, however, that response persistence can be affected by factors other than reinforcer rate, which challenges one of the basic tenets of behavioral momentum theory - that persistence is affected only by the stimulus-reinforcer relation in a discriminative-stimulus situation.

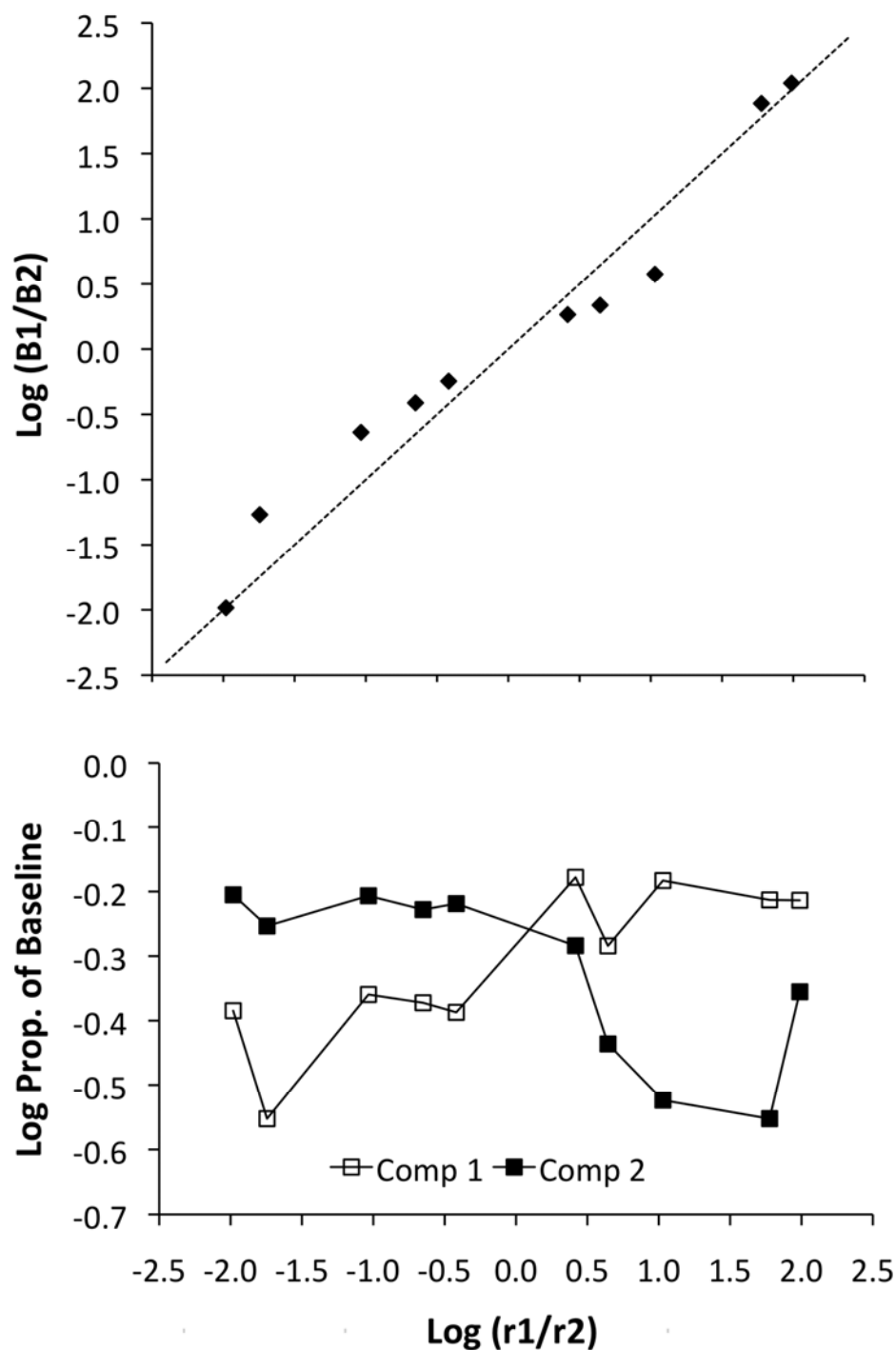
### **Extremely Different Reinforcer Rates**

In addition to challenges when reinforcer rates are the same, the generality of Pavlovian determination of resistance to change recently has been challenged from the opposite direction, when reinforcer rates are very different. McLean, Grace, and Nevin (2012) arranged standard two-component multiple VI VI schedules that covered a far greater range of reinforcer-rate ratios than any previous study. The studies reviewed

above that reported greater resistance to change in a multiple-schedule component with more frequent reinforcement arranged VI schedules with reinforcer-rate ratios between 3:1 and 12:1. By contrast, McLean et al. covered a range from about 1:100 to 100:1 and assessed resistance to change using pre-feeding.

Figure 2.4 depicts a summary of the results of this (admittedly complex) study. In this figure, the  $x$ -axis is log (base 10) reinforcer-rate ratios for Components 1 and 2 ( $r_1$  and  $r_2$ , respectively). The  $y$ -axis in the top panel shows log response-rate ratios in Components 1 and 2 ( $B_1$  and  $B_2$ ), and the  $y$ -axis in the bottom panel shows log proportion-of-baseline response rates during disruption for both components. These data were log-transformed because this technique has the advantage of rendering equal unit changes for proportional differences. For example, a decrease in responding from 0.4 to 0.2 proportion of baseline (a 50% decrease) will be reflected in an equal change in log units as a change from 0.2 to 0.1. McLean et al. (2012) found that response rates were always higher in the richer component, and that the ratio of response rates between the two components increased and approached matching to the most extreme reinforcer-rate ratios (see the top panel of Figure 2.4). Resistance to pre-feeding, however, became less differentiated between rich and lean components at those extreme ratios (see the bottom panel of Figure 2.4), suggesting that differential Pavlovian stimulus-reinforcer relations are not sufficient to account for differential resistance to change. McLean et al. (2012) noted that when response ratios match reinforcer ratios, it is necessarily true that the probability of reinforcement per response is the same in both components. Therefore, there should be little or no difference in resistance to change at extreme reinforcer ratios





*Figure 2.4.* Log response-rate ratios and log proportion of baseline, both plotted as a function of log reinforcer-rate ratios across multiple-schedule conditions used by McLean et al. (2012). Note that as the reinforcer-rate ratios became more extreme (closer to the left or right side of the  $x$ -axis), log proportion-of-baseline response rates were more similar between the two components than they were at less extreme ratios. Average data adapted from McLean et al. (2012).

if probability rather than rate of reinforcement determines resistance to change. In standard multiple VI VI schedules, such as those that were used in this experiment, reinforcer probability and rate are generally confounded, so support for this notion must be sought elsewhere.

The findings of greater resistance to change of lower than higher response rates with equated reinforcer rates, described above, are consistent with determination by reinforcer probability. The effects of reinforcer delays described above, however, are contrary to expectation because the higher response rates observed with immediate reinforcers necessarily correspond to lower reinforcer probabilities per response. Neither can reinforcer probability account for the effects of reinforcer context found by Nevin (1992b) because in that study, lower response rates in a constant component when the alternated component was rich were less resistant to change than when the alternated component was lean—a result consistent with Pavlovian determination of resistance to change. At least to our current knowledge, no single principle can account for all of these findings that challenge momentum theory.

### **Resistance to Change in Single Schedules**

Another situation in which behavioral momentum theory has difficulty predicting response persistence has to do with how the schedules of reinforcement are arranged. As previously described, virtually all laboratory research on resistance to change has used multiple schedules. This arrangement allows baseline response rates and resistance to change to be compared within subjects and sessions, and resistance to extinction is usually greater in the rich component than in the lean component. By contrast, when

different conditions of reinforcement are arranged in single schedules for entire sessions and compared across successive conditions, the usual positive relation between resistance to change and reinforcer rate might not be obtained. For example, with rats as subjects, Cohen, Riley, and Weigle (1993) found that resistance to prefeeding was about the same for VI 30-s, VI 60-s, and VI 120-s schedules arranged singly in successive conditions (i.e., not in a multiple schedule). If resistance to change followed the usual result, behavior should have been most persistent in the richest schedule (VI 30-s) and least persistent in the leanest schedule (VI 120-s).

Cohen (1998) suggested that the difference between resistance to change in single and multiple schedules arose from the frequency of alternating exposure to different reinforcer rates. He compared resistance to both pre-feeding and extinction after training with VI 30-s and VI 120-s schedules in different arrangements. Schedules were arranged singly in successive conditions (Part 1), on alternating days (Part 2), and in a standard multiple schedule (Part 3). Distinctive stimuli accompanied the schedules throughout all three phases.

Cohen (1998) found that resistance to pre-feeding was about the same for both schedules in Part 1 (successive conditions) but was greater for the richer component in Part 3 (the standard multiple schedule); results for Part 2 were mixed. Relatedly, resistance to extinction was greater in the richer component during Phase 3 (the standard multiple schedule), but differed in the opposite direction (i.e., behavior maintained by the leaner schedule was more persistent) in Phases 1 (successive conditions) and 2 (alternating days). The latter findings essentially replicate the well-known ‘partial-

reinforcement extinction effect' that routinely is observed in single schedules (see Sutherland & Mackintosh, 1971). That is, in single schedules, behavior that is intermittently reinforced (or reinforced at a relatively low rate) tends to be more persistent than behavior that is reinforced continuously or relatively frequently. Cohen's and other authors' (e.g., Shull & Grimes, 2006) finding resistance to extinction is *negatively* related to baseline reinforcer rate in single schedules is not easily reconciled with momentum theory (see Nevin, 2012, for a discussion).

A recent study by Lionello-DeNolf and Dube (2011) compared the effects of added VT reinforcement (cf., Nevin et al., 1990) in successive conditions and in multiple schedules with separate groups of children with various developmental disabilities. In different stimulus conditions, all participants tapped pictures on a touch screen to gain access to either edibles or tokens exchangeable for various preferred items. In both conditions, reinforcers were delivered dependently on tapping the touch screen according to VI 12-s schedules. In one condition, free reinforcers also were delivered independently of responding according to a VT 6-s schedule. Tapping the touch screen was disrupted by presenting a different stimulus that signaled VI 8-s reinforcement for an alternative response presented concurrently with the target response. The results were striking: Responding was less disrupted in the VI+VT component for all six children trained and tested with multiple schedules, consistent with many previous findings described above, but the same ordering was observed with only two of six children experiencing the same schedules in successive conditions. Evidently, the difference between single and multiple schedules extends to translational settings and includes the effects of added response-

independent reinforcers.

In summary, it appears that the direct relation between resistance to change and the rate of reinforcement that is characteristic of behavior maintained in multiple-schedule components does not generalize to behavior maintained by single schedules. As we know from Nevin (1992b), resistance to change in a constant component depends inversely on the reinforcer rate in an alternated component; equivalently, resistance to change depends directly on the relative rate of reinforcement in a component. In single schedules, where environmental conditions and reinforcer rates are uniform throughout the session, relative reinforcer rates cannot be meaningfully calculated. In that sense, behavioral momentum theory is not challenged by single-schedule data. However, resistance to change is a fundamental dependent variable of great interest in clinical and educational settings, and the inability of momentum theory to incorporate single-schedule data is a serious limitation to the theory's application.

The preceding discussion has highlighted some findings that are problematic for behavioral momentum theory, as it historically has been used to describe the contribution of the Pavlovian stimulus-reinforcer relation to resistance to change. Undoubtedly, these considerations challenge the generality of behavioral momentum as a unified framework for describing behavioral persistence. Theoretical development continues within the framework, however, and recently it has been extended to more complex aspects of behavior (i.e., relapse and stimulus control). In the following section, we hope to demonstrate that, though there are a number of challenges to behavioral momentum theory, the applicability of the theory outside of these challenging situations is robust.

### **Extensions of Behavioral Momentum Theory**

Most research on resistance to change has employed multiple schedules of reinforcement and measured the rate of a response in the steady state and during disruption. As reviewed above, many studies have shown that baseline response rate is more resistant to change in a multiple-schedule component with larger or more frequent reinforcers. Given the generality of this finding, one reasonable question is: To what extent does reinforcer rate or magnitude govern other aspects of behavior?

In light of this question, behavioral momentum theory recently has been extended to account for more complex behavioral phenomena. One extension of behavioral momentum is to the recurrence (or “relapse”) of previously reinforced behavior. Behavioral momentum also has been applied to studying the resistance to change of a qualitative dimension of operant behavior, remembering. In the following section, we will describe both of these recent extensions.

#### **Behavioral Momentum and Relapse**

In clinical situations, extinction often is used in conjunction with other behavioral interventions as a method for decreasing the frequency of undesirable behavior (see Lerman & Iwata, 1996). One characteristic of behavior that demonstrates persistence is the propensity of that behavior to relapse when the conditions of disruption that were established during treatment are altered in some way (see Podlesnik & Shahan, 2009; 2010; Shahan & Sweeney, 2011). Just as it is important to understand the factors that contribute to the resistance to change of behavior, it is also important to understand the

conditions under which one might anticipate that behavior will return, and to what degree.

There are three general relapse paradigms: reinstatement, renewal, and resurgence. Reinstatement, the most commonly investigated relapse phenomenon, occurs when a stimulus that was previously associated with reinforcement (or the reinforcer, itself) is presented following the extinction of a target response (e.g., Reid, 1958; see also Katz & Higgins, 2003, for a review of the reinstatement paradigm in the context of drug use). For example, an ex-smoker, after months of abstinence and under normal circumstances, might no longer crave cigarettes. If he is exposed to cigarette-related cues (e.g., cigarette smoke, the sound of a match striking, etc.), he might experience intense cigarette cravings and potentially relapse to, or 'reinstatement,' cigarette smoking.

In the renewal paradigm, behavior first is maintained in one stimulus context (Context A) and then is extinguished in a separate stimulus context (Context B). Once behavior is extinguished, a return to the context in which it was trained (Context A) typically results in the reoccurrence of the target responding. For example, a child might learn to aggress against others to gain access to attention. In the setting of a clinic, a behavioral intervention might be implemented that effectively extinguishes his aggressing. When the child is returned to the environment in which aggressing previously was reinforced, however, its occurrence might be re-occasioned or 'renewed.' Other variations of this basic procedure, namely 'AAB' (training and extinction in one context, then a change to a second context) and 'ABC' (training in one context, extinction in a second context, and then a change to a third context) renewal, exist as well. Relapse of

operant behavior has been observed in each of these preparations (see Bouton, Todd, Vurbic, & Winterbauer, 2011).

Finally, resurgence entails the reoccurrence of a previously reinforced and since extinguished behavior when reinforcement for a more recently trained alternative response is withheld (see Leitenberg, Rawson, & Mulick, 1975; see also K. A. Lattal & St. Peter Pipkin, 2009, for review). Consider the child mentioned above. In treatment, he might have been taught to appropriately request attention instead of engaging in problem behavior. If the therapist were not to reinforce these requests, appropriate behavior might decrease in frequency and aggressing might reoccur or ‘resurge.’

Based both on the observation that relapse tends to be positively related to the rate of reinforcement in a stimulus context (cf., Leitenberg et al., 1975; see Winterbauer, Lucke, & Bouton, 2013, Experiment 1, for a more recent example) and on insights from momentum theory, Podlesnik and Shahan (2009) investigated whether the Pavlovian stimulus-reinforcer relation that governs resistance to change also governs the magnitude of relapse that is obtained in basic reinstatement, renewal, and resurgence preparations. In their first experiment, Podlesnik and Shahan investigated the role of baseline reinforcer rates on reinstatement in pigeons. Here, they arranged a two-component multiple schedule in which both components delivered food according to VI 120-s schedules (30 reinforcers per hr). In one component, VT 20-s food (180 per hr) concurrently was available in addition to the VI 120-s food. After behavior in both components was extinguished, a few food presentations were made available at the beginning of sessions to test for reinstatement. Experiment 2 investigated the effects of baseline rates of food



on resurgence. The procedure was the same as that of Experiment 1, but VI 30-s food (180 per hr) was made available for responding on an alternative-response key during extinction in both components. Alternative food was discontinued during resurgence testing. In their final experiment, Podlesnik and Shahan arranged an ABA renewal preparation in which baseline stimulus conditions were identical to those of the previous experiments, with steady house lights throughout the session (Context A). During extinction, the house lights in the pigeons' chambers flashed constantly, thereby establishing a separate stimulus context (Context B). Once behavior had been eliminated in both components, the pigeons were returned to Context A for renewal testing.

In all three relapse preparations that Podlesnik and Shahan (2009) arranged, two findings were general. First, responding in the context that was associated both with VI and VT food (and thus had an overall higher rate of food delivery) was more persistent during extinction than was behavior in the other, VI-only, component (cf., Grimes & Shull, 2001; Nevin et al., 1990; Shahan & Burke, 2004). Second, and most importantly for the current discussion, behavior in the component that was associated with both VI and VT food relapsed to a greater degree than did behavior in the VI-only component. Though reinstatement, renewal, and resurgence entail the reoccurrence of extinguished behavior through different environmental manipulations, one underlying effect appears to be common among them: More reinforcement during baseline conditions (and thus greater stimulus-reinforcer relations in those conditions) yields greater relapse following extinction.

The findings of Podlesnik and Shahan (2009) have been replicated in a number of

species using a variety of procedures. For example, Mace et al. (2010) either reinforced the targeted problem behavior of children at relatively low rates (lean reinforcement) or differentially reinforced an alternative behavior (DRA) at relatively high rates (rich reinforcement, but for an alternative behavior), across conditions. Problem behavior in the DRA condition decreased to low levels during treatment, analogous to the decrease in target responding observed in the second phase of a standard resurgence preparation. When the target and alternative behaviors were extinguished, problem behavior resurged to a higher level following the relatively rich DRA condition than following relatively lean reinforcement of problem behavior. In other words, adding reinforcers for alternative behavior made the problem behavior occur at a lower rate, but when the additional reinforcers were removed after the problem behavior was extinguished, the problem behavior came back at a higher rate than when no reinforcers were added for alternative behavior.

Two recent experiments with laboratory animals have extended the initial experiments on behavioral momentum and relapse. Pyszczynski and Shahan (2011) demonstrated that adding food to one component of a multiple schedule in which rats responded for dippers full of alcohol solutions produced behavior that was more susceptible to reinstatement. Further, Thrailkill and Shahan (2011) showed that, in pigeons, the renewal, reinstatement, and resurgence of responding maintained by conditioned reinforcement (i.e., stimuli predictive of food in an observing-response preparation; see Wyckoff, 1952) was positively related to the rate at which food was delivered prior to relapse testing.

In summary, behavioral momentum theory offers not only an approach to understanding the factors that contribute to the persistence of behavior in the face of disruption, but also helps us to understand factors that contribute to the return of extinguished responding. The implications for this extension of momentum theory are clear: It provides a formalized approach to understanding how environment and reinforcers interact to contribute to the recurrence of prior behavior. It also addresses a longstanding issue in learning theory: Does extinction abolish learning or merely affect performance? The persistence of differential strengthening effects of baseline reinforcement that are revealed in testing for relapse suggests that extinction, although characterized as an internal disruptor, leaves intact at least some aspects of a reinforcement history, expressed as behavioral mass in momentum theory. In other words, extinction does not abolish prior learning. Moreover, using momentum theory as an approach to understanding relapse might inform treatment strategies for problematic behaviors that are susceptible to relapse (i.e., drug taking, aggressive behavior, etc.).

All of the results reviewed in this chapter so far have focused on the resistance to change of one dimension of operant behavior: Response rate. Recent investigations, however, suggest that the metaphor of behavioral momentum is not limited to understanding the resistance to change of response rate in the face of disruption: It may also be extended to qualitative dimensions of behaviors. In particular, momentum theory has been used to describe the effects of reinforcer rates on the accuracy and persistence of delayed stimulus control in procedures used to assess remembering.

### **Measuring Resistance to Change of Accuracy and Response Rate**

Delayed matching-to-sample (DMTS) procedures historically have been used to assess the stimulus control over responding across time (cf., Maki, Moe, & Bierly, 1977). In DMTS preparations, a pigeon might first be presented with a sample stimulus (say, a green key). After some delay (called the 'retention interval'), two comparison stimuli are presented, one that matches the sample stimulus and one that does not. If the pigeon chooses the stimulus that matches the sample stimulus, it may gain access to food according to some schedule. The proportion of correct matches emitted during a DMTS procedure reflects the extent to which the pigeon (or rat, or person) remembers the sample stimulus given a delay. If the DMTS procedure permits the study of delayed stimulus control (or remembering), how might it be adapted to study the *resistance to change* of stimulus control?

Schaal, Odum, and Shahan (2000) developed a paradigm that incorporated DMTS and that permits measurement of both response rate and accuracy of stimulus control (and of the resistance to change of both of these aspects of behavior). Briefly, the paradigm arranges that a pigeon may respond to produce DMTS trials (instead of food) on a VI schedule; accordingly, the paradigm is designated VI DMTS. Food reinforcers for correct matches maintain responding both in the VI and DMTS portions of the preparation, and the probability or magnitude of the reinforcer can be varied between signaled multiple-schedule components. After stable baseline performances have been established in both components, resistance to change of both VI response rate and DMTS accuracy can be examined within subjects and sessions and related to the conditions of reinforcement

exactly as in standard multiple schedules.

Nevin, Milo, Odum, and Shahan (2003) reported the first study to employ the multiple VI DMTS paradigm in this way. They arranged a two-component multiple schedule in which pigeons produced matching-to-sample trials according to VI 30-s schedules. The center key was lit red or green during the VI to signal the probability of reinforcement for a correct match. When the VI timed out, a center-key peck turned off the color and produced a vertical or slanted line as a sample stimulus. After 2 s, the sample was extinguished and the side keys were lit with the comparison stimuli, vertical and slanted lines displayed randomly on the left and right keys (DMTS with 0-s delay). A peck to the side key with the same orientation as the sample produced food with a probability either of .8 (rich) or .2 (lean), depending on the key color during the VI. Key colors and the correlated reinforcer probabilities alternated after four such cycles, separated by a 30-s ICI. After baseline response rates and matching accuracies were stable, resistance to change was evaluated by pre-feeding, free ICI food, extinction, and the abrupt insertion of a short delay between sample offset and comparison onset.

During baseline, both response rates and matching accuracies generally were higher in the rich component, and during disruption by prefeeding, ICI food, and extinction, both response rates and matching accuracies generally were more resistant to change. When matching performance was disrupted by a 3-s delay, response rate was largely unaffected but matching accuracy was drastically reduced, more so in the lean component. Overall, though, matching accuracy under disruption was positively correlated with VI response rate under disruption, suggesting that these separate aspects

of behavior were similarly strengthened by reinforcement.

Odum, Shahan, and Nevin (2005) modified the Nevin et al. (2003) procedure to study the resistance to change of forgetting functions—the relation between accuracy and duration of the delay between sample offset and comparison onset (see White, 1985, 1991, for quantification and discussion of forgetting functions). Specifically, they arranged identical VI 20-s schedules in the initial segments of the VI DMTS with reinforcer probabilities of .9 (rich) or .1 (lean) signaled by red or green center key lights. They used yellow or blue key lights as samples and comparisons. Samples remained on until the first peck after 3 s, after which the center key returned to its color during the VI for 0.1, 2, 4, or 8 s before onset of the side-key comparison stimuli. Correct matches were reinforced with the signaled probability. Components alternated after four such cycles, separated by 15-s ICIs. After both VI response rates and DMTS forgetting functions were judged to be stable, resistance to change was tested by presenting free ICI food and by extinction. As expected, Odum et al. observed that responding in the VI portion of the VI DMTS was more resistant to disruption in the rich component than in the lean component. Further, relative to baseline, the rate of forgetting was more resistant to disruption in the rich component than in the lean component. Thus, both response rates and the accuracy of remembering were strengthened similarly in relation to relative reinforcement in a component, extending the results of Nevin et al. (2003).

### **Separating Baseline Accuracy and Resistance to Change**

Early studies of free-operant responding in typical multiple schedules have found

that resistance to change was correlated with baseline response rate, as in Experiment 1 by Nevin (1974). Subsequent research, described above, has suggested that baseline response rate and resistance to change might be separately determined by response-reinforcer and stimulus-reinforcer relations. The studies with the VI DMTS paradigm described above found that the resistance to change of accuracy was correlated with baseline accuracy, in that higher probabilities of reinforcement maintained higher levels of accuracy and also established greater resistance to change. An extension of behavioral momentum theory to DMTS, based on findings with free-operant responding, would suggest that response-reinforcer relations within DMTS trials might control baseline accuracy whereas stimulus-reinforcer relations (i.e., relative reinforcer rate in a component) might control resistance to change.

To explore this possibility, Nevin, Ward, Jiminez-Gomez, Odum, and Shahan (2009) exploited the differential outcomes effect (DOE), whereby DMTS accuracy is higher when different outcomes are arranged for the two correct side-key responses. In an early study, for example, Peterson, Wheeler, and Trapold (1980) trained a group of pigeons in red-green matching to sample where correct responses to green comparisons were followed by a tone plus food, but correct responses to red comparisons were followed by the tone only (differential outcomes for correct green responses vs. correct red responses). A second group received tone plus food for all correct side-key responses (same outcomes for correct green responses and correct red responses). Despite the fact that the same outcomes group obtained more frequent reinforcers, accuracy was higher for the differential outcomes group, especially at longer delays between samples and

comparisons.

Nevin et al. (2009) compared differential outcomes with more-frequent same outcomes in the multiple-schedule VI DMTS paradigm. Reinforcer probabilities were .9 and .1 for correct responses to yellow and blue comparisons in the different-outcome (DO) component and probabilities were .9 and .9 for responses to both colors in the same-outcome (SO) component. Thus, relative reinforcement was greater in the SO component. The DO or SO components were signaled by lighting the center key red or green during the VI and the DMTS retention interval; components alternated after four completed DMTS trials, and were separated by 15-s ICIs. After 50 training sessions, resistance to disruption by pre-feeding, ICI food, and extinction were evaluated.

In baseline, VI response rate was higher in the SO component, consistent with the greater overall reinforcer probability in that component, but the forgetting function was substantially higher (showing better accuracy) in the DO component, replicating the standard DOE. Nevertheless, during disruption by pre-feeding, ICI food, and extinction, decreases relative to baseline in both VI response rate and DMTS accuracy were greater in the DO component. Thus, the higher level of DMTS accuracy maintained by differential response-reinforcer relations in the DO component was weaker than the lower level in the SO component with overall richer reinforcement— clear evidence of the dissociability of baseline performance and resistance to change.

In a final part of the study, reinforcer probabilities in the SO component were changed to .5, .5, so the overall probability of reinforcement was the same in both components. Baseline accuracy remained higher in the DO component, but resistance to



change was essentially the same in DO and SO components, confirming the importance of relative reinforcement in determining resistance to change.

In summary, in addition to response rates, remembering appears to follow the basic tenets of behavioral momentum theory. Greater reinforcer availability during baseline produces relatively more persistent remembering, just as greater reinforcer availability during baseline produces relatively more persistent response rates (e.g., Nevin, 1974). Further, how accurate remembering is in baseline can be dissociated from how perseverant it will be, just as how fast response rates are at baseline can generally be dissociated from how perseverant they will be (e.g., Nevin et al., 1990, 2001).

### **Conclusions**

Human and nonhuman animals alike persist in performing tasks despite disruptors every day. Behavioral momentum theory is concerned with the contribution of the Pavlovian stimulus-reinforcer relation to the persistence of behavior in the face of disruption. Like the topography, patterning, or frequency of a response, resistance to change is a fundamental dimension of operant behavior. Persistence also is a fundamental part of life. Returning to the vignettes offered in the introduction of this chapter, for example, a 3<sup>rd</sup> grade student might persist in performing math problems despite noisy classmates, or a cigarette smoker might persist in smoking despite disapproval from friends and loved ones. Regardless of the behavior in question, *that* it persists in the face of disruption is a simple observation. *To what degree* or *under what circumstances* behavior persists are the more precise attributes of behavior that are addressed by

behavioral momentum theory.

In this chapter, we provided a historical and contemporary overview both of the study of resistance to change and of the theoretical underpinnings of behavioral momentum. This overview included a description of the methods that typically are used to study behavioral persistence, some findings that have generated support for behavioral momentum theory, and some challenges to the simple metaphor. Further, we described the various facets of behavioral persistence (i.e., the resistance to change of response rates, remembering, and the relapse of previously extinguished responding), and how momentum theory has been extended to each. Clearly, the basic tenets of behavioral momentum theory are generalizable (e.g., across species, types of reinforcers, settings, behavioral dimensions, etc.), despite the practical limitations to the theory noted above.

The literature concerning the persistence of behavior in the face of disruption and behavioral momentum theory is extensive and oftentimes highly conceptual. Therefore, the overarching purpose of this chapter was to provide a *general* review of behavioral momentum and resistance to change. Because of our general approach, much of the preceding discussion focused on the ability of momentum theory to *describe*, qualitatively, the relation between the Pavlovian stimulus-reinforcer relation and resistance to change in various situations. That is, relatively high reinforcer rates tend to increase the stimulus-reinforcer relation in a given stimulus situation and thereby produce behavior that is more resistant to disruption.

Another important quality of momentum theory worth noting is its power to *predict* the degree to which a behavior will persist in a given circumstance. That is, given

information about the magnitude of the behavioral disruptor and baseline reinforcer rates, one can make precise predictions about resistance to change. This predictive capability of momentum theory is dependent on its quantitative underpinnings (see Nevin & Grace, 2000; Nevin et al., 1983; Podlesnik & Shahan, 2009, 2010; Shahan & Sweeney, 2011). A complete discussion of these models, however, is outside of the scope of this chapter. The general concepts of behavioral momentum theory as well as these more specific quantitative models have implications, though, for work outside of the animal laboratory. For example, they provide insights into how one might promote persistence when it is a desirable attribute of behavior (e.g., completing school work) and deter persistence when it is undesirable (e.g., smoking).

To summarize, behavioral momentum theory is a conceptual framework that can be used to describe *why* and *to what degree* behavior will persist in a given stimulus situation. It also may be considered a practical framework that can be used to extend the fundamental principles of resistance to change to clinical or everyday situations. Thus, there are many theoretical and real-world implications of momentum theory. This chapter outlined a few of these implications, but it will be up to future researchers to continue to determine its conceptual boundaries and clinical relevance.

**CHAPTER 3**  
**RESISTANCE TO CHANGE FOLLOWING CHANGING**  
**REINFORCER RATES<sup>2</sup>**

**Introduction**

Persistence of discriminated operant behavior tends to be positively related to baseline reinforcer rates. For example, Nevin (1974) trained pigeons to peck keys for food in two-component multiple schedules, where two stimulus situations, signaled by different key-light colors, alternated successively within sessions. In the presence of one key-light color, pecking produced food relatively frequently according to a variable-interval (VI) schedule, and in the presence of the other color, VI food was delivered relatively infrequently. When responding subsequently was challenged by presenting free food during inter-component intervals (ICIs) or by extinction, responding in the component associated with high-rate reinforcement was more resistant to change than responding in the component associated with low-rate reinforcement. This finding is general to the study of resistance to change in multiple schedules and has been demonstrated in several species (e.g., humans, rats, and goldfish; Blackman, 1968; Cohen, 1996; Grimes & Shull, 2001; Igaki & Sakagami, 2004; Mace et al., 1990; Shahan & Burke, 2004) using a variety of different disruptors (e.g., pre-session feeding, aversive

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<sup>2</sup> Chapter 3 of this dissertation was adapted from “Behavioral momentum and accumulation of mass in multiple schedules,” by A. R. Craig, P. J. Cunningham, and T. A. Shahan, 2015, *Journal of the Experimental Analysis of Behavior*, Volume 103, Issue 3, pp. 437-449, with permissions from John Wiley & Sons and P. J. Cunningham. A copy of the corresponding license agreement and permission-to-use letter may be found in Appendices C and D, respectively.

consequences, and distraction; see Craig, Nevin, & Odum, 2014; Nevin, 1992a; 2002; Nevin & Grace, 2000, for review). Note, though, that some limited evidence suggests that factors other than frequency of baseline reinforcer delivery can influence resistance to change (see, e.g., Bell, 1999; K. A. Lattal, 1989; Nevin et al., 2001; Podlesnik, Jimenez-Gomez, Ward, & Shahan, 2006).

Behavioral momentum theory (Nevin et al., 1983) offers a conceptual and quantitative framework that may be used to describe the contribution of reinforcer deliveries to resistance to change. According to momentum theory, response persistence in the face of disruption is a function of a mass-like quality of behavior engendered by reinforcer deliveries in a given stimulus situation (e.g., a multiple-schedule component). As reinforcer rates in a stimulus situation increase, the Pavlovian stimulus-reinforcer relation in the situation is strengthened, thereby producing greater behavioral mass and resistance to change (for discussion, see Nevin, 1992a; 2002; Nevin et al., 1990).

Quantitatively, the positive relation between resistance to change and baseline reinforcer rates may be expressed as follows (see Nevin et al., 1983; Nevin & Shahan, 2011):

$$\log\left(\frac{B_t}{B_x}\right) = \frac{-x}{r^b}. \quad (1)$$

The left side of Equation 1 is log-transformed proportion-of-baseline response rates given a disruptor. The right side of the equation represents those factors that contribute to responding during disruption and may be broken into two more general terms. The numerator represents the negative impact of the disruptor on responding, where  $x$  varies

with the magnitude of the disruptor applied (e.g., the amount of food given to a hungry animal during pre-session feeding preparations in the animal laboratory). The denominator of Equation 1 is thought to correspond to a mass-like construct that governs the persistence of behavior and has been shown to be a power function of pre-disruption reinforcer rates (Nevin, 1992a). Thus,  $r$  is baseline reinforcer rates, in reinforcers delivered per hr, and  $b$  is a free parameter that represents sensitivity to baseline reinforcer rates. The  $b$  parameter typically assumes a value near 0.5 when Equation 1 is fit to disruption data from multiple schedules (see Nevin, 2002).

The numerator of Equation 1 may be expanded as follows to account for the specific effects of extinction as a disruptor:

$$\log\left(\frac{B_t}{B_o}\right) = \frac{-t(c + d\Delta r)}{r^b}. \quad (2)$$

Here,  $t$  is time in extinction, measured in sessions, and  $c$  is the impact on responding of suspending the response-reinforcer contingency (a free parameter typically assuming a value near 1; Nevin & Grace, 2000). The parameters  $d$  and  $\Delta r$  collectively represent the impact on responding of transitioning from a period of reinforcement during baseline to a period of non-reinforcement during extinction (i.e., generalization decrement) where  $\Delta r$  is the change in reinforcer rates between baseline and extinction (in reinforcers omitted per hr) and  $d$  is a scaling parameter that is free to vary and typically assumes a value near 0.001.

The quantitative theory of resistance to change offered by Equations 1 and 2 accounts for an array of persistence data obtained from multiple-schedule preparations

(for review, see Nevin, 1992a, 2002, 2012; Nevin & Shahan, 2011). When these models are used to describe resistance to change from these situations, behavioral mass typically is characterized by setting  $r$  in the denominator equal to programmed pre-disruption reinforcer rates. In addition, all investigations of resistance to change have examined response persistence following prolonged exposure to stable baseline reinforcer rates. Under these conditions, the method by which one calculates reinforcer rates (i.e.,  $r$ ) essentially is inconsequential: Under VI schedules, which conventionally are used in resistance-to-change research, mean obtained reinforcer rates in a multiple-schedule component over any number of sessions should approximate programmed reinforcer rates in that component. It is unclear, then, if resistance to change depends on longer-term reinforcer rates (i.e., mean reinforcer rate for a given component over the entirety of baseline) or on reinforcer rates from some smaller subset of recently experienced sessions (e.g., the mean reinforcer rate for a given component from the two most recent sessions preceding disruption). In short, it is unknown how long particular discriminative stimulus-reinforcer situations must be in effect before the reinforcer rates signaled by those stimuli affect the persistence of responding.

Thus, the purpose of the present experiment was to determine if the temporal epoch over which discriminative stimulus-reinforcer relations are in effect prior to disruption impacts relative resistance to that disruption. To this end, pigeons pecked keys in multiple schedules of reinforcement in which the component stimuli signaled different reinforcement rates for a larger or smaller number of sessions prior to disruption. Overall baseline reinforcer rates in the multiple-schedule components were the same when

calculated across conditions but differed between components immediately before extinction testing. The number of sessions during which these differences were held constant prior to extinction was varied between conditions

## **Method**

### **Subjects**

Seven unsexed homing pigeons with previous experience responding under schedules of positive reinforcement served in all conditions of the experiment. An eighth unsexed homing pigeon, also with experience responding under schedules of positive reinforcement, was included in conditions 3-7. Pigeons were housed separately in a temperature-controlled colony room with a 12:12 hr light/dark cycle and were maintained at 80% of their free-feeding weights by the use of supplementary post-session feedings as necessary. Each pigeon had free access to water when not in sessions. Animal care and all procedures detailed below were conducted in accordance with guidelines set forth by Utah State University's Institutional Animal Care and Use Committee.

### **Apparatus**

Four Lehigh Valley Electronics operant chambers for pigeons (dimensions 35-cm long, 35-cm high, and 30-cm wide) were used. Each chamber was constructed of painted aluminum and had a brushed-aluminum work panel on the front wall. Each work panel was equipped with three equally spaced response keys. Only the center key was used in this experiment and was transilluminated various colors to signal the different components of the multiple schedule across pigeons and conditions (see Appendix E for a



list of stimulus assignments). A force of at least 0.1 N was required to operate the key. A rectangular food aperture (5-cm wide by 5.5-cm tall, with its center 10 cm above the floor of the chamber) also was located on the work panel. The food aperture was illuminated by a 28-v DC bulb during reinforcer deliveries, which consisted of 1.5 s of access to Purina Pigeon Checkers collected from a hopper in the illuminated aperture. This reinforcer duration is standard for our laboratory and ensures maintenance of pigeons' criterion weights given that pigeon chow is a denser food source by vol than mixed grain. General illumination was provided at all times by a 28-v DC house light that was centered 4.5 cm above the center response key, except during blackout periods and reinforcer deliveries. A ventilation fan and a white-noise generator masked extraneous sounds at all times. Timing and recording of experimental events was controlled by Med PC software that was run on a PC computer in an adjoining control room.

### **Procedure**

Under all conditions of the experiment, pigeons key pecked for food under a two-component multiple schedule with the following specifications: Each component of the multiple schedule lasted for three min, components were separated by 30-s ICIs, and each session consisted of 10 strictly alternating components (i.e., 30 min of session time, excluding time for ICIs and reinforcer deliveries). The first component that occurred was randomly determined at the start of each session.

One multiple-schedule component stimulus initially signaled a VI 30-s schedule of reinforcement (i.e., the rich schedule) while the other component stimulus initially signaled a VI 120-s schedule of reinforcement (i.e., the lean schedule). Both VI schedules

consisted of 10 intervals derived from Fleshler and Hoffman's (1962) constant-probability algorithm. In each condition, the component stimuli associated with rich and lean reinforcement schedules were constant within sessions but alternated across sessions for the entirety of baseline. The number of sessions between each alternation was 20, 5, 3, 2, or 1 session(s), depending on the condition. For example, in the 5-Day alternation condition, one component stimulus signaled the rich schedule while the other component stimulus signaled the lean schedule for five sessions. Then, schedule-stimulus associations changed such that the component that first signaled the rich schedule signaled the lean schedule, and the component that first signaled the lean schedule signaled the rich schedule, for another five sessions. Alternations of the component stimuli associated with rich and lean schedules continued across blocks of sessions specified by each condition until baseline ended. In each condition, schedule alternations were arranged such that the component that started rich ended lean (hereafter the "Rich-to-Lean" component) and the schedule that started lean ended rich (hereafter the "Lean-to-Rich" component) prior to extinction testing. Consequently, both multiple-schedule component stimuli were associated with the VI 30-s and VI 120-s schedules for an equal number of sessions, and overall rates of reinforcement were the same for each component when averaged over the entirety of baseline. Further, the VI 120-s schedule was in effect in the Rich-to-Lean component, and the VI 30-s schedule was in effect in the Lean-to-Rich component, just prior to extinction testing. The chronological list of conditions (including the number of sessions per schedule alternation and the number of sessions per condition) can be found in Table 3.1.

Table 3.1

*Condition Order, Number of Sessions per Baseline Condition, and Component-Wide Food Rates*

Condition	Sessions	Component-wide foods/min			
		Lean-rich		Rich-lean	
		Mean	<i>SEM</i>	Mean	<i>SEM</i>
20-Day	40	1.14	0.04	1.15	0.04
1-Day	30	1.15	0.05	1.14	0.05
5-Day	30	1.15	0.05	1.14	0.05
3-Day	30	1.15	0.05	1.15	0.05
2-Day	32	1.15	0.05	1.15	0.05
5-Day (Rep.)	30	1.14	0.05	1.14	0.05
20-Day (Rep.)	40	1.14	0.04	1.16	0.05

Following each baseline schedule, extinction was assessed for five sessions. In extinction, the stimulus situation was the same as during the preceding baseline condition. Responding, however, had no consequences.

### Results

Mean obtained reinforcer rates for both components across sessions of baseline in each condition are shown in Figure 3.1. Obtained reinforcer rates within a component approximated programmed reinforcer rates. Importantly, there were no noticeable decreases in overall obtained reinforcer rates following a change in schedule value. That is, obtained reinforcer rates between components were maintained across the course of a condition. Mean (plus standard error of the mean; *SEM*) overall, component-wide

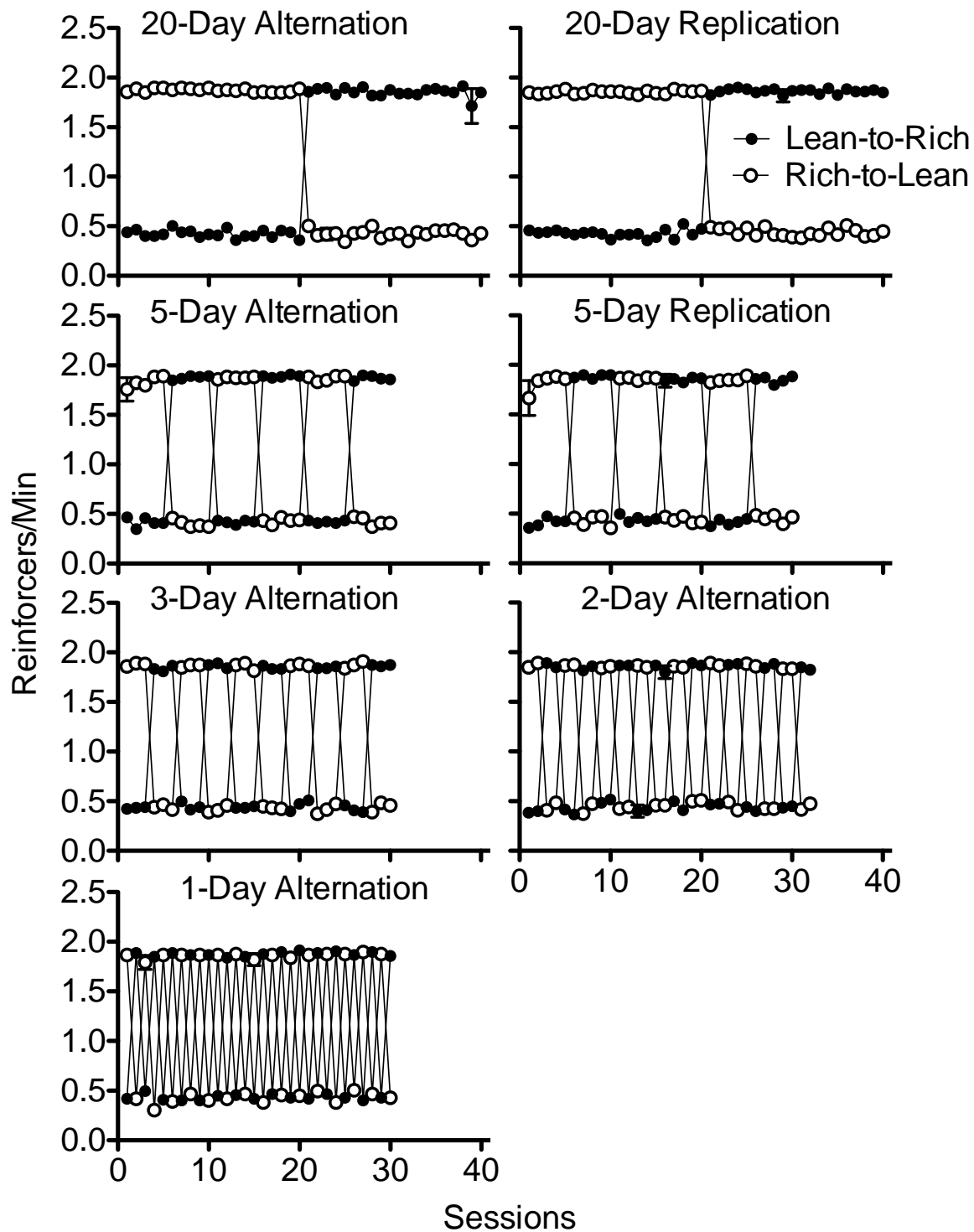


Figure 3.1. Mean reinforcers per min (plus SEM) from both multiple-schedule components across sessions of each baseline condition.

reinforcer rates for each condition are included in Table 3.1. These rates were virtually the same across components and conditions.

Mean response rates across sessions of baseline in both components for each condition are shown in Figure 3.2. Response rates tended to track reinforcer rates across baseline sessions. That is, response rates tended to be higher in the component that was associated with the VI 30-s schedule of reinforcement during a session, and lower in the component that was associated with the VI 120-s schedule. A change in reinforcer rate for a given component was accompanied by a change in response rate for that component, usually within the first session following the change in reinforcer rate. For example, the Rich-to-Lean component in the 20-Day alternation conditions arranged VI 30-s food for the first 20 sessions of baseline, after which this component arranged VI 120-s food for the remaining 20 sessions (see top panels of Figure 3.1). Response rates in this component were higher than in the Lean-to-Rich component for the first 20 sessions of baseline (when that component signaled the VI 30-s schedule) but were lower than in the Lean-to-Rich component for the last 20 sessions of baseline (when that component signaled the VI 120-s schedule). A similar patterning of changes in response rate following changes in reinforcer rate was present in each of the other conditions.

The extent to which differences in resistance to extinction between components were associated with frequency of baseline-schedule alternation was examined using relative resistance-to-extinction measures (see Grace & Nevin, 1997). First, proportion-of-baseline response rates were calculated for each subject in each condition by dividing response rates during each session of extinction by response rates during the last session

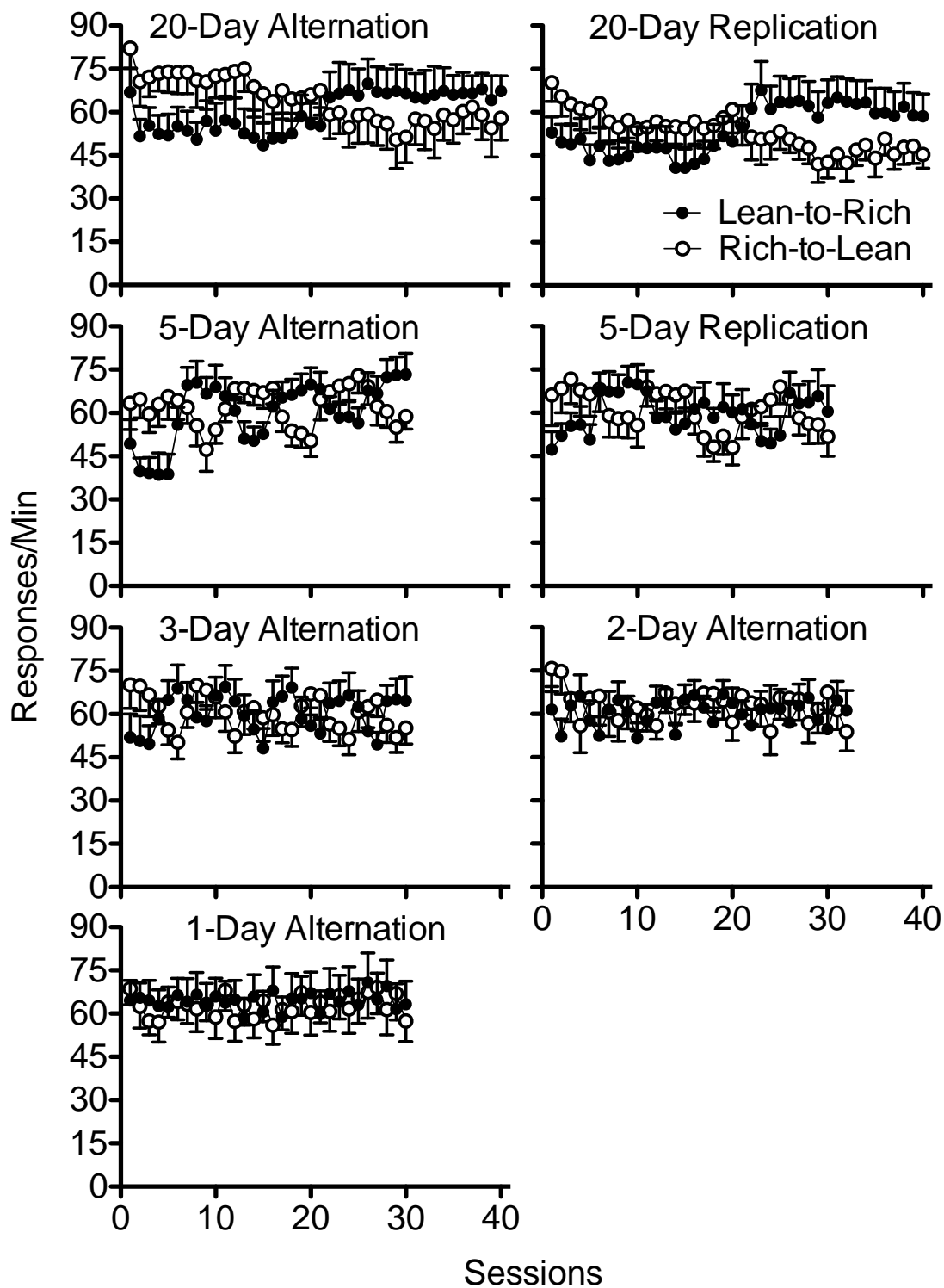


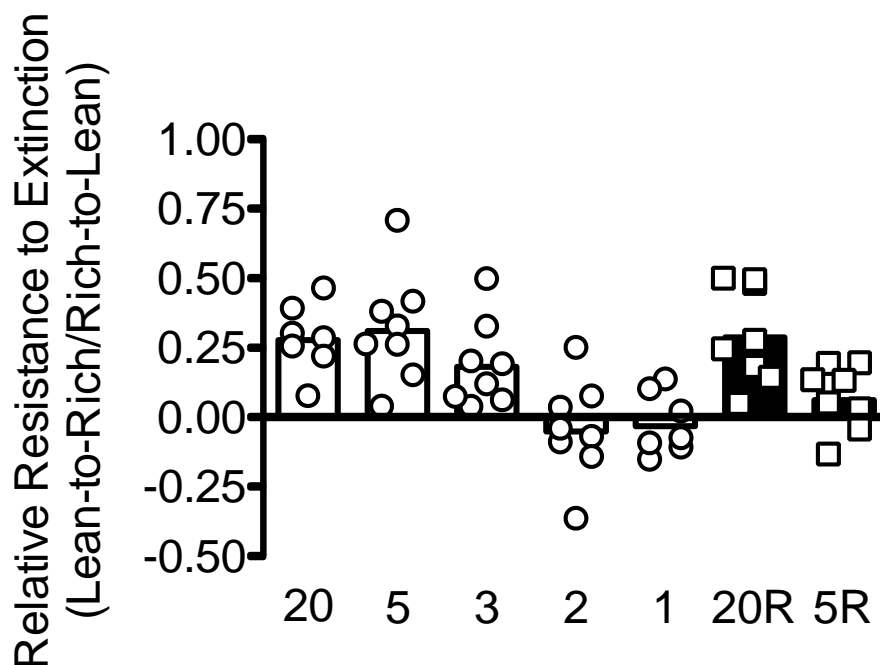
Figure 3.2. Mean responses per min (plus SEM) from both multiple-schedule components across sessions of each baseline condition.

of the corresponding baseline condition.<sup>3</sup> Then, relative resistance to extinction was calculated by averaging proportion-of-baseline response rates across all five sessions of extinction separately for each component and in each condition. This value for the Lean-to-Rich component in a condition then was divided by the equivalent measure for the Rich-to-Lean component, after which this ratio was log transformed. Values of 0 indicate no difference in resistance to extinction between Lean-to-Rich and Rich-to-Lean components, values greater than 0 indicate greater resistance to extinction in the Lean-to-Rich component, and values less than 0 indicate greater resistance to extinction in the Rich-to-Lean component. Results of this analysis for each condition of the experiment are shown in Figure 3.3. Bars represent mean relative-resistance measures, and individual data points represent these measures for individual subjects. Data are plotted with respect to frequency of schedule alternation within a condition and not order of condition presentation.

Without exception, resistance to extinction was greater in the Lean-to-Rich component (i.e., the component that arranged VI 30-s food in the sessions just before extinction testing) than in the Rich-to-Lean component (i.e., the component that arranged VI 120-s food in the sessions just before extinction testing) in the 20-Day, 5-Day, and 3-

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<sup>3</sup> Though response rates changed across sessions of baseline with respect to obtained reinforcer rates, the method by which proportion-of-baseline response rates were calculated did not affect measurement of relative resistance to extinction. Proportion-of-baseline response rates were calculated for each condition using mean response rates from the last 1, 2, 3, 5, and 10 sessions, then converted into relative resistance-to-extinction-measures. A 7 X 5 (Condition X Method) repeated-measures analysis of variance (ANOVA) was used to determine if the manner by which proportion-of-baseline response rates were calculated (Method) affected relative resistance-to-extinction measures. Neither the main effect of Method nor the Condition X Method interaction was statistically significant (respectively,  $F[1.23, 24] = 7.35$ , NS; and  $F[24, 144] = 1.40$ , NS; note the Greenhouse-Geisser correction for degrees of freedom were applied to the main effect of Method because assumptions of sphericity, tested using Mauchly's method, were violated).



*Figure 3.3.* Relative-resistance-to-extinction (Lean-to-Rich/Rich-to-Lean; see text for details) measures aggregated across subjects for each condition. Bars represent group means and data points represent measures for individual subjects. From left to right, data are shown from the 20-Day, 5-Day, 3-Day, 2-Day, 1-Day, 20-Day-Replication, and 5-Day replication conditions.

Day alternation conditions. There were not, however, systematic differences in relative resistance to extinction between these conditions. In the 2-Day and 1-Day alternation conditions, resistance to extinction was not systematically higher in one component than in the other component. Relative resistance to extinction from replication of the 20-Day alternation condition was essentially the same as the first 20-Day alternation condition. Though resistance to extinction tended to be higher in the Lean-to-Rich component than in the Rich-to-Lean component during replication of the 5-Day alternation condition, the effect was not as pronounced as it was during the initial 5-Day alternation condition. A one-way repeated-measures ANOVA was conducted on relative resistance-to-extinction



measures to further examine mean differences in these measures between conditions. The main effect was significant,  $F(6, 36) = 10.67, p < .001$ . Least-significant difference post-hoc comparisons were conducted to examine this main effect more closely. These comparisons used estimated marginal mean scores for relative resistance to extinction from each condition to determine for which conditions relative resistance to extinction differed. Results from this analysis are summarized in Table 3.2. Most importantly, these post hoc analyses revealed that relative resistance to extinction differed significantly between those conditions where responding was more persistent in the Lean-to-Rich component than in the Rich-to-Lean component (i.e., the 20-Day, 5-Day, and 3-Day

Table 3.2

*Absolute Mean Differences Between Grouped Relative-Resistance-to-Extinction Measures from Each Condition*

Condition/ Condition	20-Day	20-Day (Rep.)	5-Day	5-Day (Rep.)	3-Day	2-Day	1-Day
20-Day	-	-	-	-	-	-	-
20-Day (Rep.)	-0.033 (0.058)	-	-	-	-	-	-
5-Day	-0.057 (0.078)	-0.024 (0.084)	-	-	-	-	-
5-Day (Rep.)	0.212* (0.079)	0.245* (0.088)	0.207* (0.082)	-	-	-	-
3-Day	0.116 (0.077)	0.149 (0.069)	0.173 (0.101)	-0.097 (0.052)	-	-	-
2-Day	0.370* (0.080)	0.403* (0.067)	0.427* (0.082)	0.158 (0.068)	0.254 (0.072)	-	-
1-Day	0.309* (0.050)	0.342* (0.059)	0.366* (0.094)	0.097 (0.075)	0.193* (0.057)	-0.061 (0.054)	-

*Note.* alues in parentheses represent *SEM*.

\*Mean difference is statistically significant ( $p < .05$ ).

alternation conditions) and those conditions where no differential resistance to extinction was observed (i.e., the 2-Day and 1-Day alternation conditions).

Relative resistance to extinction provides a measure of differences in resistance to extinction between components, but this measure is limited in that it does not necessarily show the origins of these differences. For example, a relative resistance-to-extinction value of 0 could indicate that proportion-of-baseline response rates in both multiple-schedule components were virtually unaffected by extinction or that responding occurred at zero rates in both multiple-schedule components across sessions of extinction. Accordingly, comparisons of proportion-of-baseline response rates between conditions were conducted to determine if the frequency of schedule alternation during baseline affected rate of extinction. Proportion-of-baseline response rates (calculated here as above) across extinction sessions for each condition (excluding 5-Day and 20-Day replications for clarity), separated for each component, are shown in Figure 3.4. Data from the Rich-to-Lean component are shown in the top panel of this figure, and data from the Lean-to-Rich component are shown in the bottom panel.

Proportion-of-baseline response rates in the 2-Day and 1-Day alternation conditions in the Rich-to-Lean component were elevated above those rates from the remaining components during the second and third sessions of extinction testing. A 7 X 6 (Condition X Session) repeated-measure ANOVA conducted on these data revealed significant main effects of Condition,  $F(6, 36) = 2.48, p < .05$ , and Session,  $F(5, 30) = 139.94, p < .001$ , but a non-significant interaction between these terms,  $F(30, 180) = 1.30, NS$ . Least-significant-difference post-hoc tests based on estimated marginal means

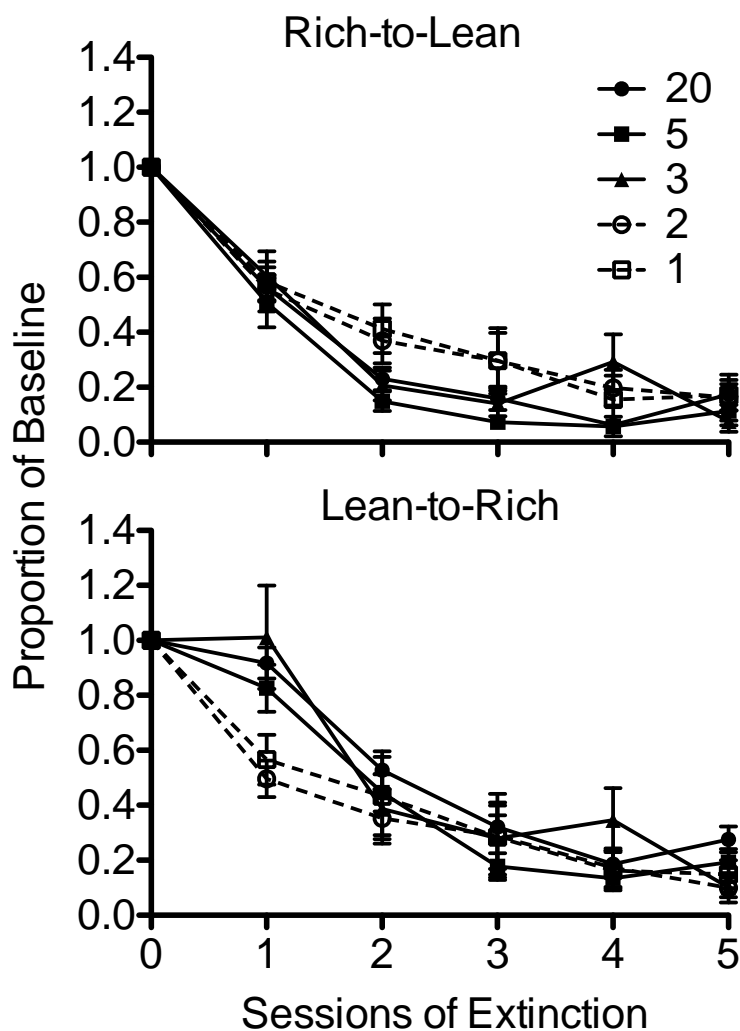


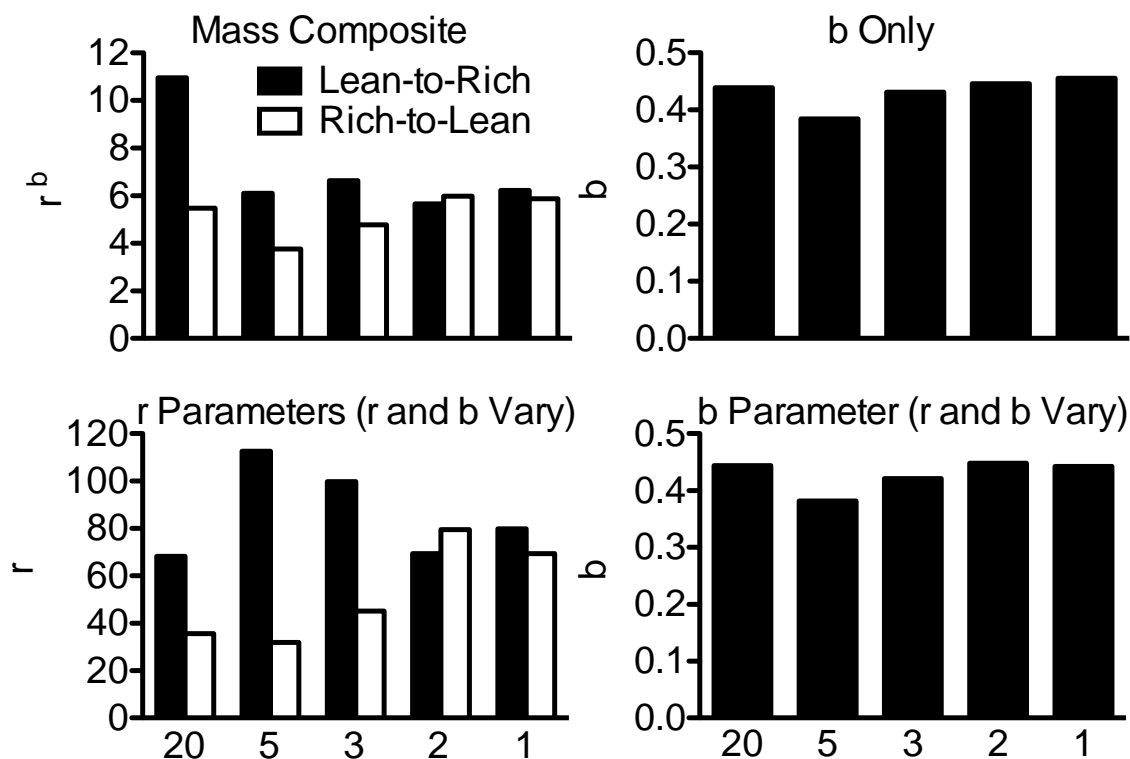
Figure 3.4. Mean (plus SEM) proportion-of-baseline response rates across sessions of extinction for the Rich-to-Lean (top panel) and Lean-to-Rich (bottom panel) components.

for Condition revealed that extinction progressed significantly faster in the 5-Day and replication of the 20-Day alternation conditions than in the 2-Day alternation condition. In the Lean-to-Rich component, responding was less resistant to extinction in the 2-Day and 1-Day alternation conditions during the first session of extinction, but the extinction functions did not differ systematically thereafter. A 7 X 6 (Condition X Session) repeated-measures ANOVA conducted on these data revealed a significant main effect of

Session and a significant Condition X Session interaction (respectively,  $F[5, 30] = 78.61$ ,  $p < .001$ ; and  $F[30, 180] = 1.70$ ,  $p < .05$ ). The main effect of Condition was non-significant,  $F(2.69, 16.14) = 2.14$ , NS (note that Greenhouse-Geisser corrections for degrees of freedom were used because, according to Mauchly's method, the assumption of sphericity for Condition was violated). Thus, differences in resistance to extinction between conditions depended on session, as suggested above. In summary, resistance to extinction was lower in the 2-Day and 1-Day alternation conditions than in the other conditions during the first day of extinction in the Lean-to-Rich component. Further, in the Rich-to-Learn component, responding tended to persist to a greater degree in the 2-Day and 1-Day alternation conditions than in the other conditions. This difference was only statistically significant, however, between the 2-Day alternation condition and the 5-Day and replication of the 20-Day alternation conditions.

To examine how frequency of baseline-schedule alternation affected estimates of behavioral mass, Equation 2 was fit to mean log proportion-of-baseline response rates several different ways via least-squares regression using Microsoft Excel Solver. Data from replication of the 20-Day and 5-Day conditions were excluded from these analyses. There is no principled reason to believe that alternation of stimulus-reinforcer relations during baseline should change the disruptive impacts of suspending the response-reinforcer contingency or of generalization decrement during extinction. Accordingly, for all fits, the free parameters  $c$  and  $d$  were fixed at 1 and 0.001, respectively, and the  $\Delta r$  term in the numerator was fixed to 30 and 120 reinforcers omitted per hr for the Rich-to-Learn and Lean-to-Rich components, respectively.

First, to determine how behavioral mass, *per se*, was impacted by frequency of schedule alternation, the denominator of the equation was collapsed into a composite mass term that was free to vary between components. This mass composite was substantially larger in the Lean-to-Rich component than in the Rich-to-Lean component in the 20-Day, 5-Day, and 3-Day alternation conditions but similar between components in the 2-Day and 1-Day alternation conditions (see the top-left panel of Figure 3.5). Next, to determine if these changes in mass could be attributed to changes in sensitivity to baseline reinforcer rates, the  $r$  parameter in the denominator of the model was fixed at 30 and 120 reinforcers per hr for the Rich-to-Lean and Lean-to-Rich components, respectively, while  $b$  was free to vary. Sensitivity to baseline reinforcer rates did not change systematically between conditions (see the top-right panel of Figure 3.5). Thus, changes in  $b$  likely did not produce the observed changes in relative resistance to extinction across conditions. Finally,  $b$  was allowed to vary as in the previous fit, and the reinforcer-rate terms in the denominator (i.e.,  $r$ ) were allowed to vary between components as a parameter. In this fit,  $b$  assumed similar values as in the previous fit (see the bottom-right panel of Figure 3.5), but the reinforcer-rate terms ( $r$  in the bottom-left panel of Figure 3.5) were substantially larger in the Lean-to-Rich component than in the Rich-to-Lean component in the 20-Day, 5-Day, and 3-Day alternation conditions. These parameter values were similar between components in the 2-Day and 1-Day alternation conditions.



*Figure 3.5.* Parameter values from fits of the augmented model of resistance to extinction data obtained from each condition. Top left: composite-mass values ( $r^b$ ). Top right: sensitivity values ( $b$ ) when only this parameter was allowed to vary. Bottom left: baseline-reinforcer-rate values ( $r$  in the denominator of Equation 2) from both components when  $b$  was allowed to vary and shared by both components and  $r$  was allowed to vary between components. Bottom right: sensitivity values when  $b$  was allowed to vary and shared by both components and  $r$  was allowed to vary between components. From left to right, data are shown from the 20-Day, 5-Day, 3-Day, 2-Day, and 1-Day alternation conditions.

## Discussion

Behavioral momentum theory is centrally concerned with the relation between Pavlovian stimulus-reinforcer contingencies and persistence of discriminated, free-operant responding (see Craig, Nevin, & Odum, 2014; Nevin, 2012; Nevin & Grace, 2000). Despite the well-established Pavlovian determination of resistance to change (e.g.,

Nevin, 1984a; Nevin et al., 1990), no research previously has examined the timeframe over which stimulus-reinforcer relations have functional effects on resistance to change in multiple schedules. Investigations of resistance to change historically have focused on response persistence following periods of prolonged exposure to stable baseline reinforcer rates, precluding identification of how behavioral mass (i.e., the term in the denominators of Equations 1 and 2) accumulates in these conditioning situations.

The present experiment aimed to address this gap in the literature by arranging situations in which stimulus-reinforcer relations varied over the course of baseline. If, for example, resistance to change depended on the association between condition-wide reinforcer rates (i.e., the average reinforcer rate in a given stimulus situation across baseline) and multiple-schedule component stimuli, proportion-of-baseline response rates across sessions of extinction should have been the same in both multiple-schedule components in all conditions because both stimulus situations were correlated with VI 30-s and VI 120-s food for an equal number of sessions. If resistance to change depended only on the association between stimuli and those reinforcer rates experienced most recently (i.e., during the last session of baseline), proportion-of-baseline response rates should have been higher in the Lean-to-Rich component (the component that arranged VI 30-s food during the last session of baseline training), regardless of frequency of schedule alternation.

The results from the present experiment agree with neither of these possibilities: Proportion-of-baseline response rates tended to be higher in the multiple-schedule component most recently associated with VI 30-s food (i.e., the Lean-to-Rich component)

than in the component most recently associated with VI 120-s food (i.e., the Rich-to-Lean component) only when schedules alternated as frequently as every three sessions. When schedules alternated more frequently (i.e., every session or every other session) resistance to extinction was similar between components. Differences in relative resistance to extinction between conditions resulted from systematic differences in proportion-of-baseline response rates between those conditions where resistance to extinction differed between components (i.e., the 20-Day, 5-Day, and 3-Day alternation conditions) and those conditions where no differences were present (i.e., the 2-Day and 1-Day alternation conditions). That is, in both multiple-schedule components, proportion-of-baseline rates from the 20-Day, 5-Day, and 3-Day conditions tended to cluster together across sessions of extinction, and the same was true for the 2-Day and 1-Day conditions. These clusters of rates, however, behaved differently during extinction. Specifically, in the Rich-to-Lean component, responding tended to persist to a greater degree in the 2-Day and 1-Day alternation conditions than in the other conditions. In the Lean-to-Rich component, the opposite was true—responding, at least initially, tended to be less persistent in the 2-Day and 1-Day alternation conditions than in the other conditions.

Fits of Equation 2 to the present data clarified the behavioral mass produced by these conditioning situations. When stimulus-reinforcer relations alternated as frequently as every three sessions, behavioral mass was substantially higher in the Lean-to-Rich component than in the Rich-to-Lean component. This difference was absent, however, when schedules alternated more frequently. Further, differences in mass were not the result of differences in sensitivity to baseline reinforcer rate. Instead, they apparently



were related to the reinforcer-rate parameters of the mass term in Equation 2, suggesting that behavioral mass in multiple schedules reflects a combination of recently experienced reinforcer rates within a discriminative-stimulus situation.

Experiments investigating choice dynamics in stochastic environments might provide insights into the manner by which recently experienced stimulus-reinforcer relations combine to govern response persistence in multiple schedules. For example, in foraging situations, non-human animals such as rats, squirrels, chipmunks, horses, and canines allocate foraging behavior in temporally dynamic ways (see J. A. Devenport & Devenport, 1993; J. A. Devenport, Patterson, & Devenport, 2005; L. D. Devenport & Devenport, 1994; L. D. Devenport, Hill, Wilson, & Ogden, 1997). Specifically, if these organisms are exposed to several foraging options directly prior to being given a choice between those options, they tend to prefer the option that most recently produced food regardless of patch yield (i.e., the amount of food earned per patch visit). If, however, choice between options is assessed following an extended delay, these organisms tend to allocate foraging behavior with respect to overall patch yield (i.e., they prefer options that provided more food over options that provided less food). Similar findings have been demonstrated in the Pavlovian reversal-learning literature (e.g., Rescorla, 2007), thus demonstrating the dependency of behavior on temporally recent information is relatively robust and not necessarily restricted to choice situations.

To explain these findings, L. D. Devenport et al. (1997) argued that, when foraging options are experienced relatively recently with respect to a choice opportunity, it is likely that the option that most recently produced food still contains food. That is,

under these circumstances information about food availability is reliable, so recent experience might govern choice. As information about patch payoff grows older, recently gathered information concerning patch quality might become unreliable, producing a default foraging strategy governed by average incomes. It is reasonable to believe that changing the reinforcer rates associated with the discriminative-stimulus situations in the present experiment might have impacted the reliability of stimulus-reinforcer relations associated with those situations in a similar manner. When stimulus-reinforcer relations were relatively stable with respect to recent experience, it is possible that the discriminative stimuli were associated most strongly with recently experienced reinforcer rates at the onset of extinction. When these pairings were unstable (i.e., unreliable) with respect to recent experience, the discriminative stimuli might have been associated with the mean rate of reinforcement historically delivered in its presence at the onset of extinction. From this perspective, this experiment suggests three sessions of stable stimulus-reinforcer pairings are sufficient for these relations to be considered reliable, at least with pigeons responding within multiple schedules of reinforcement.

Choice behavior in stochastic environments also is a function of the frequency with which reinforcer rates change. For example, Gallistel, Mark, King, and Latham (2001) examined adaptation of rats' response allocation in two-lever choice situations when relative reinforcer rates delivered for left- and right-lever responding changed. In one phase of the experiment, relative reinforcer rates were held constant for 32 sessions, after which relative rates changed midsession and were held constant for another 20 sessions. In another phase, relative reinforcer rates changed both between and within

sessions for the entirety of the condition. Under conditions of infrequent change, behavioral allocation adapted slowly (i.e., across several session) to prevailing contingencies following a change in relative reinforcer rates (see also Mazur, 1995, 1996). Under conditions of frequent change, however, behavioral allocation adapted to prevailing contingencies quickly, usually within a few cycles of visits to both levers (see also Baum, 2010; Baum & Davison, 2014).

Choice data like those above suggest that, under conditions of frequently changing reinforcer rates, subjects may discriminate changes in rate (and estimate newly introduced rates) very quickly. Further, once previously collected information about reinforcer rates becomes unreliable based on frequency of changes in rate, this information no longer influences behavior. Based on these findings, it is reasonable to believe that pigeons in the present experiment learned the relation between a component stimulus and the reinforcer rate it signaled over the course of a single session when reinforcer rates alternated frequently. That is, within sessions of the 2-Day and 1-Day alternation conditions, transient stimulus-reinforcer relations may have been established. Indeed, in these conditions, response rates tended to track reinforcer rates, even when reinforcement schedules alternated frequently, suggesting that the pigeons discriminated the reinforcer rates associated with component stimuli. Because of frequent changes in reinforcer rates, however, it is possible that stimulus-reinforcer relations established within sessions did not exert control over behavior in subsequent sessions (cf., Gallistel et al., 2001). If this were the case, one might anticipate the observed undifferentiated resistance to extinction between Rich-to-Lean and Lean-to-Rich components.

If Pavlovian stimulus-reinforcer relations indeed were established within sessions in the 2-Day and 1-Day alternation conditions of the present experiment, dependency of resistance to extinction on recently experienced reinforcer rates might be observed in these conditions if extinction were introduced at the end of a baseline session (i.e., after the relation between component stimuli and reinforcer rate was established but before it was “lost” in the interim between sessions). Thus, results from the present experiment do not necessarily preclude the possibility that stimulus-reinforcer relations in multiple schedules are determined over very small, within-session timeframes. Instead, the lack of differential resistance to extinction observed in these conditions might have resulted from stochasticity-induced deterioration of stimulus control once subjects were removed from the conditioning situation.

Doughty et al. (2005) conducted a series of experiments investigating behavioral history effects on resistance to change that were conceptually similar to the current experiment. In their Experiment 2, Doughty et al. examined resistance to change of pigeons' key pecking in a multiple schedule where one component arranged a VI 90-s schedule while the other arranged extinction for the first 90 sessions of baseline. Following the 90<sup>th</sup> session, the extinction component was switched to a VI 90-s schedule, thus arranging equal reinforcer rates in both multiple-schedule components. Resistance to change was examined using probe extinction sessions in the 5<sup>th</sup>, 10<sup>th</sup>, and 15<sup>th</sup> session following the transition to the multiple VI 90-s VI 90-s schedule. Responding was less resistant to change in the component previously associated with extinction during the first extinction probe session, while there were no differences in resistance to change in

subsequent extinction probes.

As in the present experiment, the Doughty et al. (2005) findings demonstrated that effects of previously experienced conditions of reinforcement exert less control over resistance to change as they become increasingly temporally distant from resistance testing. Interestingly, 5 days of equal reinforcement rates in both components was not sufficient to eliminate the effects of previously experienced extinction contingencies in the Doughty et al. experiment (though the effect was relatively small), which is at odds with results from the present experiment (i.e., alternations of rich and lean schedules between multiple-schedule stimulus situations every five sessions were sufficient to produce dependency of resistance to extinction on recently experienced reinforcer rates). Perhaps these differences can be attributed to differences in frequency with which reinforcement schedule-stimulus alternations occurred in the present experiment. In Doughty et al., the 5<sup>th</sup> session following the transition was preceded by 90 sessions of stable baseline conditions, while the 5-Day alternation condition here arranged changes in reinforcement schedules associated with multiple-schedule component stimuli every five sessions. Thus, extended exposure to changing stimulus-reinforcer contingencies (as in the current experiment) might produce greater sensitivity to current reinforcer rates (or decreased sensitivity to previously arranged reinforcer rates) than extended exposure to stable stimulus-reinforcer contingencies (as in the Doughty et al. experiment). Such an interpretation would be consistent with the Gallistel et al. (2001) findings with choice preparations discussed above.

To summarize, the present findings suggest the construct relating baseline

reinforcer rates to response persistence from the perspective of behavioral momentum theory, behavioral mass, is temporally dynamic. That is, it represents some subset of experienced stimulus-reinforcer rate relations that might be influenced both by the recency with which those relations were experienced and the frequency with which those relations change in an organism's environment. Identifying the precise function relating previously experienced stimulus-reinforcer relations to mass (e.g., a moving average or some other such rule), however, is beyond the scope of these data.

That only one disruptor (extinction) was used in the present experiment limits determination of the generality of the present findings. For example, it remains unclear whether accumulation of behavioral mass in multiple schedules would be similar if other disruptors were applied. Studies examining resistance to change generally include multiple disruptors such as pre-feeding and presentation of free food during ICIs, both of which tend to produce more consistent response suppression than extinction (see, e.g., Nevin 1992a, 2002). Because the patterning of relative resistance to extinction in the present experiment was relatively consistent between subjects in most conditions (see, e.g., Figure 3.3) and because applications of extinction, pre-feeding, and presentation of ICI food as disruptors produce similar results in multiple schedules (i.e., a positive relation between baseline reinforcer rates and resistance to change), however, it is reasonable to believe that results from the present experiment would be general across disruptor types. Nevertheless, this empirical question is a direction for future research.

The present data extend previous investigations of response persistence in several ways that could have practical, as well as theoretical, implications. As previously noted,

all investigations of resistance to change in multiple schedules have assessed persistence following many sessions of static stimulus-reinforcer rate pairings (see Nevin, 1992a; 2002; Nevin & Grace, 2000, for summary). The present data suggest that these protracted periods of exposure might not be necessary to build behavioral mass, or discriminative stimulus-reinforcer relations, sufficient to produce dependency of response persistence on previously experienced reinforcer rates. Indeed, three sessions were sufficient to produce this dependency in the present experiment.

Further, the present experiment demonstrates that, when reinforcer rates change relatively rapidly in an organism's environment (here, as often as every three sessions), experience from the distant past might become irrelevant in terms of governance of resistance to change. This second extension of previous work in resistance-to-change research could have implications for application of the principles of behavioral momentum theory to clinical settings (see Nevin & Shahan, 2011, for discussion). In every-day situations, the sources and rates of reinforcement for human behavior may be (and in all likelihood, are) much more difficult to control than rates of reinforcement programmed for pigeons pecking keys in an operant chamber. Despite probable variability in stimulus-reinforcer relations across time in naturalistic settings, persistence of human behavior might depend only on some subset of recent experiences, like those arranged during treatment of problem behavior. Defining precisely which experiences matter in terms of resistance to change might depend on the individual's history of reinforcement (e.g., how many and when reinforcers were experienced, how often rates of reinforcement for responding changed), among other variables.

## **CHAPTER 4**

### **BEHAVIORAL MASS DURING EXTINCTION**

#### **Introduction**

Suspension of reinforcement that previously maintained an operant behavior is termed “extinction” (for reviews, see K. A. Lattal, St. Peter, & Escobar, 2013; K. M. Lattal & Lattal, 2012), and behavior usually decreases in frequency across time in the absence of reinforcement. Extinction is a common component of clinical interventions aimed at decreasing problematic operant behavior in humans (e.g., Lerman & Iwata, 1996; Lerman et al., 1998; Petscher & Bailey, 2008; Petscher et al., 2009). Further, behavior during extinction is thought to reveal important characteristics of pre-extinction reinforcement processes (Nevin, 2012) and adaptive behavioral strategies in the face of changing environments (Craig & Shahan, 2016b; Gallistel, 2012). Accordingly, determining the processes that are responsible for persistence of behavior during extinction (conventionally “resistance to extinction”) is important for both practical and theoretical reasons.

One thoroughly documented finding from the resistance-to-extinction literature is that persistence of discriminated operant behavior during extinction tends to be positively related to pre-extinction reinforcer rates (see, for review, Craig, Nevin, & Odum, 2014; Nevin, 2012). That is, after reinforcement has been suspended, behavior maintained in a multiple-schedule component associated with a relatively high rate of reinforcement tends to persist to a greater degree than behavior maintained in a component associated



with relatively low-rate reinforcement. The positive relation between reinforcer rates and resistance to extinction within multiple-schedule components is robust and has been demonstrated in several species including pigeons (e.g., Nevin, 1974; Nevin et al., 1990), rats (e.g., Cohen, 1998; Cohen et al., 1993), humans (e.g., Cohen, 1996; Mace et al., 2010), and goldfish (Igaki & Sakagami, 2004). Further, this finding served as part of the empirical basis for a conceptual approach to understanding persistence of operant behavior termed “behavioral momentum theory” (Nevin et al., 1983; see also Nevin, 1992a; 2002).

Momentum theory states that resistance to extinction of discriminated operant behavior is determined by the interaction between two opposing forces. On the one hand, disruptive factors produce decreases in response rate. Response strength, on the other hand, promotes persistence of operant behavior and is determined by the Pavlovian discriminative stimulus-reinforcer relation established during baseline conditioning (see, however, Aló et al., 2015; K. A. Lattal, 1989; Nevin et al., 2001, for data that challenge Pavlovian determination of resistance to change). The momentum-based augmented model of extinction (see Nevin & Grace, 2000) expresses these relations as follows:

$$\log\left(\frac{B_t}{B_o}\right) = \frac{-t(c + d\Delta r)}{r^b} . \quad (1)$$

The left side of the equation is log-transformed proportion-of-baseline response rates at time  $t$  during extinction, and the right side of the equation represents the disruptive and response-strengthening factors that affect behavior during extinction. In the numerator,  $c$  is the disruptive impact of suspending the response-reinforcer contingency and  $d$  and  $\Delta r$  collectively represent generalization decrement produced by removing reinforcers from

the conditioning context ( $\Delta r$  is the change in reinforcer rates between baseline and extinction in reinforcers omitted per hr and  $d$  is a scaling parameter). Disruption from these two sources grows with time in extinction,  $t$  (measured in sessions). The denominator represents response strength (metaphorically, “behavioral mass”) engendered by stimulus-reinforcer pairings experienced prior to extinction. Here,  $r$  is the baseline rate of reinforcement in the presence of a multiple-schedule component stimulus (in reinforcers per hr), and  $b$  is a sensitivity parameter. Equation 1 suggests that a Pavlovian stimulus-reinforcer relation that is formed during baseline remains intact during extinction (see Nevin & Grace, 2000; Nevin & Shahan, 2011, for review). Put another way, behavioral mass ( $r^b$  in the denominator of the equation) does not change with extinction experiences. Instead, decreases in responding during extinction are attributed to the growing impact of disruptive factors across time.

Though Equation 1 provides a satisfactory description of extinction data from multiple schedules after steady-state conditions (see, e.g., Nevin, 2012), an experiment by Craig, Cunningham, and Shahan (2015) calls into question momentum theory’s characterization of response strength during extinction. In this experiment, pigeons pecked keys in a multiple schedule where the reinforcer rates associated with the component stimuli changed during baseline before assessing resistance to extinction of key pecking. In one condition, for example, one component initially was associated with 120 food deliveries per hr (a relatively high rate) and the other component was associated with 30 foods per hr (a relatively low rate). After 20 sessions, the reinforcement schedules associated with the multiple-schedule component stimuli were switched, such

that the component previously associated with high-rate food was then associated with low-rate food and vice versa for an additional 20 sessions. In this condition, then, the stimulus-reinforcer rate pairings alternated every 20 sessions. Several other conditions were conducted in which stimulus-reinforcer rate pairings alternated between components more frequently (including every five, three, two, and one session[s]). During extinction testing, key pecking was more persistent in the component most recently associated with high-rate food than the component most recently associated with low-rate food when discriminative stimulus-reinforcer rate pairings alternated during baseline as frequently as every three sessions. When these pairings alternated more frequently (every two or one session[s]), resistance to extinction was the same between components.

Craig et al. (2015) asserted that behavioral momentum theory could be extended to account for their findings by allowing behavioral mass to vary between components and across conditions. A series of fits of Equation 1 to data from each of these conditions revealed that mass was larger in the component most recently associated with high-rate food than in the component associated with low-rate food when stimulus-reinforcer rate pairings alternated every 20, 5, or 3 sessions. Mass was similar between components when alternations occurred every two or one session(s). The authors thus concluded that behavioral mass is a dynamic construct that changes when stimulus-reinforcer rate relations change. Given that extinction is functionally a change to zero-rate reinforcement, it is reasonable to believe that behavioral mass could change during extinction in a manner similar to that reported by Craig et al. In the absence of a formal

function that incorporates reinforcer rates that change across time into behavioral mass, however, momentum-based quantitative analyses of conventional multiple-schedule extinction data cannot be used to determine whether mass changes during extinction—As Equation 1 currently is understood, any changes in mass would be subsumed into variations in the disruptive terms in the numerator to describe decreases in response rate across sessions of extinction.

Other findings from the resistance-to-change literature could offer a potential method for addressing this empirical question. For example, resistance to extinction in one multiple-schedule component has been shown to depend both on the reinforcer rate experienced in that component *and on the reinforcer rates in other components*. In a seminal study on this topic, Nevin (1992b) trained pigeons to peck keys in a series of multiple schedules where one, target, component was always associated with 60 reinforcers per hr. Reinforcement in the other, alternative, component was delivered at a rate of 300, 60, or 10 reinforcers per hr. The critical comparison in this experiment was resistance to extinction of target-component key pecking across conditions. Resistance to extinction in this component was highest when it was paired with the 10 reinforcers per hr in the alternative component and lowest when it was paired with the 300 reinforcers per hr (see also Grace, Arantes, & Berg, 2012; Grace, McLean, & Nevin, 2003; Nevin & Grace, 1999). Nevin suggested these “behavioral contrast” effects on resistance to change represent changes in behavioral mass ( $r^b$  in Equation 1), where mass in the target multiple-schedule component is expressed in terms of Gibbon’s (1981) Pavlovian-contingency ratio as follows:

$$\log \left( \frac{B_t}{B_o} \right) = \frac{-t(c + d\Delta r)}{\left( \frac{r_s}{r_c} \right)^b}. \quad (2)$$

In the denominator,  $r_s$  is the reinforcer rate experienced in the presence of target-component stimulus and  $r_c$  is the contextual reinforcer rate ( $r_c = [r_{Target} + r_{Alternative}]/2$ ; i.e., session-wide reinforcer rate, averaged between components), both in reinforcers delivered per hr.

Based on these insights and on the findings of Craig et al. (2015), it is reasonable to believe that changing the rate of reinforcement in an alternative multiple-schedule component for several sessions prior to persistence testing could affect behavioral mass and thus produce a contrast effect on resistance to change of behavior maintained in another, target, component. More specifically for present purposes, introducing extinction in an alternative-component stimulus situation before introducing extinction in the target component could influence subsequent target-component resistance to extinction. The present experiment aimed to test this possibility. Across several conditions, pigeons' key pecking was reinforced during baseline and subsequently extinguished during persistence testing in a two-component multiple schedule. In all conditions, baseline reinforcement was provided at the same rate in both components, and an alternative-component treatment phase intervened between baseline and persistence testing. During the alternative-component treatment, the key-light color associated with the alternative component was presented alone in a single schedule, and pecking this key produced either the same rate of reinforcement as during baseline, a higher rate, or no reinforcement.

Delivering a higher rate of reinforcement in the alternative component should *decrease* subsequent resistance to extinction of key pecking in the target component because the target component would be associated with a relatively low rate of reinforcement in that condition, and exposure to zero-rate reinforcement in the alternative component should *increase* target-component resistance to extinction because the target component then would be associated with a relatively high reinforcer rate (cf. Grace et al., 2012, 2003; Nevin, 1992b; Nevin & Grace, 1999). Manipulations of the rate of reinforcement in the alternative component were conducted outside of the multiple schedule to avoid potential issues associated with behavioral-contrast effects on baseline response rates (see, e.g., McSweeney, 1983; McSweeney, Dougan, Higa, & Farmer, 1986). That is, changing the rate of reinforcement in an alternative multiple-schedule component can lead to changes in target-component response rate, despite no change in reinforcer rate in that component. If contrast of response rates produced different baseline response rates between conditions, target-component proportion-of-baseline response rates might be rendered unreliable for the purposes of between-condition comparisons. The major dependent variable in this experiment was target-component proportion-of-baseline response rates during persistence testing, and this variable was compared between conditions. Momentum-based quantitative analyses were used to explore potential mechanisms responsible for differences in target-component extinction performance between conditions.

## Method

### Design

A within-subjects ABCA (counterbalanced ACBA) design was used for this experiment. Conditions labeled “A” were Control conditions, where alternative-component reinforcer rates were the same in baseline and treatment. The purpose of these conditions was to determine levels of target-component resistance to extinction following an alternative-component treatment without any reinforcer-rate manipulation. Further, two Control conditions were included to determine potential effects of repeated extinction tests on resistance to extinction across conditions. The “B” condition was a High-Rate condition, where key pecking in the alternative-component stimulus situation produced reinforcement four times as frequently as during baseline prior to target-component extinction. The effects of off-baseline exposure to different reinforcer rates in an alternative-component stimulus situation on subsequent resistance to change of target-component responding has never been investigated. Accordingly, the High-Rate condition was included as a manipulation check. As reviewed above, exposure to relatively high-rate reinforcement in an alternative multiple-schedule component reduces resistance to extinction of target-key pecking when both components are presented together in a multiple schedule (Grace et al., 2012, 2003; Nevin, 1992b; Nevin & Grace, 1999). Thus, reduced resistance to extinction of target-component pecking in the High-Rate condition would indicate similar behavioral effects of off-baseline and during-baseline alternative-component reinforcer-rate manipulation. Finally, Condition “C” was an Extinction condition, where extinction of key pecking in the alternative-component

stimulus situation was arranged prior to target-component extinction. Thus, every pigeon experienced the Control condition first (referred to as the “Control-1” condition below) and last (referred to as the “Control-2” condition below). Pigeons were exposure to the Extinction and High-Rate conditions in a counterbalanced order.

### **Subjects**

Seven unsexed homing pigeons with identical histories of responding under schedules of positive reinforcement (see Craig & Shahan, 2016b) served. Pigeons were housed individually in a temperature-controlled colony room with a 12:12 hr light/dark cycle (lights on at 7:00 AM). Each pigeon had free access to water in its home cage and was maintained at 80% of its free-feeding body weight ( $\pm 15$ g) by the use of supplementary post-session feedings when necessary. Animal housing and care were conducted in accordance with the regulations of Utah State University’s Institutional Animal Care and Use Committee (protocol #2150).

### **Apparatus**

Four operant chambers for pigeons (dimensions approximately 29 cm long, 26 cm wide, and 29 cm high), enclosed in sound-attenuating chambers, were used. These chambers were constructed of clear Plexiglas and aluminum with an aluminum work panel on the front wall. Each work panel was equipped with two opaque response keys measuring 2.5 cm in diameter and located 16 cm from the floor of each chamber and 2 cm from either of the sidewalls. Only the left key was used during this experiment and was transilluminated blue or white to signal the two multiple-schedule components

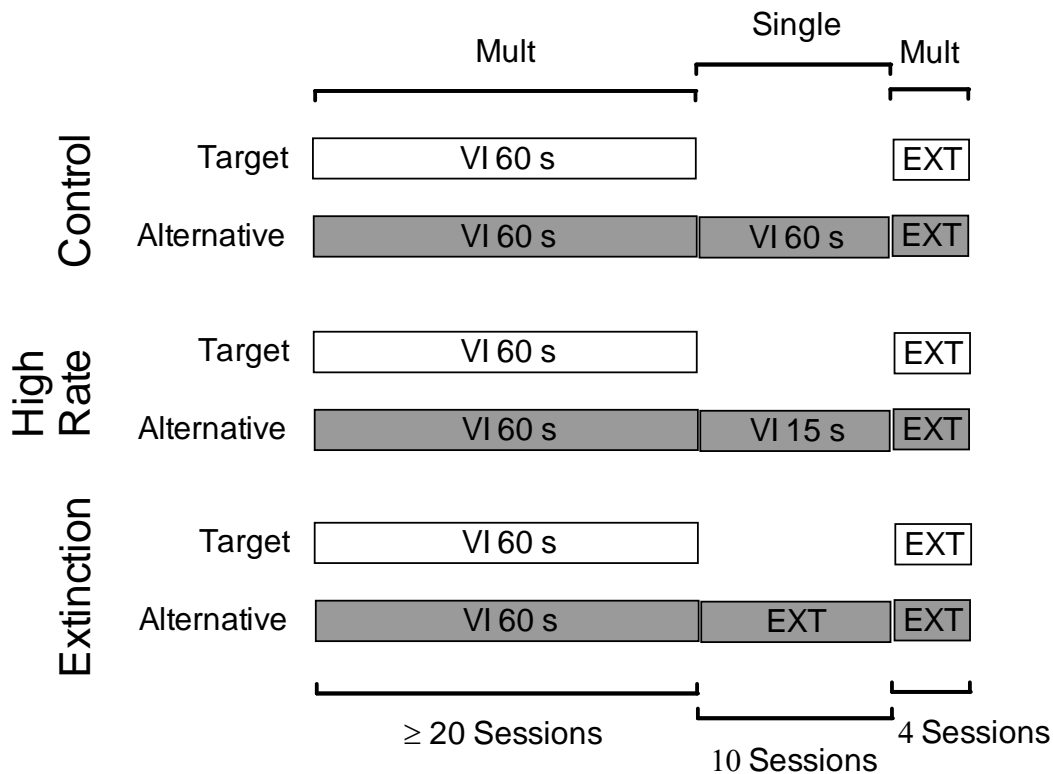


(colors counterbalanced across pigeons). A 28-V lamp located in the center of the work panel and 23 cm from the floor of the chamber provided general illumination. Both this lamp and the left key light were illuminated at all times except during reinforcer deliveries and inter-component intervals (ICIs). A food aperture measuring 6 cm wide by 5 cm high was located in the center of the work panel 5 cm from the floor of the chamber. A 28-V lamp illuminated this aperture during reinforcement, which consisted of 1.5 s of access to Purina ® Pigeon Checkers delivered by a solenoid-operated food hopper. White noise was present at all times to mask extraneous sound. All experimental sessions were controlled by MedPC ® software from a PC computer.

## **Procedure**

**General features.** The experiment consisted of three conditions, and each condition consisted of three phases. A graphical summary of these procedures may be found in Figure 4.1. In Phases 1 (baseline) and 3 (persistence test), a two-component multiple schedule was in place. One component was designated the “target” component, and the other was designated the “alternative” component. Components lasted for three min and were separated by 30-s ICIs. The first component within each session was selected randomly, after which components strictly alternated for a total of 10 component presentations (five target and five alternative).

In Phase 1, key pecking in both components produced food according to a variable-interval (VI) 60-s schedule constructed of 10 intervals using Fleshler and Hoffman’s (1962) constant-probability algorithm. This phase lasted for a minimum of 20 sessions during the Control-1 condition and a minimum of 10 sessions for each remaining



*Figure 4.1.* A graphical summary of reinforcement schedules across phases of each condition. “Target” and “Alternative” refer to the target and alternative components, respectively. “Mult” and “Single” indicate that phases consisted of either a multiple or single schedule of reinforcement.

condition. Further, pigeons finished Phase 1 only if no visual trends in response rates were evident in either component during the final five sessions of the phase. Phase 2 differed between conditions as described in the sections below. Phase 2 lasted for 10 sessions in each condition. Sessions of Phase 3 were identical to sessions of Phase 1, except key pecking was placed on extinction. This phase lasted for four sessions in each condition.

**Control conditions.** The key-light associated with the alternative component was

available continuously (i.e., a single schedule of reinforcement was arranged) for 15 min, and pecking this key produced food according to a VI 60-s schedule.

**High-rate condition.** The key-light associated with the alternative component was presented for 15 min in a single schedule. Pecks to this key produced food according to a VI 15-s schedule.

**Extinction condition.** As in the other Phase-2 conditions the key-light associated with the alternative component was available continuously for 15 min, but reinforcement for key pecking was suspended.

**Data analyses.** All statistical tests reported below were deemed significant at an  $\alpha$  level of .05. The assumption of sphericity for repeated factors in analyses of variance (ANOVA) was tested using Mauchly's method and, if this assumption was violated, Greenhouse-Geisser reductions to degrees of freedom were used.

## Results

### Phase 1 (Baseline)

Figure 4.2 shows mean response and reinforcer rates from the last five sessions of each baseline condition in both multiple-schedule components. Pecking occurred at comparable rates across conditions and at roughly equal rates in the target and alternative components. Obtained reinforcer rates from the last five sessions of each baseline condition closely approximated programmed the reinforcer rate (i.e., one reinforcer per min) across components and conditions. Baseline phases for lasted an average of 23.42 ( $SD = 2.15$ ), 15.86 ( $SD = 4.56$ ), 14.29 ( $SD = 3.40$ ), and 15.57 ( $SD = 4.50$ ) sessions in the Control-1, High-Rate, Extinction, and Control-2 conditions, respectively.

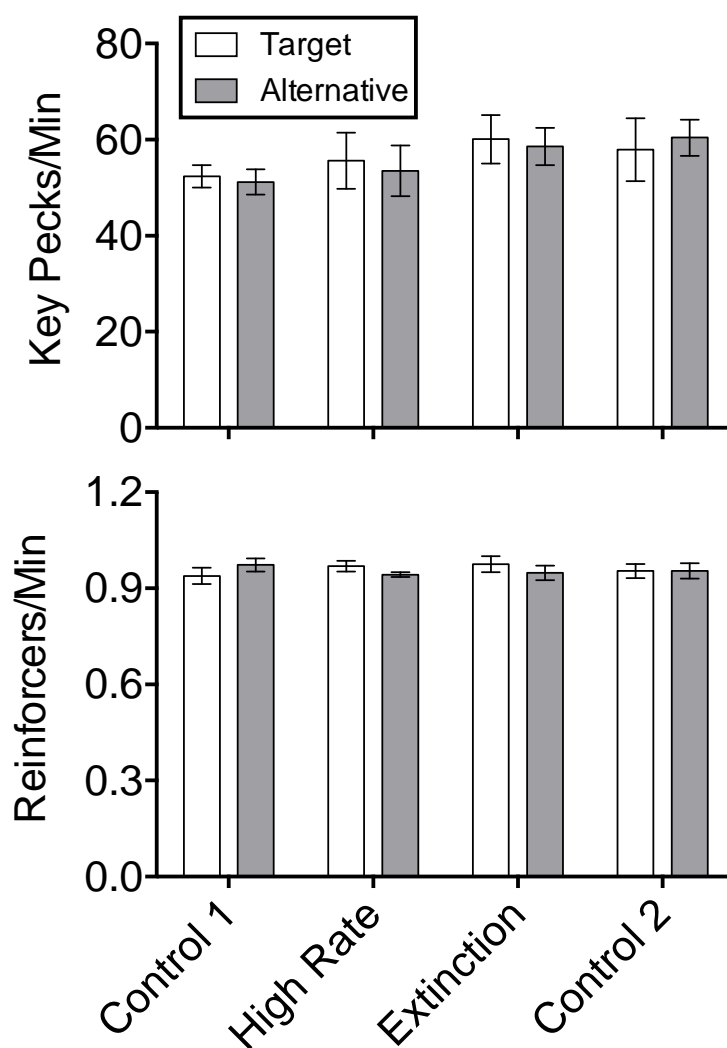


Figure 4.2. Mean (plus *SEM*) key pecks and reinforcers per min in both multiple-schedule components across conditions.

### Phase 2 (Treatment)

Mean proportion-of-baseline response rates in the alternative component across sessions of each treatment condition are shown in Figure 4.3. Proportion-of-baseline response rates were calculated for each pigeon by dividing response rates in each session of treatment by the mean rate of responding obtained during the final five sessions of the

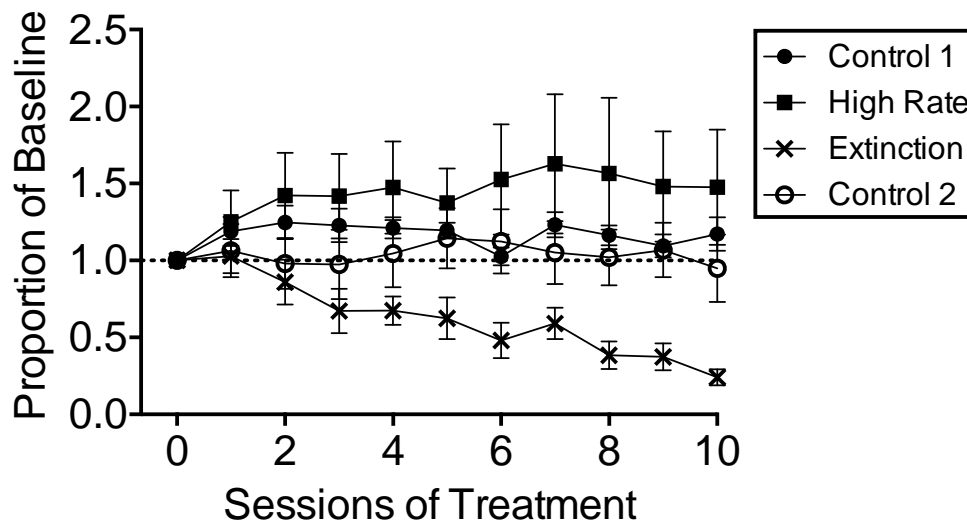


Figure 4.3. Mean (plus *SEM*) alternative-component proportion-of-baseline response rates across sessions of the treatment phase in each condition. Session “0” represents response rates during the final five sessions of Phase-1 baseline.

preceding baseline condition. Session “0” and the dashed line that bisects the figure horizontally represent baseline levels of responding. Alternative-component key pecking in the Control conditions tended to occur at baseline levels throughout the course of treatment. Response rates were slightly elevated relative to baseline in the High-Rate condition, and key pecking decrease across sessions of the phase in the Extinction condition. These observations were supported by a 4 X 11 (Condition X Session) repeated-measures ANOVA. The main effects of Condition,  $F(3, 18) = 16.11$ ,  $MSE = 0.38$ ,  $p < .001$ , Session,  $F(10, 60) = 2.01$ ,  $MSE = 0.03$ ,  $p = .048$ , and Condition X Session interaction,  $F(30, 180) = 5.30$ ,  $MSE = 0.03$ ,  $p < .001$ , were significant. To identify the source of the significant interaction, follow-up 2 X 11 (Condition X Session) repeated-measures ANOVA were conducted on each pairwise comparison of group, and results of

these analyses are found in Table 4.1. The interaction term remained significant when responding in the Extinction treatment was compared to responding in the other three (Control-1, High-Rate, and Control-2) conditions. No other pairwise comparisons yielded a significant interaction. Thus, responding decreased in the Extinction condition but continued roughly at baseline rates in the other conditions.

Mean reinforcer rates from the last five sessions of the Control and High-Rate treatment conditions are shown in Figure 4.4. Note that the Extinction condition was omitted from this figure because reinforcer rates were zero across Phase-2 sessions. Obtained Phase-2 reinforcer rates approximated programmed rates in each condition (i.e., one reinforcer per min in the Control-1 and Control-2 conditions and four reinforcers per min in the High-Rate condition).

### Phase 3 (Extinction Testing)

**Within-component comparisons.** Mean proportion-of-baseline alternative-

Table 4.1

*Results from Follow-Up 2 X 11 (Condition X Session) Repeated-Measures ANOVA Conducted on Each Pairwise Comparison of Condition for Alternative-Component Proportion-of-Baseline Response Rates from Treatment Conditions*

Comparison	$F^a$	$MSE$	$p$
Control 1 vs. Control 2	0.96	0.04	.489
Control 1 vs. High Rate	0.93	0.01	.514
Control 1 vs. Extinction	9.47	0.03	< .001
Control 2 vs. High Rate	0.71	0.03	.716
Control 2 vs. Extinction	7.13	0.04	< .001
High Rate vs. Extinction	14.85	0.02	< .001

<sup>a</sup> Interaction degrees of freedom = 10; error degrees of freedom = 60

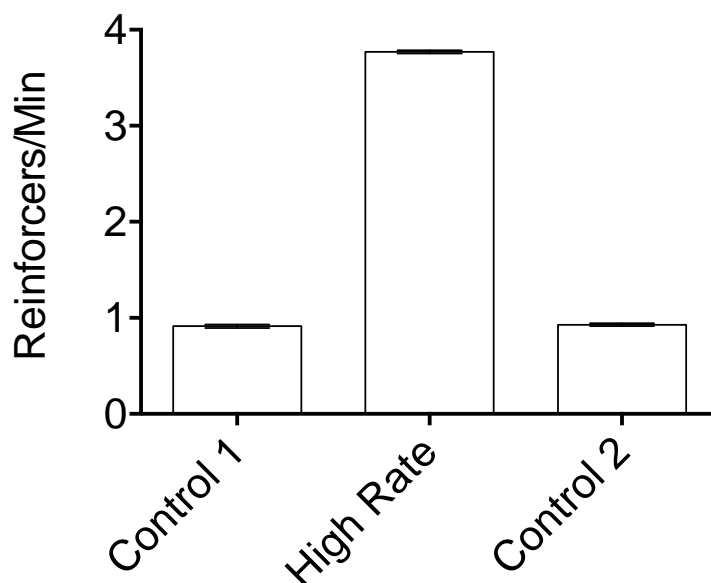


Figure 4.4. Mean (plus SEM) alternative-component reinforcer rates from the final five sessions of the treatment phase from the Control-1, High-Rate, and Control-2 conditions.

component response rates from each extinction test are shown in Figure 4.5. Session “0” represents baseline rates of responding. Alternative-component key pecking decreased across sessions of extinction in all conditions and occurred at the lowest rate in the Extinction condition. Further, comparisons between data presented in Figure 4.3 and 4.5 reveal that key pecking in this condition remained low between the treatment and test phases. In the Control-1, High-Rate, and Control-2 conditions, responding decreased at roughly equivalent rates. A 4 X 4 (Condition X Session) repeated-measures ANOVA was conducted to support these observations. Note that Sessions 0 in Figure 4.5 was excluded from this analysis because treatment conditions intervened between baseline and testing. The main effects of Condition,  $F(3, 18) = 14.43$ ,  $MSE = 0.11$ ,  $p < .001$ , and Session,  $F(3, 18) = 36.41$ ,  $MSE = 0.02$ ,  $p < .001$ , and the interaction between these terms,  $F(9, 54) = 2.82$ ,  $MSE = 0.02$ ,  $p = .009$ , were significant. Follow-up 2 X 4 (Condition X Session)

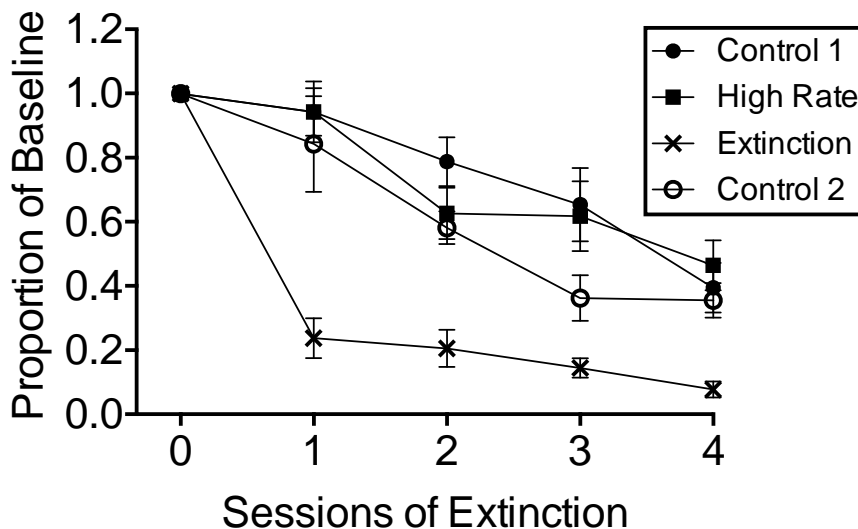


Figure 4.5. Mean (plus SEM) alternative-component proportion-of-baseline response rates across sessions of Phase-3 persistence testing. Session “0” represents response rates from the last session of Phase-1 baseline.

repeated-measures ANOVA were conducted for each pairwise comparison of Condition to identify the source of the significant interaction. Results from these analyses may be found in Table 4.2. The interaction term remained significant when proportion-of-baseline response rates in the Extinction condition were compared to the other three conditions. No other pairwise comparisons were significant.

Mean target-component proportion-of-baseline response rates during extinction in each condition are shown in Figure 4.6. Key pecking decreased across sessions of extinction in each condition, and it tended to decrease at roughly equal rates between conditions. Proportion-of-baseline response rates, however, were lower in the Extinction condition than in the remaining conditions and were slightly elevated in the initial Control-1 condition. A 4 X 5 (Condition X Session) repeated-measures ANOVA was conducted to determine the statistical reliability of these group differences. The main

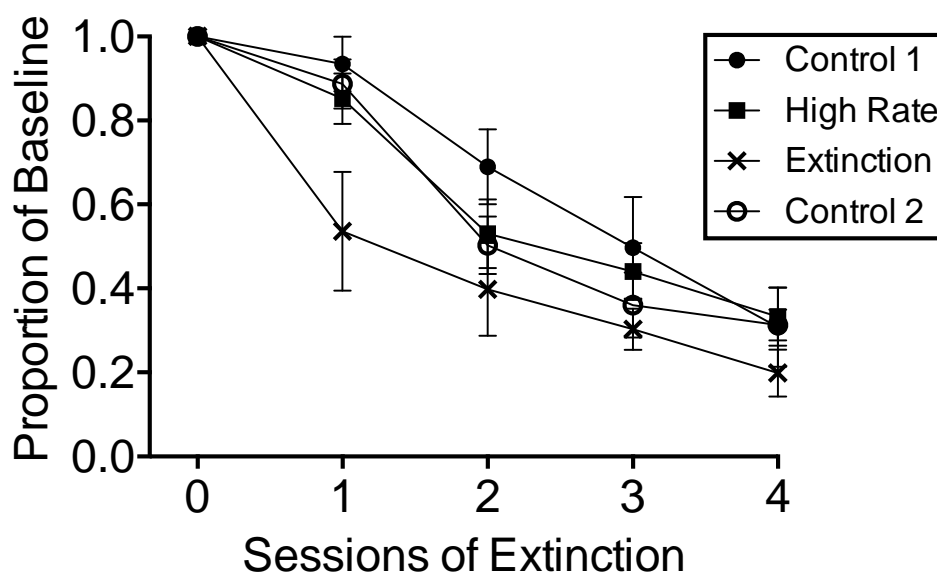


Table 4.2

*Results from Follow-Up 2 X 4 (Condition X Session) Repeated-Measures ANOVA Conducted on Each Pairwise Comparison of Condition for Alternative-Component Proportion-of-Baseline Response Rates from Persistence Testing*

Comparisons	$F^a$	$MSE$	$p$
Control 1 vs. Control 2	1.52	0.03	.244
Control 1 vs. High Rate	1.14	0.03	.360
Control 1 vs. Extinction	7.61	0.01	.002
Control 2 vs. High Rate	1.46	0.02	.259
Control 2 vs. Extinction	4.55	0.02	.015
High Rate vs. Extinction	3.60	0.02	.034

<sup>a</sup> Interaction degrees of freedom = 10; error degrees of freedom = 60.



*Figure 4.6.* Mean (plus SEM) target-component proportion-of-baseline response rates across sessions of Phase-3 persistence testing. Session “0” represents response rates from the last session of Phase-1 baseline.

effects of Condition,  $F(3, 18) = 3.37$ ,  $MSE = 0.07$ ,  $p = .042$ , and Session,  $F(4, 24) = 75.01$ ,  $MSE = 0.32$ ,  $p < .001$ , were significant, but the Condition X Session interaction was not,  $F(12, 72) = 1.76$ ,  $MSE = 0.02$ ,  $p = .071$ . Fisher's protected  $t$ -tests were used to follow up on the significant main effect of Condition, and the results from these analyses are found in Table 4.3. Proportion-of-baseline response rates, collapsed across sessions, were lower in the Extinction condition than in the Control-1 and High-Rate conditions. Response rates, however, were not statistically different between the Extinction and Control-2 conditions. Further, comparisons between the Control-1, High-Rate, and Control-2 conditions were not significant. Thus, target-component key pecking persisted most in the Control-1 and High-Rate conditions, least in the Extinction condition, and to an intermediate degree in the Control-2 condition.<sup>4</sup>

Table 4.3

*Fisher's Protected t Tests Comparing Overall Levels of Target-Component Persistence Between Conditions*

Comparisons	$D^a$	95% confidence interval		$p$
		Lower bound	Upper bound	
Control 1 vs. Control 2	0.07	-0.12	0.26	.381
Control 1 vs. High Rate	0.06	-0.05	0.16	.259
Control 1 vs. Extinction	0.20	0.01	0.38	.039
Control 2 vs. High Rate	-0.02	-0.17	0.13	.772
Control 2 vs. Extinction	0.13	-0.04	0.29	.117
High Rate vs. Extinction	0.14	0.01	0.28	.039

<sup>a</sup> Mean difference.

<sup>4</sup> The pattern of results shown in Figures 4.5 and 4.6 also were evident on the individual-subject level. Relative resistance to extinction, expressed as the log ratio of mean proportion-of-baseline response rates for each pairwise comparison of conditions, may be found in Appendix F. Data points represent individual subjects, and bars represent mean relative resistance. The left panel of the figure shows comparisons across conditions for the Alternative component, and the right panel shows comparisons for the Target component.

**Between-component comparisons.** Mean proportion-of-baseline response rates in the target and alternative components, organized by condition, are shown in Figure 4.7. Regardless of condition, proportion-of-baseline responding tended to decrease at comparable rates between components. Further, in the Control-1, High-Rate, and Control-2 conditions, proportion-of-baseline response rates were comparable between components. In the Extinction condition, however, responding occurred at a lower rate in the alternative component than in the target component. Decreases in response rates across sessions of extinction in this condition also tended to be less extreme than in the other conditions. These observations were confirmed by 2 X 4 (Component X Session) repeated-measures ANOVA conducted on proportion-of-baseline data for each condition,

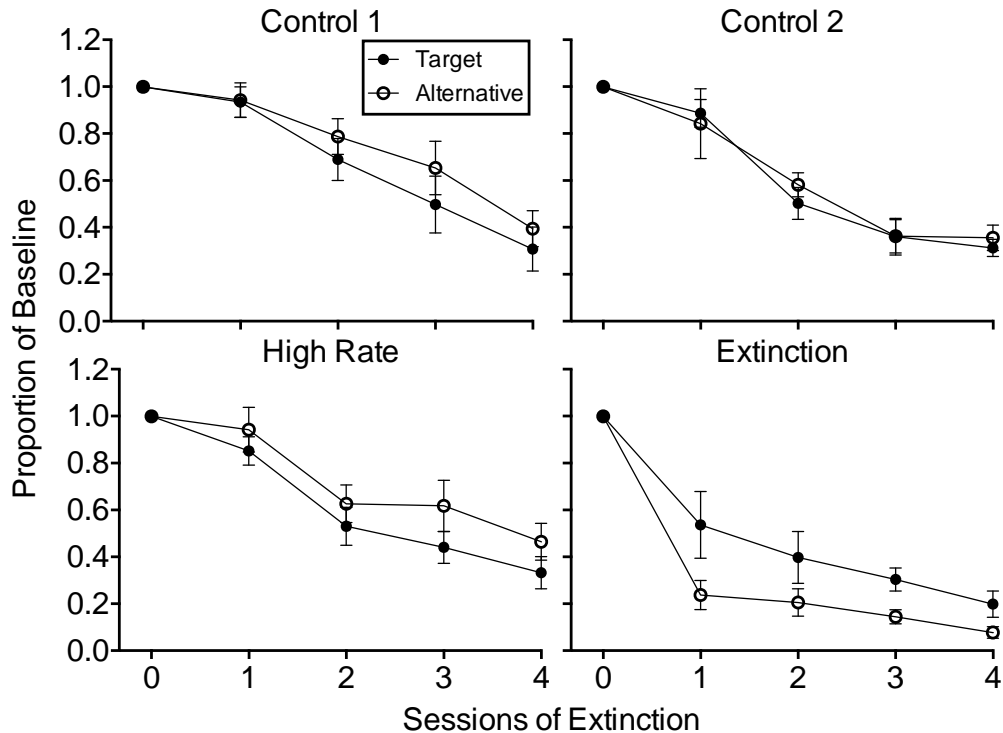


Figure 4.7. Mean (plus SEM) target- and alternative-component proportion-of-baseline response rates from each condition.

separately. The results from these analyses are found in Table 4.4. Similar patterns of results were obtained from analyses of data from them Control-1, High-Rate, and Control-2 conditions. That is, the main effects of Session were the only significant effects in these models. In the Extinction condition, however, only the main effect of Component was significant.

### **Modeling Treatment Effects on Target-Component Persistence**

It was of interest to determine the extent to which behavioral momentum theory could be extended to account for systematic differences in target-component resistance to

Table 4.4

*Results from 2 X 4 (Component X Session) Repeated-Measures ANOVA Conducted on Target- and Alternative-Component Proportion-of-Baseline Response Rates during Persistence Testing*

Condition	Effect	<i>F</i>	Degrees of freedom		<i>MSE</i>	<i>p</i>
			Effect	Error		
Control 1	Component	4.25	1.00	6.00	0.03	.085
	Session	23.26	3.00	18.00	0.04	< .001
	Component X Session	1.70	3.00	18.00	0.01	.204
Control 2	Component	0.10	1.00	6.00	0.06	.767
	Session	34.85	3.00	18.00	0.02	< .001
	Component X Session	0.50	3.00	18.00	0.02	.684
High Rate	Component	2.49	1.00	6.00	0.09	.166
	Session	23.80	3.00	18.00	0.03	< .001
	Component X Session	0.88	1.53	9.21	0.01	.421
Extinction	Component	23.79	1.00	6.00	0.02	.003
	Session	2.61	1.69	10.16	0.06	.127
	Component X Session	1.84	2.32	13.91	1.84	.193

extinction across conditions of the present experiment. Fits described below were conducted by minimizing the sum of squared residuals between obtained and predicted target-component proportion-of-baseline response rates using Microsoft Excel Solver. Because treatment contingencies were the same between the Control-1 and Control-2 conditions and patterns of behavior during these conditions were statistically the same, the Control-2 condition was omitted.

Craig et al. (2015) suggested that the reinforcer-rate term associated with behavioral mass (i.e.,  $r$  in the denominator of Equation 1) changes when the reinforcer rate associated with a discriminative-stimulus situation changes. Accordingly, one approach to modeling target-component resistance to extinction between conditions might be to assume that changes in alternative-component reinforcer rates during the various treatment conditions affected calculation of  $r_c$  in Equation 2, where  $r_c = (r_{Target} + r_{Alternative})/2$  and both  $r$  terms are expressed in reinforcers per hr. Craig et al. also noted that the form of the specific function relating stimulus-reinforcer relations experienced across time is unknown. Thus, estimates of  $r_{Alternative}$  for each condition were free to vary but were assumed to be bounded by the reinforcer rates experienced in the alternative component during baseline and treatment. For the control, high-rate, and extinction conditions, respectively, these bounds were:  $[60, 60] = 60$ ,  $[60, 240]$ , and  $[0, 60]$ .<sup>5</sup> Values of  $c$  and  $d$  were allowed to vary and were shared between conditions. The  $b$  parameter also was shared between conditions. In one round of fits, this parameter was allowed to

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<sup>5</sup> Based on this premise,  $r_{Target}$ ,  $r_{Alternative}$ , and  $r_s$  should continue to change during Phase-3 extinction. Nevertheless, the modeling approach described above provides a strong test of the *ordinal* predictions offered by Nevin's (1992 b) approach.

vary. In another, it was fixed at a conventional value of  $b = 0.5$  (see Nevin et al., 2017).

Resulting parameter estimates from these model fits are found in Table 4.5 (see columns titled “Equation 2”), and model predictions are plotted along with obtained data in the top panels of Figure 4.8. Both fits revealed a similar pattern of results. Estimates of  $d$  approximated typical values derived from fits of Equation 1 to obtained multiple-schedule extinction data from pigeons (i.e.,  $d = .001$ ; see, Craig & Shahan, 2016b), but estimates of  $c$  were substantially smaller than the typically reported value of  $c = 1$ . Estimates of  $c$  were likely smaller than 1 because Nevin’s (1992b) method for calculating behavioral mass results in smaller overall estimates than the method offered by the augmented extinction model. That is, within-component reinforcer rates are divided by session-wide reinforcer rates in Equation 2 but not in Equation 1. When sensitivity to

Table 4.5

*Parameter Estimates from Model Fits to Target-Component Extinction Data Across Conditions*

Parameter	Equation 2		Equation 3		Mass	Disruption
	$b$ Fixed	$b$ Free	$d_c$ Fixed	$d_c$ Free		
$c$	0.140	0.140	1.000	1.000	1.000	1.000
$d$	0.000	0.000	0.001	0.001	0.001	0.001
$b$	0.500	0.500	0.500	0.500	-	0.050
$r_{alt}$ (High Rate)	60.000	60.000	60.000	60.000	-	-
$r_{alt}$ (Extinction)	60.000	60.000	60.000	60.000	-	-
$d_c$	-	-	0.001	0.001	-	-
$m$ (Control)	-	-	-	-	9.140	-
$m$ (High Rate)	-	-	-	-	8.310	-
$m$ (Extinction)	-	-	-	-	5.900	-
$x_d$ (Control)	-	-	-	-	-	0.000
$x_d$ (High Rate)	-	-	-	-	-	0.000
$x_d$ (Extinction)	-	-	-	-	-	0.340
$R^2$	.860	.860	.860	.860	.960	.940

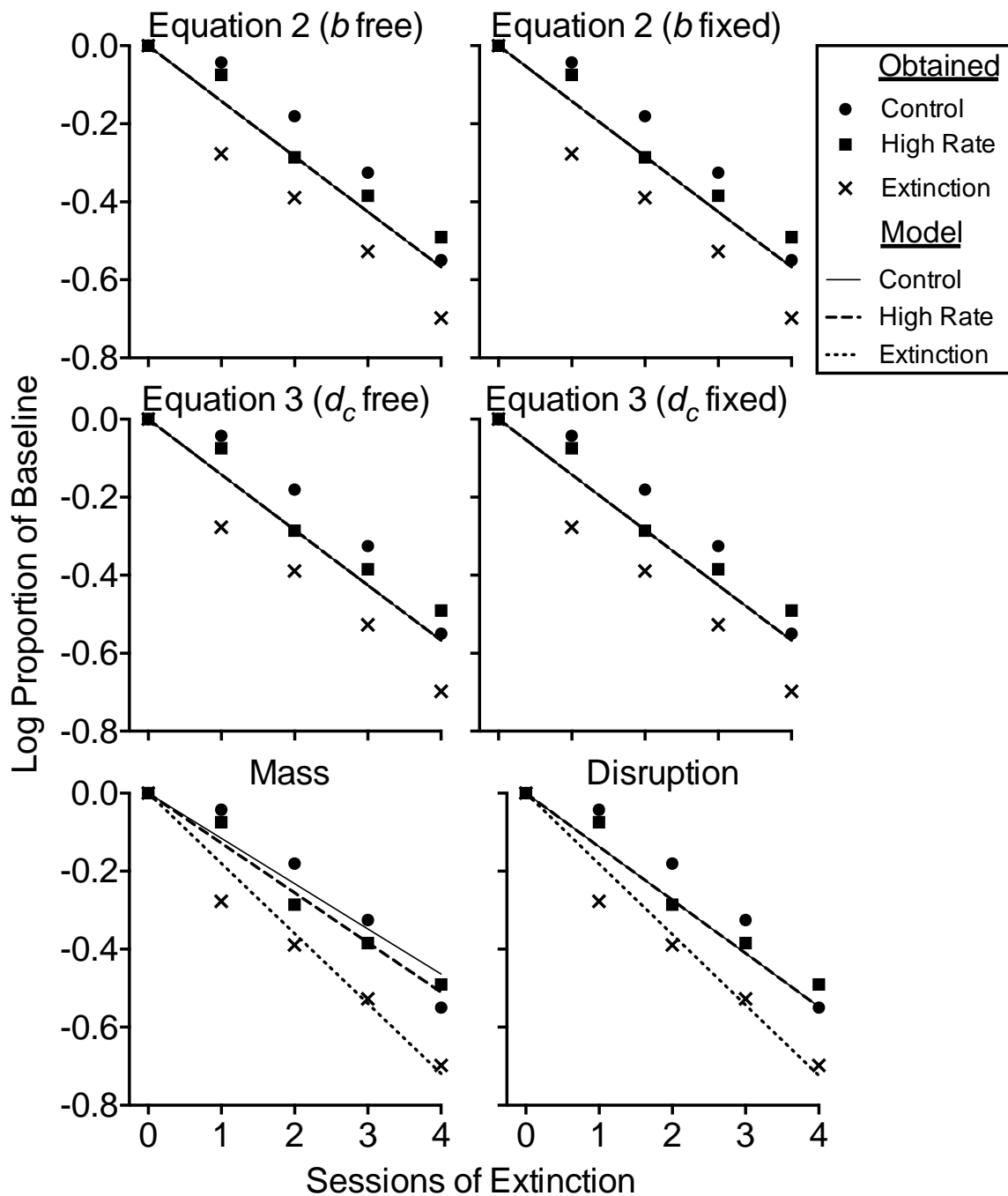


Figure 4.8. Fits of Equations 2 and 3, and the models with free variation in mass ( $m$ ) and disruption ( $x_d$ ) to obtained target-component extinction data across conditions.

baseline reinforcer rates ( $b$ ) was allowed to vary, the best-fitting estimate of this parameter was  $b = 0.5$ . In both fits, estimates of  $r_{Alternative}$  in each condition were 60. Inasmuch, the behavioral-mass term in the denominator =  $60/([60 + 60]/2) = 1$  in all conditions, resulting in identical model predictions between conditions. Equation 2 thus failed to account for the differences in target-component resistance to extinction between conditions of the present experiment, even with complete freedom for non-fixed parameters within to model to vary. Additional fits where  $r_{Alternative}$  was fixed at values other than 60 in the High-Rate and Extinction conditions resulted estimates of  $b = 0$ , eliminating any differential impact of alternative-component reinforcer rates between conditions on target-component resistance to extinction.

Nevin and Grace (1999) argued that Nevin's (1992b) formalization of behavioral mass was incorrect because these authors failed to demonstrate contrast effects on resistance to change using any disruptor other than extinction. They reasoned that, if contextual reinforcer rates modify behavioral mass, contrast effects should occur regardless of the disruptor applied. Instead, Nevin and Grace suggested that effects of alternative-component reinforcer rates on target-component resistance to change should be isolated to extinction and could be expressed by adding an additional source of disruption to the numerator of Equation 1 as follows:

$$\log\left(\frac{B_t}{B_o}\right) = \frac{-t(c + d\Delta r + d_c\Delta r_c)}{r^b}. \quad (3)$$

The  $\Delta r_c$  term in this expression is the change in overall session-average reinforcer rates between baseline and extinction and  $d_c$  scales this disruption. Subsequent studies (Grace et al., 2003, 2012), including one condition from Nevin (1992b), have found contrast



effects in resistance to change using prefeeding and presentations of free inter-component interval food as disruptors with pigeons, suggesting Equation 2 provides a more general approach to modeling these contrast effects than Equation 3. Nevertheless, this model was fitted to obtained data to more thoroughly explore potential momentum-based approaches to modeling target-component resistance to extinction in the present experiment.

Two model fits were conducted. In both fits,  $c$ ,  $d$ , and  $b$  were allowed to vary, and the  $r$  and  $\Delta r$  parameters in Equation 3 were fixed at 60 reinforcers per hr. The contextual reinforcer rate term ( $\Delta r_c$ ) in the numerator was calculated by averaging target- and alternative-component reinforcer rates prior to Phase 3 (i.e.,  $\Delta r_c = (r_{Target} + r_{Alternative})/2$ ), and  $r_{Alternative}$  was allowed to vary under the same constraints that were in place for the fits of Equation 2 described above. That is, this term was bounded by the same values in the Control (i.e.,  $r_{Alternative} = [60, 60] = 60$  reinforcers per hr), High-Rate (i.e.,  $r_{Alternative} = [60, 240]$  reinforcer per hr), and Extinction (i.e.,  $r_{Alternative} = [0, 60]$  reinforcer per hr) conditions. In the first model fit,  $d_c$  was allowed to vary. In the second fit, this parameter was fixed at  $d_c = 0.001$  (see Nevin & Grace, 1999). Results of these fits are shown in Table 4.5 (see columns titled “Equation 3”), and model predictions are plotted along with obtained data in the middle panels of Figure 4.8. Equation 3 converged on predictions that were identical between conditions—when  $d_c$  was allowed to vary, this parameter assumed a value of 0.001, and  $r_{Alternative} = 60$  in all conditions in both fits. Of note, predictions of Equation 3 were identical to those of Equation 2, and, in addition, model fits that fixed  $r_{Alternative}$  at any value other than 60 resulted in estimates of  $d_c = 0$ . Thus,

even provided substantial flexibility in parameter variation, Equation 3 accounted poorly for between-condition differences in target-component resistance to extinction.

Two additional model fits were conducted in the absence of any functional influences of contextual reinforcer rates on behavioral mass and disruption to determine whether free variations in these terms could adequately describe changes in target-component resistance to extinction across conditions. The fitted models were as follows:

$$\log\left(\frac{B_t}{B_o}\right) = \frac{-t(c + d\Delta r)}{m} \quad (4a)$$

and

$$\log\left(\frac{B_t}{B_o}\right) = \frac{-t(c + d\Delta r + x_d)}{r^b} \quad (4b)$$

In both fits, the following parameters were held at constant values:  $c = 1$ ,  $d = 0.001$ , and  $\Delta r = 60$  reinforcer omitted per hr. For fits of Equation 4a,  $m$  represented a composite mass term that was allowed to vary between conditions (see Craig et al., 2015). For fits of Equation 4b,  $r$  and  $b$  in the denominator were set equal to 60 and 0.5, respectively, and  $x_d$  in the numerator was allowed to vary between conditions.

Resulting parameter estimates may be found in Table 4.5 (see columns labeled “Mass” and “Disruption”), and model predictions are plotted along with obtained data in the bottom panels of Figure 4.8. Estimates of  $m$  in Equation 4a were smaller in the Extinction condition and roughly comparable between the Control and High-Rate conditions. When Equation 4b was fitted to obtained target-component extinction functions,  $x_d$  assumed values of 0 for both the Control and High-Rate conditions, but additional disruption from this parameter was evident in the Extinction condition. Of

note, both approaches described lower proportion-of-baseline response rates in the Extinction condition than in the other two conditions, thus accounting for substantially more variation in obtained data than the other modeling approaches described above (see Table 4.5).

### **Discussion**

The purpose of the present experiment was to determine whether previous exposure to extinction in one (alternative) multiple-schedule component would affect subsequent resistance to extinction of behavior maintained in a second (target) component. More specifically, this experiment aimed to explore the possibility that behavioral mass, the construct within behavioral momentum theory that relates stimulus-reinforcer contingencies to response persistence, changes during extinction. To this end, pigeons pecked keys for VI 60-s food in both components of a two-component multiple schedule during baseline phases. Next, the alternative-component key was presented in a single schedule and, across conditions, different treatments were introduced. Pecking the alternative key either produced the same rate of reinforcement as during baseline (i.e., 60 reinforcers per hr in the Control conditions), a higher rate (i.e., 240 reinforcers per hr in the High-Rate Condition), or a zero rate (i.e., extinction in the Extinction condition). Finally, the multiple schedule was reintroduced, but key pecking in both components was placed on extinction.

This experiment used a preparation similar to those used to examine behavioral-contrast effects in resistance to change, where baseline reinforcer rates in a target

multiple-schedule component remain the same but reinforcer rates in an alternative component vary across conditions. Thus, it is important to compare results from the present study to those of others examining contextual reinforcer-rate effects on response persistence. As reviewed in the Introduction, the routine finding from these experiments is that behavior in the target component tends to be more persistent when the alternative component arranges relatively low-rate reinforcement during baseline and less persistent when a high rate of reinforcement is arranged in the alternative component (see Grace et al., 2012, 2003; Nevin, 1992b; Nevin & Grace, 1999). That is, persistence in the unchanging component is *inversely* related to reinforcer rates in the other, changing, component.

If behavioral contrasts of resistance to change occurred in the present experiment as in the studies reviewed above, one would expect resistance to extinction of target-component key pecking to be lowest in the High-Rate condition and highest in the Extinction condition. Relative to these predictions, results from the present experiment differed in two major ways. First, exposure to a four-fold increase in reinforcer rates for key pecking in the alternative component during Phase-2 treatment had no impact on subsequent target-component resistance to extinction relative to conditions where Phase-2 treatment arranged an intermediate rate of reinforcement. Further Phase-3 key pecking was *less* resistant to extinction in the target component in the Extinction condition than in the other conditions. Thus, even though introducing extinction into the alternative-component during Phase-2 treatment changed the subsequent resistance to extinction of target-component key pecking, behavioral contrast might not be responsible for this

effect.

Fits of the momentum-based models used to describe behavioral-contrast effects on resistance to change (i.e., Equations 2 and 3) to the present target-component extinction data across conditions corroborate this conclusion. These models suggest that session-wide, contextual reinforcer rates ( $r_c$ ) affect resistance to change of target-component behavior by modulating behavioral mass (Equation 2) and by adding a source of disruption when reinforcement is suspended (Equation 3). Despite freedom of  $r_c$  to vary in a manner consistent with reinforcer rates experienced across phases of each condition (and complete flexibility of the other free parameters in these models to vary), neither model was able to describe lower target-component persistence in the Extinction condition than in the other conditions. Clearly, alternative explanations for the present findings are worth exploring.

Discriminative stimuli are thought exert control over operant behavior because they provide information about current reinforcement contingencies. These stimuli could, for example, be temporally discrete (e.g., Craig, Lattal, & Hall, 2014; Marcucella, 1976; Marcucella & Margolius, 1978) or extended (e.g., Andrzejewski, Terry-Cain, & Bersh, 2004; Cohen, 1998; Fuhrman et al., 2016; Tiger, Wierzba, Fisher, & Benitez, 2017) cues in the presence of which reinforcement for a specific response is available and in the absence of which reinforcement is unavailable. In the case of multiple schedules with reinforcers available in all schedule components, the stimuli associated with the components serve discriminative functions because they are associated with different rates, magnitudes, or qualities of reinforcement (see Nevin, 1974, for discussion). During

baseline conditions of the present experiment, reinforcement contingencies were the same between target and alternative multiple-schedule components. Because the component stimuli did not differentially signal any dimension of reinforcement during baseline, it is possible that key pecking failed to come under discriminative control by these stimuli despite different manipulations of alternative-component reinforcer rates across treatment phases. This possibility could help to explain lack of differential resistance to extinction between components during the High-Rate condition. If behavior had come under discriminative-stimulus control, momentum theory (and myriad research on reinforcer-rate effects on resistance to extinction in multiple schedules) would predict greater persistence of key pecking in the alternative component during this condition because that component most recently was associated with a reinforcer rate that was four-times as high than in the target component. Resistance to extinction during the Extinction condition, however, was greater in the target component than in the alternative component, suggesting that the different key colors in the multiple-schedule components exerted some amount of discriminative control over key pecking. Thus, an account based solely on stimulus control cannot describe the *overall* pattern of resistance to extinction across conditions in the present experiment.

A second potential explanation for lower target-component persistence during the Extinction condition than during the other conditions is that extinction learning that took place in the alternative-component stimulus situation during Phase 2 generalized not only between phases but also to some extent between component stimuli. Relative to terminal Phase-2 response rates, responding in the alternative component during the Extinction

condition remained low. Further, persistence of target-component responding in this condition was greater than persistence of alternative-component responding. Thus, from this perspective Phase-2 extinction learning in the alternative component could have *fully* generalized to the alternative component and *partially* generalized to the target component during Phase 3. The extent to which operant learning generalizes between stimulus conditions depends in part on the similarity between the stimulus in the presence of which original learning took place and the stimulus to which that learning is meant to generalize (e.g., Blough, 1969; Hanson, 1957, 1959). Because the key-light stimulus was the same between phases in the alternative component but different in the target component, then, data from this condition are reasonably consistent with data from conventional tests of stimulus generalization.

It is important to note that, according to this argument, Phase-2 exposure to high-rate reinforcement in the alternative-component stimulus situation apparently failed to generalize between conditions. This is evidenced by the lack of differential resistance to extinction between components in the High-Rate condition and the lack of differential resistance to extinction of alternative-component key pecking between the Control and High-Rate conditions. It is unclear at present why extinction learning would be expected to generalize between stimulus situations more readily than learning about new reinforcer rates, but recent conceptual approaches to understanding multiple-schedule extinction processes could inform this issue. Craig and Shahan (2016b; see also Gallistel, 2012), for example, argued that behavior during extinction in a multiple schedule might depend partially on organisms' overall assessment of reinforcer availability. More specifically,

discrimination of extinction in one multiple-schedule component is likely to indicate a global change in reinforcer availability and, accordingly, reduce the amount of evidence necessary for discrimination of extinction contingencies in other schedule components. In the present experiment, previous experience with extinction contingencies in the alternative component during the Extinction condition might have influenced the pigeons' overall assessment of reinforcer availability and thus produced generalization of extinction learning between component stimuli. Further, because reinforcement was still available for alternative-component key pecking in Phase 2 of the High-Rate condition, treatment in that condition would not be expected to influence an assessment of *whether or not* reinforcement is available globally. Craig and Shahan's discussion of this approach was admittedly speculative and, inasmuch, is applied tentatively here.

Whatever the underlying behavioral processes that are responsible for decreased target-component resistance to extinction in the Extinction condition of the present experiment, behavioral momentum theory as it presently is understood does not offer any quantitative method for describing this effect. The augmented model of extinction (Equation 1), for example, suggests that extinction processes should operate independently in multiple-schedule components (for discussion, see Nevin & Grace, 1999, 2000). To the contrary, data from the present experiment clearly demonstrate that expression of extinction learning is not necessarily specific to discriminative-stimulus situations previously paired with extinction. Further, Equations 2 and 3 which incorporate potential cross-component influences of reinforcer rates failed to capture differential target-component persistence between conditions. Exploratory fits of Equations 4a and



4b to target-component extinction data demonstrate that decreased target-component persistence following exposure to extinction in the alternative component might be equally well characterized by a decrease in behavioral mass (i.e.,  $m$  in Equation 4a) or an increase in disruption (i.e.,  $x_d$  in Equation 4b). Data from the present experiment are insufficient to distinguish between these possibilities. Future empirical and theoretical work is necessary to determine more precisely the mechanism(s) through which extinction in one stimulus situation subsequently affects resistance extinction of behavior in other correlated stimulus conditions. Inasmuch, the answer to the empirical question posed earlier, whether or not behavioral mass remains static during extinction as behavioral momentum theory currently asserts, remains unknown.

An alternative approach to answering this question that might be worth pursuing is to individually extinguish behavior in an alternative component of a multiple schedule while maintaining reinforcement in the target component prior to a test where behavior in both components is placed on extinction. Because this procedure is more similar to procedures typically used to study behavioral contrast in resistance to change, it might produce a result that is substantially different from the present experiment and, perhaps, more in line with the results typical results of previous (cf. Grace et al., 2012, 2003; Nevin, 1992b; Nevin & Grace, 1999). As described previously, this procedure was not pursued here due to the potential for extinction of alternative-component responding to affect target-component response rates prior to extinction and thus render proportion-of-baseline response rates unreliable. This approach, however, might at the least provide initial insights into the potential dynamics of response strength during extinction.

## CHAPTER 5

### GENERAL DISCUSSION

#### Introduction

The work contained in this dissertation had two overarching focuses. First, Chapters 1 and 2 offered a review of behavioral momentum theory and the resistance-to-change research that has provided its empirical foundations. These chapters were meant to provide a thorough background from which to evaluate the predictive and descriptive utility of the behavioral-momentum metaphor and to detail the conceptual underpinnings of the theory. Second, Chapters 3 and 4 broadly aimed to explore factors associated with resistance to change of operant behavior that had not been previously examined. More specifically, Chapter 3 described an experiment conducted to determine the effect of changing over time the stimulus-reinforcer relations experienced prior to disruption on resistance to change. The experiment detailed in Chapter 4 provided a novel examination of the dynamics of response elimination by manipulating reinforcer rates in one discriminative-stimulus situation prior to extinction of behavior maintained in a correlated stimulus situation. An additional goal of the experiments detailed in these chapters was to critically analyze how behavioral momentum theory might be used to describe resistance to change under these novel treatment conditions.

As detailed above, the augmented model of extinction (see Nevin & Grace, 2000) suggests persistence of behavior at time  $t$  in extinction is directly related to the disruptive impact of suspending the response-reinforcer contingency ( $c$ ) and generalization

decrement ( $d\Delta r$ ). Further, persistence is inversely proportional to a mass-like quality of behavior engendered by the Pavlovian stimulus-reinforcer relation in a conditioning situation (i.e., “behavioral mass”;  $r^b$ ) as follows:

$$\log\left(\frac{B_t}{B_o}\right) = \frac{-t(c + d\Delta r)}{r^b}. \quad (1)$$

Chapter 3 asked whether and how  $r^b$  in Equation 1 changes when stimulus-reinforcer relations alternate between multiple-schedule components prior to extinction. Chapter 4 asked whether  $r^b$  remains constant or whether it changes when reinforcer rates are dramatically reduced in a discriminative-stimulus situation during extinction.

In the sections that follow, findings from these studies first will be summarized from the perspective of behavioral momentum theory. Based on this discussion, potential extensions of the momentum-based quantitative framework of resistance to change will be offered to describe the findings reported in Chapters 3 and 4. Practical implications and future areas for empirical work also will be described.

### **Implications for Behavioral Momentum Theory**

The study reviewed in Chapter 3 was the first to examine effects of temporally dynamic reinforcer rates on resistance to change in multiple schedules. The principle finding from this experiment was that resistance to extinction of pigeons’ key pecking depended most heavily on stimulus-reinforcer relations that were arranged in the sessions just prior to extinction testing. Further, the extent to which resistance to extinction was related to these reinforcer rates depended on the number of sessions during which they were held constant. At least three sessions with the same stimulus-reinforcer relations

arranged in the multiple-schedule components prior to extinction testing were required for these relations to differentially affect resistance to change. When stimulus-reinforcer relations changed more frequently (i.e., every session or every two sessions), persistence was the same between components.

With respect to Equation 1, assuming that persistence was governed by average baseline reinforcer rates would result in predictions of non-differential persistence between components in all condition because both multiple-schedule components were associated with high- and low-rate reinforcement for equal numbers of sessions per condition. Likewise, assuming persistence was governed by the stimulus-reinforcer rate relation most recently experienced prior to extinction would result in predictions of greater persistence in the component last associated with high-rate reinforcement regardless of condition. As reviewed above, neither of these possible outcomes were observed. Fits of Equation 1 to these data revealed that the reinforcer-rate parameter in the behavioral-mass term,  $r$ , changed to account for between-condition differences in relative resistance to extinction. Based on this finding, one may conclude that behavioral mass is temporally dynamic. That is, the term changes when the reinforcer rate within a stimulus situation changes in a manner that depends most heavily on recently experienced stimulus-reinforcer rate pairings.

It was argued in Chapter 3 that changing stimulus-reinforcer relations during baseline should not affect the disruptive impacts of suspending the response-reinforcer contingency or generalization decrement during extinction, so model fits were carried out holding these parameters in Equation 1 (i.e.,  $c$  and  $d\Delta r$ ) constant. Data published more

recently, however, challenge this assumption. Using single schedules of reinforcement, Craig and Shahan (2016b) found that changing the rate of reinforcement for pigeons' key pecking within and between sessions of baseline hastened extinction of key pecking relative to a condition where baseline reinforcer rates stayed the same. Further, fits of Equation 1 to their data revealed that the disruptive impact of generalization decrement ( $d\Delta r$ ) was greater following changing than following non-changing baseline reinforcement (a finding that is consistent with theories of extinction and choice based on statistical change-detection mechanisms; see, e.g., Gallistel, 2012; Gallistel et al., 2001). Accordingly, Equation 1 was refitted to extinction data from Chapter 3 to evaluate the possibility that generalization decrement contributed to the differential relative resistance to extinction observed between conditions. The model was fitted to data from each condition individual while allowing  $c$ ,  $d$ , and  $b$  to vary. Values of  $r$  and  $\Delta r$  were fixed at 30 and 120 reinforcers per hr, depending on the schedule of reinforcement in a component that was in effect just prior to extinction testing. Resulting parameter and  $R^2$  estimates from these model fits may be found in Table 5.1.

Table 5.1

*Parameter Estimates from Reanalysis of Data Reported in Chapter 3*

Condition	Parameter estimate			$R^2$
	$c$	$d$	$b$	
20 Day	0.89	0.0010	0.41	.78
5 Day	0.89	0.0010	0.36	.77
3 Day	0.55	0.0011	0.29	.80
2 Day	0.26	0.0016	0.18	.96
1 Day	0.32	0.0016	0.22	.96

Two results from these fits are particularly noteworthy. First, estimates of  $d$  did not vary substantially between conditions, suggesting minimal impact on generalization decrement of changing stimulus-reinforcer relations prior to extinction. Indeed, Craig and Shahan (2016b) reported values of  $d$  that differed by several orders of magnitude between conditions with stable and changing reinforcer rates. Differences between these results and those of Craig and Shahan could have owed to any of a number of procedural differences between these studies (e.g., use of single vs. multiple schedules, rapidity of reinforcer-rate changes prior to extinction, the specific reinforcement schedules used, etc.). Second, estimates of  $c$  and  $b$  tended to decrease with increasing frequency of stimulus-reinforcer rate alternations. Mathematically, this result was due to the decreases in relative resistance to change across conditions. At  $b = 0$ , Equation 1 suggests no impact of pre-extinction reinforcer rates on resistance to extinction because  $r^0 = 1$  regardless of the value of  $r$ . Subsequently,  $c$  decreased to describe the fact that responding persisted despite relatively little behavioral mass to support persistence.

These model fits present an example of the *post hoc* flexibility of the momentum-based equations to describe data that do not necessarily accord with their basic predictions. Without *a priori* or empirically driven reasons to assume systematic variations in parameter estimates under different treatment situations (like those provided in Chapter 3 and by Craig & Shahan, 2016b), interpretation of such results warrants caution. Atypical variation in parameter estimates might, on the one hand, direct researchers towards higher order dependent variables that affects response persistence (for discussion, see Nevin, 1984b). On the other hand, it might also represent an inherent

shortcoming of the momentum-based quantitative framework for understanding resistance to change (for related discussion, see Craig & Shahan, 2016a; Shahan & Craig, 2017). That is, with sufficient flexibility of model parameters to vary between conditions, Equation 1 could describe almost any pattern of results from resistance-to-change studies whether or not the specific parameter estimates are related in a meaningful way to underlying behavioral processes. At present, there is no clear reason to believe that changing stimulus-reinforcer rate relations prior to extinction should impact  $c$  or  $b$  in Equation 1 in the manner reported in Table 5.1. Thus, assuming that stimulus-reinforcer relations that change over time impact behavioral mass appears to be the most theoretically grounded explanation for the results reported in Chapter 3.

This interpretation of the data reported in Chapter 3 directly provided the theoretical rationale for the experiment described in Chapter 4. If behavioral mass changes when discriminative stimulus-reinforcer rate pairings change and extinction functionally represents an extreme decrease in reinforcer rate, it stood to reason that behavioral mass might change during extinction. Results from this study demonstrated that exposure to extinction in one stimulus situation did, indeed, affect subsequent extinction of behavior in a correlated stimulus situation. Specifically, off-baseline exposure to extinction in an alternative multiple-schedule component hastened subsequent elimination of pigeons' target-component key pecking relative to conditions where the alternative component was associated with a constant rate of reinforcement prior to persistence testing. Further, off-baseline treatment contingencies in the alternative component affected target-component extinction only when that treatment entailed

extinction: Exposure to a higher rate of reinforcement in the alternative-component stimulus situation had no systematic impact on persistence of target-component key pecking.

These findings did not conform to initial predications based on the literature investigating behavioral-contrast effects on resistance to change in multiple schedules (see Grace et al., 2012, 2003; Nevin, 1992b; Nevin & Grace, 1999). The pattern of results from these studies would suggest that resistance to extinction of target-component key pecking should have been highest following previous exposure to extinction, and lowest following previous exposure to high-rate reinforcement, in the alternative-component stimulus situation during treatment. Exploratory quantitative analyses of target-component persistence from this experiment revealed that lower resistance to extinction of target-component key pecking following alternative-component extinction could be characterized either by assuming that behavioral mass was smaller *or* that disruption of key pecking was larger in this condition. These model fits, however, relied on unconstrained variation of model parameter between conditions, precluding identification of any precise mechanisms responsible for differential resistance to change. Thus, it remains unclear whether behavioral mass ought to or ought not to change during exposure to zero-rate reinforcement in extinction.

Despite inability to make any firm conclusions about the mechanisms responsible for the effects reported in Chapter 4, it is noteworthy these findings are not well described by models of resistance to extinction offered by behavioral momentum theory. For example, the augmented model of extinction (Equation 1) asserts that extinction



processes affect behavior in discriminative-stimulus situations independently (see Nevin & Grace, 2000). Because reinforcement contingencies in the target component were identical between conditions, Equation 1 would predict no effect of alternative-component reinforcer rates on persistence of responding in the target component. Extensions of Equation 1 that incorporate alternative-component reinforcers rates in determination of target-component resistance to change (i.e., Equations 2 and 3 in Chapter 4; Nevin, 1992b; Nevin & Grace, 1999) also failed to account for differences in target-component resistance to extinction between conditions: Best-fitting parameter estimates from these models predicted no difference in target-component persistence. Thus, these data further challenge the specificity of the resistance-to-change mechanisms offered by behavioral momentum theory.

To conclude, data reported in Chapters 3 and 4 suggest the current behavioral-momentum based understanding of resistance to change is incomplete. These findings add to a broader literature, reviewed in Chapter 2, that delimits the scope of behavioral momentum theory in terms of the generality of its basic predictions. It is important to acknowledge, however, that the limitations to the theory described in Chapter 2 and those described in Chapters 3 and 4 might be qualitatively different. The fundamental argument of momentum theory is that that behavior in the presence of a stimulus becomes stronger (i.e., more resistant to change) when the rate of reinforcement delivered in the presence of that stimulus increases. Further, effects of this stimulus-reinforcer relation on persistence are completely independent of operant response-reinforcer relations. Thus, failure of momentum theory to adequately describe response persistence in single

schedules (e.g., Cohen, 1998; Cohen et al., 1993), in multiple schedules with extremely different reinforcer rates (McLean et al., 2012), or in the face of different response-reinforcer contingencies (e.g., K. A. Lattal, 1989; Nevin et al., 2001) calls into question the adequacy of the underlying analogy between Newton's (1686) laws of motion and operant behavior. With few exceptions (e.g., Craig & Shahan, 2016b), resistance to change has never been studied following exposure to dynamic environments like those used in the experiments described above, so little was known about resistance to change under conditions associated with changing reinforcer rates prior to this work.

Accordingly, inability to extend the *specific* momentum-based quantitative models of response persistence to data reported in Chapters 3 and 4 might indicate a lack of *precision* in these models when applied to novel treatment situations instead of a failure of the underlying metaphor. The section that follows will explore potential quantitative approaches to describe these findings in a more exact manner.

### **Modeling the Effects of Changing Stimulus-Reinforcer**

#### **Relations on Persistence**

The findings reported in Chapter 3 suggest that a quantitative method for incorporating stimulus-reinforcer relations that change over time into behavioral mass should weight recently experienced reinforcer rates such that they contribute more heavily to the term than reinforcer rates experienced in the distant past. Possibly the simplest quantitative approach to accomplishing this task would be a moving average, where  $r_w = (r_m + r_{m-1} + \dots + r_{m-n}) / n$ . Here,  $r_w$  is a weighted reinforcer-rate term,  $r_m$  is the

discriminative stimulus-reinforcer relation in the most recently experienced session, and  $n$  is the number of sessions that are considered by the moving average. Because  $n$  is defined by the experimenter, this approach (and any other method that relies on a moving window over which to calculate an average; e.g., Harley, 1981; Killeen, 1982, 1984; Wynne, Staddon, & Delius, 1996) is limited in that it arbitrarily defines which experiences within an organism's reinforcement history *should be* relevant to current behavior. To avoid this issue, it would be helpful to consider functions that incorporate larger subsets of an organism's historical experiences into behavioral mass and that place particular relevance on relatively recent experiences.

Exponential-decay functions often are used in experimental psychology to represent how the passage of time affects memorial and valuation processes (see, e.g., Killeen, 2015; White, 2001). A simple exponential-decay function may be expressed as:

$$w_x = e^{-kx}, \quad (2)$$

where the parameter  $k$  modifies the steepness of the function's decay and  $x$  represents time (measured in sessions for present purposes). This function could be used to reflect how behavioral mass changes when stimulus-reinforcer rate relations change across time by assuming that  $w_x$  is a weighting factor and  $x$  is the number of sessions that have passed since the to-be-weighted experience. Figure 5.1 shows exponential weighting functions with  $k = 0.25$ ,  $k = 0.5$ , and  $k = 1$  distributed across 10 sessions. Here, "10" on the  $x$ -axis is an experience that happened 10 sessions ago and "1" is the most recently experienced

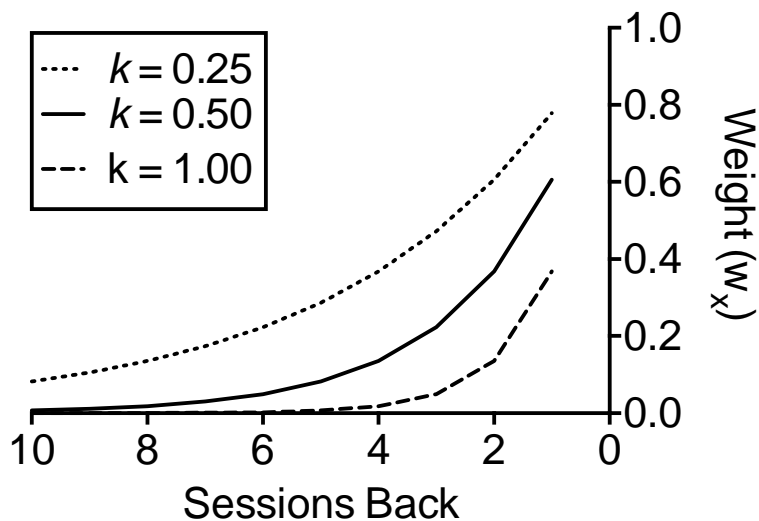


Figure 5.1. Potential exponential weighting functions generated using Equation 2 with  $k = 0.25$ ,  $k = 0.50$ , and  $k = 1.00$ .

session. These factors then could be multiplied by the reinforcer rates experienced in their corresponding sessions, and these products could be summed across the series to compute behavioral mass as follows:

$$r_w = \sum_{i=1}^n w_i r_i. \quad (3)$$

Though an exponential-weighting function distributes more weight to recently experienced reinforcer rates, this function has one important limitation. If, for example, 60 reinforcers per hr were delivered in each of the 10 sessions for which weights are displayed in Figure 5.1, the output from Equation 3 using the parameter values shown in the figure would differ from the veridical reinforcer rate (i.e.,  $r_w = 193.91$ ,  $91.87$  and  $34.92$  reinforcer per hr for  $k = 0.25$ ,  $0.50$ , and  $1.00$ , respectively). There are no practical or conceptual reasons to believe organisms systematically overestimate or underestimate

the rate of reinforcement delivered in the presence of discriminative stimuli. For the output of Equation 3 to match veridical reinforcer rates in this example, it is necessary that the weights derived from Equation 2 sum to unity—this condition may be met with  $k \approx 0.69$ . The specific limits to  $k$  required to produce weights that sum to 1, however, will depend on the number of sessions being weighted with larger values required for a larger number of sessions. The dependency between  $k$  and experiment duration potentially limits the utility of Equation 2 as a descriptor of how past experiences that are temporally separated influence behavioral mass.

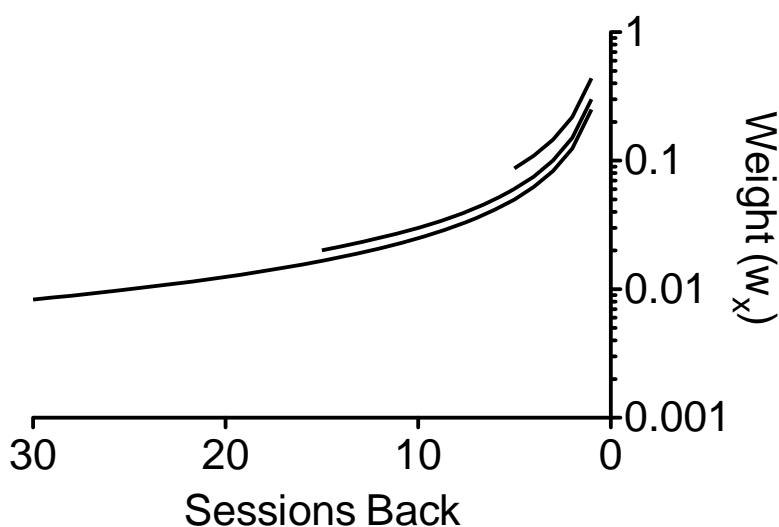
J. A. Devenport and Devenport (1993) introduced a model to describe the dynamics of foraging behavior in changing environments that avoids this issue. Their model, referred to as the Temporal Weighting Rule (TWR), is parameter-free and assumes only that recent experiences contribute more to an organism's estimate of the overall quality of a patch than do temporally distant experiences. According to the TWR, the weight assigned to a previous experience ( $w_x$ ) is determined by the relative recency with which that experience occurred as follows:

$$w_x = \frac{1/t_x}{\sum_{i=1}^n 1/t_i}. \quad (4)$$

Here, the recency of a given experience ( $1/t_x$ ) is 1 divided by the number of temporal intervals (e.g., minutes, hours, days; for present purposes, sessions) that have passed since that experience. This recency then is divided by the sum of the recencies associated with all previous experiences with a particular patch, such that all weights sum to 1 regardless of the number of time points being weighted. According to Equation 4,

weights decrease hyperbolically as patch experiences move more distantly into the past, and the amount of weight distributed to recent experiences depends on the length of an organism's history of reinforcement with a particular foraging situation. Figure 5.2 shows weighting functions derived from reinforcement histories 5-, 15-, and 30-sessions long to illustrate these properties. Using Equation 4 to calculate  $w_x$ ,  $r_w$  could be determined using Equation 3.

Equation 4 has been applied successfully to describe the choice behavior of rats (L. D. Devenport et al., 1997), horses (J. A. Devenport et al., 2005) dogs (J. A. Devenport & Devenport, 1993), squirrels, and chipmunks (L. D. Devenport & Devenport, 1994; Winterrowd & Devenport, 2004) in foraging situations where patch qualities were varied systematically across time. In the operant laboratory, Equation 4 also has been used to describe the choice behavior of pigeons responding under dynamic concurrent-schedule



*Figure 5.2.* Weighting functions generated by the Temporal Weighting Rule (Equation 5) for experiences spread across 5, 15, and 30 sessions.

procedures (see Mazur, 1995, 1996). Thus, it is reasonable to believe that the TWR captures some underlying behavioral process related to organisms' valuation of response alternatives over time.

Because the TWR is a parameter-free model, Shahan and Craig (2017) suggested this equation might not be sufficiently flexible to describe individual or species differences in how organisms weight previous experiences based on their relative recencies. These authors suggested a scaled version of Equation 4 could be used to describe these potential differences in weighting that appears as follows:

$$w_x = \frac{1/t_x^s}{\sum_{i=1}^n 1/t_i^s}, \quad (5)$$

where  $s$  determines the proportion of weight that is given to past experiences. When  $s$  is greater than 1, more weight is given to recent experiences and less to more temporally distant experiences. The opposite is true when  $s$  is less than 1. That is, weight is distributed more evenly across experiences being weighted, with weights being distributed equally to each previous experience when  $s = 0$ .

In sum, Equation 5 offers the following characteristics that suggest it would be an appropriate candidate function for representing how stimulus-reinforcer relations that are experienced across time contribute to behavioral mass. First, it asserts that all previously experienced conditions of reinforcement that are associated with a particular discriminative stimulus contribute to behavioral mass. Second, the weights determined by Equation 5 when applied to a series of any length sum to 1. The equation therefore avoids issues related to over- or underestimation of the reinforcer rate associated with a

discriminative stimulus that were present with Equation 2. Finally, unlike Equation 4, Equation 5 may account for individual or species differences in how strongly temporally distant experiences influence organisms' behavior.

Several different model fits were conducted to determine if including Equation 5 into Equation 1 increases the ability of the model to account for resistance-to-change data under conditions with changing stimulus-reinforcer relations during baseline. First, Equation 1 was fitted to log-transformed proportion-of-baseline response rates from the 20-, 5-, 3-, 2-, and 1-Day conditions from the experiment reported in Chapter 3 simultaneously. That is, values of  $c$ ,  $d$ , and  $b$  were shared between conditions. Further, the  $r$  and  $\Delta r$  terms were fixed at values of 120 and 30 reinforcers per hr, depending on the reinforcer rate most recently associated with a multiple-schedule component prior to extinction. This fit was conducted to provide a point of comparison for the remaining model fits that incorporate Equation 5 and will be referred to hereafter as the "Standard" model.

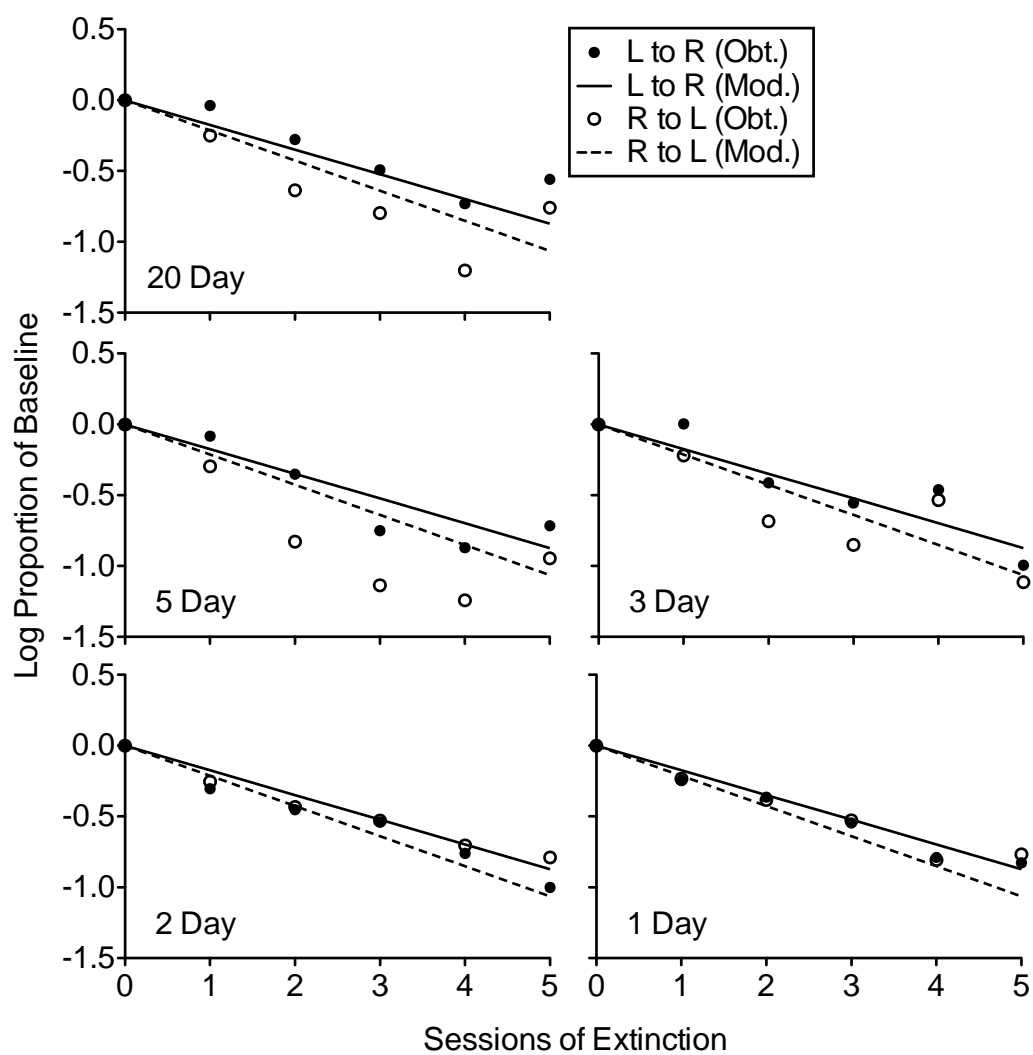
Whether or not behavioral mass changes during extinction of operant behavior remains equivocal based on the results from the experiment reported in Chapter 4. Thus, Equation 5 was applied in two ways to describe these data. The first application operated under the assumption that behavioral mass *does not change* during extinction— Equation 5 (with  $s$  free to vary here and below) was used to determine  $r_w$  for both multiple-schedule components such that, during extinction, these terms remained the same. This approach will be referred to as the "Weighted-Baseline" model.

The second application was conducted under the assumption that behavioral mass *does*



*change* during extinction. Experiences continued to be weighted during extinction, meaning that zero-rate reinforcement contributed to  $r_w$  in both multiple-schedule components as extinction progressed. Thus,  $r_w$  decreased during extinction. As reviewed previously, Equation 1 currently describes decreases in behavior during extinction by assuming that disruptive factors grow with time in extinction,  $t$ . If the behavioral-mass term in the denominator of the equation decreases, these two assumption might be redundant. Thus, in the case of the second application, fits were conducted with and without  $t$  in the numerator of the equation (referred to hereafter as the “Weighted-Extinction [ $t$ ]” and “Weighted-Extinction [no  $t$ ]” models, respectively). Because  $r_w$  could be taken to represents organisms’ estimates of expected reinforcer rates within a discriminative context,  $r_w$  terms also were incorporated into generalization decrement (i.e.,  $d\Delta r$  in the numerator of Equation 1) such that  $\Delta r_w$  replaced  $\Delta r$  in both schedule components for fits of the Weighted Baseline, Weighted-Extinction ( $t$ ), and Weighted-Extinction (no  $t$ ) models. Results from these model fits may be found in Figures 5.3 through 5.6 in the following order: standard, weighted baseline, weighted extinction ( $t$ ), and weighted extinction (no  $t$ ). Parameter estimates derived from these fits may be found in Table 5.2.

The Standard model provided a relatively poor description of these data ( $R^2 = .77$ ; see Figure 5.3). As one would expect, because the same  $r$  and  $\Delta r$  values were used in each condition, model predictions were identical across conditions. The Weighted-Baseline model accounted for a slightly larger proportion of variance in obtained data than did fits of the Standard model (i.e.,  $R^2 = .79$ ). This model predicted decreasing



*Figure 5.3.* Fits of the standard model (Equation 1) of extinction to data reported in Chapter 3.

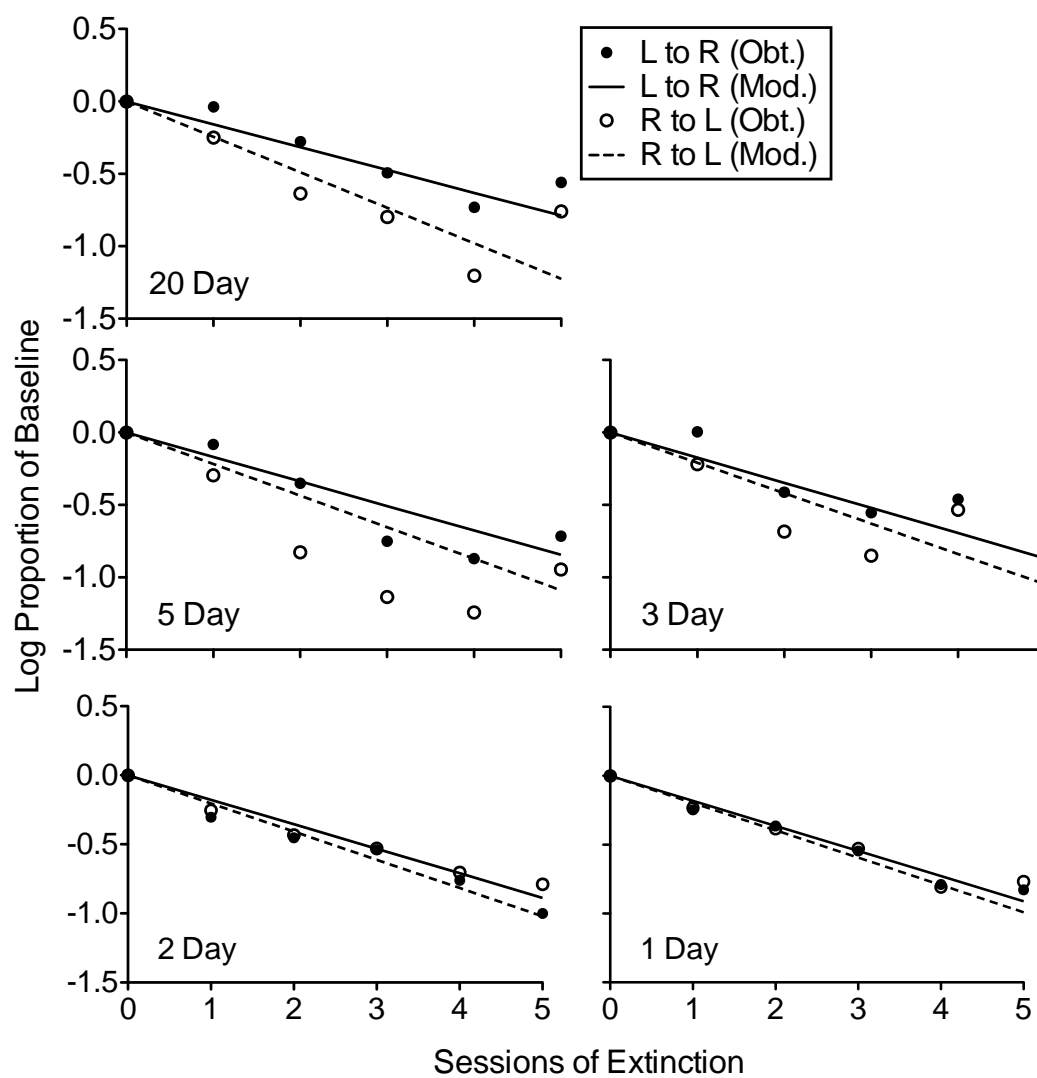


Figure 5.4. Fits of the weighted-baseline model (Equation 1 with  $r_w$ , where this term did not change during extinction) to data reported in Chapter 3.

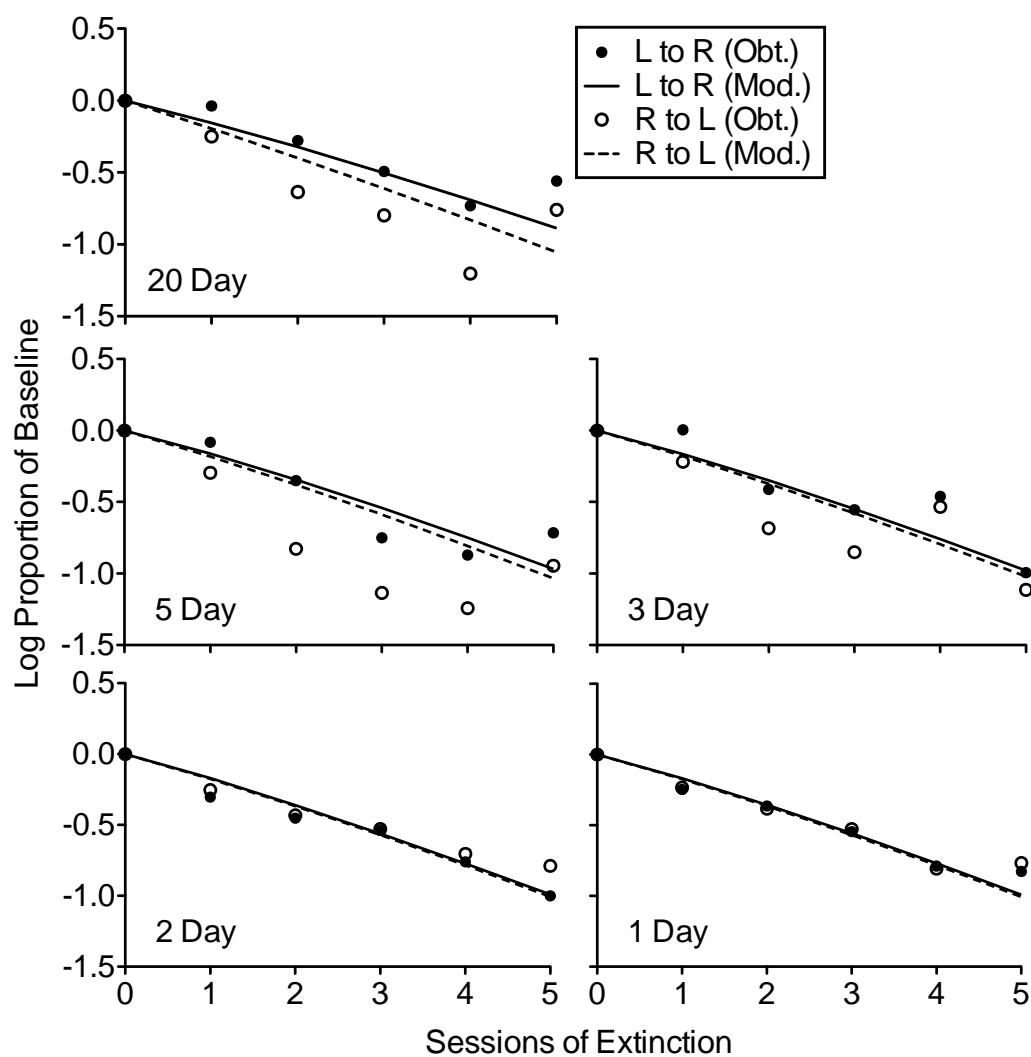
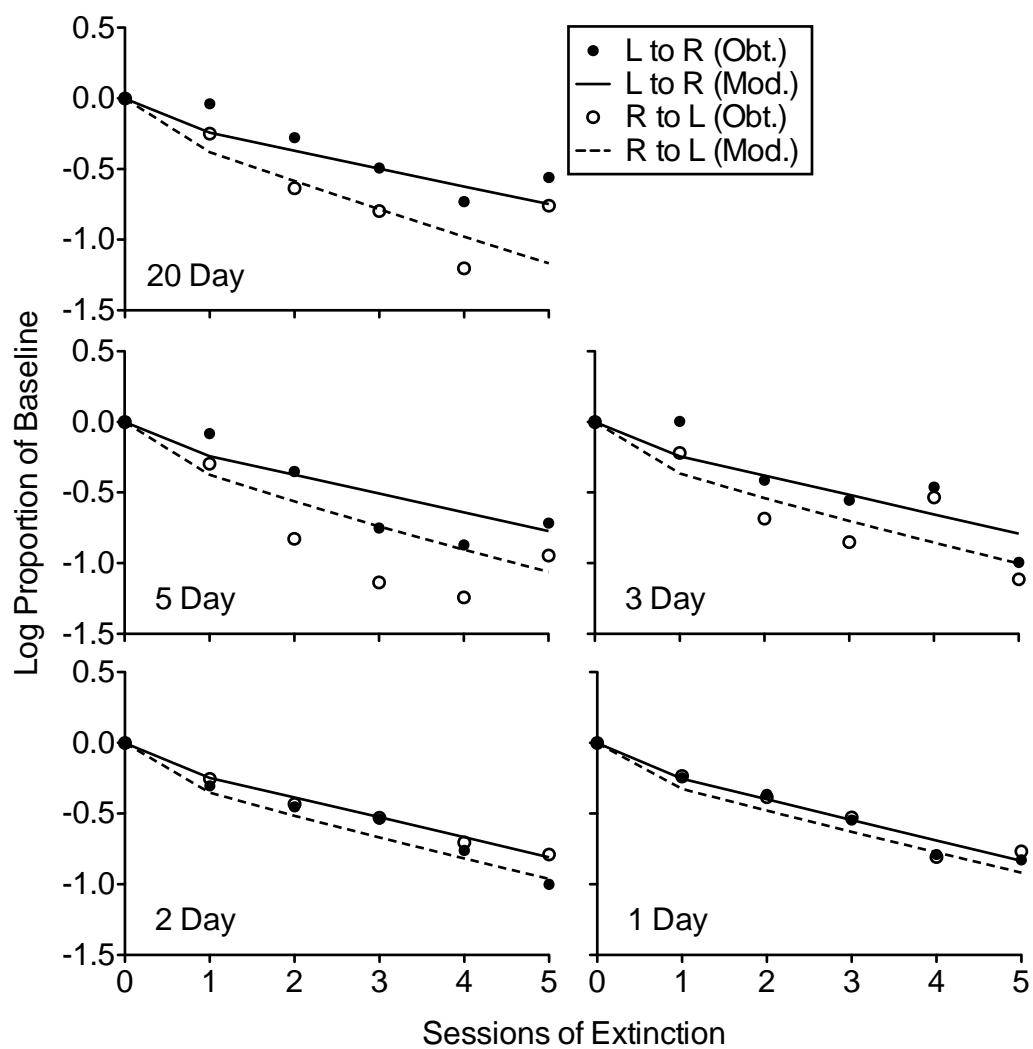


Figure 5.5. Fits of the weighted-extinction ( $t$ ) model (Equation 1 with  $r_w$ , where this term changed during extinction, and  $t$  included in the numerator) to data reported in Chapter 3.



*Figure 5.6.* Fits of the weighted-extinction (no  $t$ ) model (Equation 1 with  $r_w$ , where this term changed during extinction, and  $t$  omitted from the numerator) to data reported in Chapter 3.

Table 5.2

*Parameter Estimates,  $R^2$ , and  $AIC_c$  Values from Fits of Four Models to Data Reported in Chapter 3*

Model	Parameter estimates				$R^2$	$AIC_c$
	$c$	$d$	$b$	$s$		
Standard	0.50	0.001	0.27	-	.77	-263.05
Weighted baseline	3.41	0.000	0.67	0.76	.79	-267.82
Weighted extinction ( $t$ )	0.88	0.000	0.40	0.78	.75	-255.40
Weighted extinction (no $t$ )	0.53	0.001	0.33	3.74	.82	-277.55

*Note.* Values of  $c$ ,  $b$ , and  $s$  are rounded to the nearest hundredth of a whole number. Values of  $d$  are rounded to the nearest thousandth.  $AIC_c$  = Akaike information criterion with correction for small sample sizes.

relative resistance to extinction as the frequency of stimulus-reinforcer rate alternations increased (see Figure 5.4). This was true because, as the frequency with which these relations alternated increased,  $r_w$  became more similar between multiple-schedule components. A similar pattern was obtained from the fit of the Weighted-Extinction ( $t$ ) model (see Figure 5.5). That is, predicted relative resistance to extinction tended to decrease as stimulus-reinforcer rate relations alternated more frequently across conditions. It is noteworthy, however, that this model predicted relatively modest differences in resistance to extinction between components in every condition, even though persistence differed substantially between components in the 20-, 5-, and 3-Day conditions. In addition, this model accounted for the lowest proportion of variance in the data of any of the four fitted models (i.e.,  $R^2 = .75$ ). Finally, the Weighted-Extinction (no  $t$ ) model predicted diminished differences in relative resistance to extinction across conditions as in the previous two model fits, and the size of the predicted difference in

persistence between components was roughly proportional to obtained differences in persistence between conditions (see Figure 5.6). Of the present model fits, those of the Weighted-Extinction (no  $t$ ) model accounted for the largest proportion of variance in obtained extinction data ( $R^2 = .82$ ).

Because the standard model has one fewer parameter ( $n = 3$ ) than the other models tested here ( $n = 4$  each), comparisons between models based on  $R^2$  are not entirely appropriate. Accordingly, Akaike information criteria with corrections for small samples ( $AIC_c$ ; see Hu, 2007) were applied to each model fit to determine the relative quality of these fits by weighing the goodness of each individual fit against the corresponding model's complexity. Smaller values of  $AIC_c$  indicate higher quality models, with differences between values greater than 6 indicating strong support for the model with the smaller value and differences greater than 10 indicating almost no support for the model with the larger value (see Akaike, 1973; Bai, Cowie, & Podlesnik, 2017; Navakatikyan, Murrell, Bensemann, Davison, & Elliffe, 2013). Values of  $AIC_c$  may be found in Table 5.2. According to this method of model comparison, the model ranking (from highest to lowest quality) was: weighted extinction (no  $t$ ), weighted baseline, standard, and weighted extinction ( $t$ ). Further,  $AIC_c$  associated with the weighted-extinction (no  $t$ ) model was at least 10 units smaller than for any other model fit except for the weighted-baseline model ( $\Delta AIC_c = 9.73$ ), providing strong support for superior capability of the weighted-extinction (no  $t$ ) model to account for the present data despite its complexity.

Based on the model fits shown in Figures 5.3 through 5.6, and on values of  $AIC_c$  derived from these fits, it is clear that the behavioral-momentum based model of

extinction as it currently stands (i.e., the Standard model) is not adequate to describe effects of changing stimulus-reinforcer rate relations on response persistence.

Incorporating a temporal-weighting based approach to calculating behavioral mass into Nevin and Grace's (2000) augmented model of extinction provides one promising method for extending the behavioral-momentum metaphor to understand these effects. According to the present model fits, two methods for incorporating Equation 5 into Equation 1 are particularly promising. Weighting reinforcer rates experienced across baseline to determine a behavioral-mass term that remains the same during extinction (i.e., the Weighted-Baseline model) accounted well for the ordinal differences in persistence between components and across conditions. Second, distributing weight to experiences with zero-rate reinforcement during extinction also produced a reasonable description of the present data, but only when the  $t$  parameter was omitted from the numerator of Equation 1 (i.e., the weighted-extinction [no  $t$ ] model).

The findings reported in Chapter 4 suggest that learning factors associated with reductions in behavior during extinction do not necessarily operate in a manner that is context dependent. Put another way, extinction learning that occurs in one context appears to generalize to other correlated contexts. Though the temporal-weighting approach offered above described well the effects of within-component variations in reinforcer rates on resistance to extinction, it is unclear how this approach could be extended to account for effects of the *interaction* between reinforcer rates in different schedule components on resistance to extinction. Further, at present it is unclear whether generalization of extinction between alternative and target multiple-schedule components



resulted from increased disruptive factors or decreased response-strengthening factors. Thus, a temporal-weighting approach to modeling data from the experiment reported in Chapter 4 will not be pursued here. Instead, two potential models of extinction generalization that are based on the pre-existing quantitative architecture of momentum theory will be developed below.

First, to provide a point of comparison for potential model extensions, Equation 1 was fitted to log-transformed proportion-of-baseline response rates from the Control-1, High-Rate, and Extinction conditions of this experiment simultaneously. In this fit,  $c$ ,  $d$ , and  $b$  were allowed to vary, and  $r$  and  $\Delta r$  were fixed at 60 reinforcers per hr (i.e., the rate of reinforcement delivered in the target-component stimulus situation during baseline in Chapter 4). Model predictions plotted with obtained mean log proportion-of-baseline response rates from each condition are shown in the top panel of Figure 5.7. Estimates of  $c$ ,  $d$ , and  $b$  were 1.01, .001, and 0.49, respectively, and Equation 1 accounted for approximately 86% of the variance in extinction data. This equation, however, predicted identical extinction functions in each condition.

The first approach to modeling these data explored here assumed that previous exposure to extinction in the presence of stimuli correlated with the alternative multiple-schedule component subsequently affected behavioral mass of target-component key pecking. More specifically, it is possible that exposure to extinction in the alternative component reduced sensitivity of pigeons' key pecking to target-component reinforcer rates that were experienced during baseline (i.e.,  $b$  in the denominator of Equation 1) – smaller values of  $b$  would result in less behavioral mass and thus and less resistance to

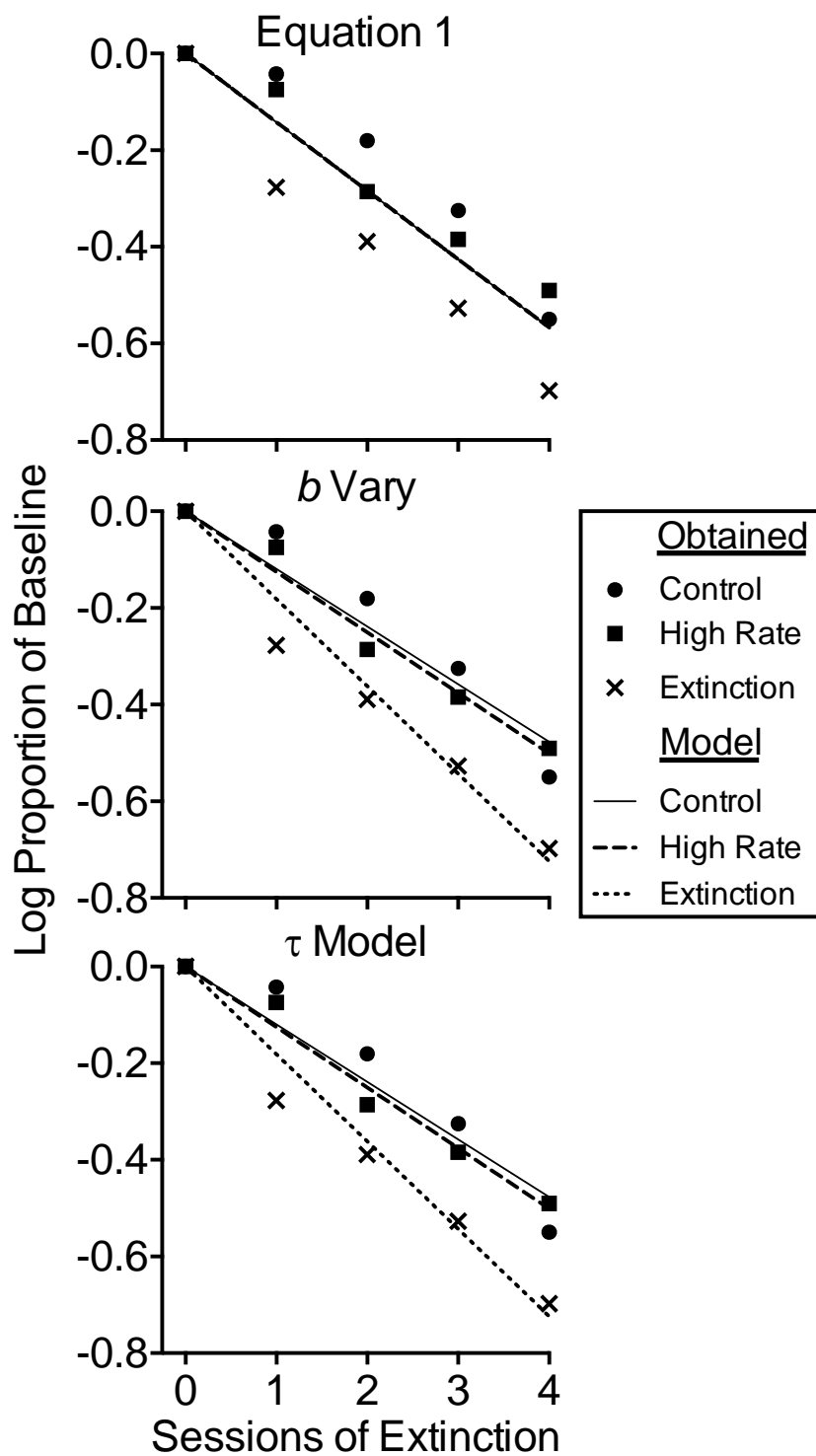


Figure 5.7. Fits of Equation 1 (top panel), Equation 1 with separate  $b$  parameters for each condition (center panel), and Equation 6 with separate  $\tau$  parameters for each condition (bottom panel) to target-component extinction data reported in Chapter 4.

extinction. To determine whether variation in  $b$  could account for differences in target-component resistance to extinction between conditions of the experiment reported in Chapter 4, Equation 1 was fitted to extinction data across conditions of this experiment simultaneously. Because fitted estimates of  $c$ ,  $d$ , and  $b$  deviated only slightly from the values that these parameters typically assume (i.e.,  $c = 1$ ,  $d = 0.001$ , and  $b = 0.5$ ; see Craig & Shahan, 2016b; Nevin & Grace, 2000) for the initial fit of Equation 1, the  $c$  and  $d$  parameters were fixed at these typical values for the present fit. Further,  $r$  and  $\Delta r$  assumed values of 60 reinforcers per hr, and the  $b$  parameter was allowed to vary between conditions.

Model predictions, plotted along with log proportion-of-baseline response rates, are shown in the middle panel of Figure 5.7. Estimates of  $b$  for the Control, High-Rate, and Extinction conditions were 0.53, 0.52, and 0.43, respectively, indicating comparable sensitivity of pigeons' key pecking to baseline reinforcer rates in the Control and High-Rate conditions with lower sensitivity in the Extinction condition. Allowing  $b$  to vary between conditions while holding all other parameters in the model constant accounted for approximately 96% of the variance in extinction performance between conditions. Importantly, affording variability in sensitivity to baseline reinforcer rates between conditions allowed Equation 1 to accurately predicted lower resistance to extinction of target-component key pecking in the Extinction condition than in the other conditions.

Some evidence from the choice literature provides support for this method for characterizing differential resistance to extinction of target-component key pecking across conditions of this experiment. For example, Davison and Jones (1995)

demonstrated that pigeons' behavior in concurrent schedules tends to be allocated between response alternatives in a manner that is roughly proportional to the reinforcer rates obtained from those alternatives when intermediate reinforcer-rate ratios (e.g., less than 10:1 or greater than 1:10) are arranged. Under more extreme reinforcer-rate ratios, however, more behavior tends to be allocated to alternatives associated with low-rate reinforcement than anticipated by the generalized matching law (see Baum, 1974). That is, as the rate of reinforcement delivered by one alternative decreases to near zero, pigeons' behavior becomes less sensitive to relative reinforcer rates (see also Davison & Jones, 1998, who demonstrated similar effects under concurrent VI extinction schedules). Thus, to the extent that sensitivity to reinforcer rates in choice situations is similar to sensitivity to reinforcer rates in multiple-schedule components, it is reasonable to assert that exposure to extinction in an alternative multiple-schedule component might decrease sensitivity of behavior in a target component to baseline reinforcer rates.

Another straightforward approach to modeling generalization of extinction between the alternative and target components in this experiment is to assume that, when extinction initially was introduced in the alternative-component stimulus situation during the Phase-2 treatment, time in extinction began to accumulate in the target component. Put another way, generalization of extinction might have resulted from increased disruption of target-component key pecking despite lack of experience with extinction in that component. Quantitatively, generalization of extinction in this manner may be expressed by multiplying the  $t$  parameter in Equation 1 by a scaling factor,  $\tau$ , as follows (see Podlesnik & Shahan, 2010, for a similar approach to modeling contextual control of

operant extinction):

$$\log\left(\frac{B_t}{B_o}\right) = \frac{-(\tau t)(c + d\Delta r)}{r^b} . \quad (6)$$

When  $\tau = 1$ , Equation 6 is the same as Equation 1. Larger values of  $\tau$  indicate greater disruption by extinction due to generalization of previous extinction experiences to the present stimulus situation. Equation 6 was fitted to obtained target-component extinction data from Chapter 4 to determine whether the model provided a satisfactory description of between-condition differences in resistance to extinction of target-component key pecking. For these fits,  $c$ ,  $d$ , and  $b$  were held constant at values of 1, 0.001, and 0.5, respectively, and values of  $\tau$  were allowed to vary between conditions.

Predictions of Equation 6 plotted along with obtained log proportion-of-baseline response rates from each condition of the experiment may be found in the bottom panel of Figure 5.7. Overall, Equation 6 accounted for approximately 96% of the variance in extinction functions between conditions. For the Control, High-Rate, and Extinction conditions, respectively, estimates of  $\tau$  were 0.87, 0.91, and 1.32. These estimates were roughly equal and less than 1 for the Control and High-Rate conditions, indicating diminished suppressive effects of time on extinction performance. A clear conceptual explanation for these estimates is not immediately apparent. Indeed, because no alternative-component reinforcer-rate change occurred in the Control condition, and extinction performance was statistically the same between the Control and High-Rate conditions, one would expect  $\tau$  to approximately equal 1. It is possible that decreases in  $\tau$  occurred for these conditions because all other parameters within the model were fixed for demonstrative purposes. Additional flexibility of other model parameters to vary

could result in equally accurate fits with  $\tau = 1$ . Most importantly, however, the passage of time contributed roughly 43% more to disruption of target-component key pecking in the Extinction condition than in the other conditions. As a result, the model accurately described between-condition differences in resistance to extinction.

Because each fitted model shown in Figure 5.7 included three free parameters (i.e.,  $c$ ,  $d$ , and  $b$  in the top panel; three  $b$  parameters in the center panel; and three  $\tau$  parameters in the bottom panel), relative goodness of fit may be judged based on  $R^2$ . The model fits shown in the center and bottom panels of the figure accounted for a substantially larger proportion of variance than the fit shown in the top panel (i.e.,  $R^2 = .96$  vs.  $R^2 = .86$ ). Thus, Equation 6, and Equation 1 with variation in sensitivity to baseline reinforcer rates between conditions, most accurately described extinction data from Chapter 4. Moreover, the novel model applications explored here predicted identical extinction functions. These modeling efforts corroborate the conclusions drawn from the exploratory model fits included in Chapter 4. That is, principled changes in behavioral mass account equally well for the generalization-of-extinction effects observed in this experiment as changes in disruption. Relatively speaking, though, the present models come closer to identifying potential *mechanisms* of behavior change in this experiment.

To summarize, the modeling approaches detailed above offer potential behavioral-momentum based methods for describing the effects of reinforcer rates that change over time on persistence of operant behavior. Weighting previously experienced stimulus-reinforcer relations in such a way that recent experiences more heavily influenced behavioral mass than temporally distant experiences accounted well for the

findings reported in Chapter 3. Further, it was possible to describe generalization of extinction between multiple-schedule components observed in Chapter 4 by assuming that previous exposure to extinction either decreased pigeons' sensitivity to baseline reinforcer rates or increased the suppressive effects of time on extinction performance. These models extend momentum theory by highlighting potential behavioral mechanisms capable of describing resistance to change in dynamic environments.

### **Practical Applications**

In addition to any theoretical implications, results from the studies described in Chapters 3 and 4 might also have direct applications outside of the laboratory. As described in the Discussion section of Chapter 3, persistence of human behavior might depend only on recently experienced stimulus-reinforcer relations. Thus, acutely changing the rate of reinforcement for a behavior likely to face disruption in the future could strongly influence the extent to which behavior persists. This insight could introduce a novel technology for manipulating response persistence to achieve therapeutic outcomes. For example, briefly increasing reinforcer rates could increase the likelihood that desirable behavior would persist if disrupted. Similarly, briefly decreasing the frequency of reinforcer deliveries for a problematic behavior prior to treatment could decrease the propensity of that behavior to persist in the face of treatment contingencies.

Tentative support for this conjecture may be found in the literature examining resurgence of extinguished behavior following loss of alternative reinforcement. Delivering alternative reinforcers during extinction of target behavior has been shown to

increase the likelihood that behavior will relapse once these reinforcers ultimately are suspended (e.g., Bouton & Trask, 2016; Craig & Shahan, 2016a; Leitenberg et al., 1975). The extensions of behavioral momentum theory to relapse (as described in Chapter 2; see also Nevin & Shahan, 2011; Podlesnik & Shahan, 2009, 2010; Shahan & Sweeney, 2011) suggests that alternative reinforcers increase resurgence by adding to the mass of target behavior because they are delivered in the presence of stimuli previously associated with reinforcement of that behavior. Gradually reducing the rate of alternative reinforcement during target-response extinction results in less resurgence when alternative reinforcement subsequently is discontinued than consistent delivery of high-rate alternative reinforcement before relapse testing (Schepers & Bouton, 2015; Sweeney & Shahan, 2013; Winterbauer & Bouton, 2012). From the current perspective, “thinning” alternative-reinforcer rates in this manner might reduce resurgence by weakening the Pavlovian stimulus-reinforcer relation that contributes to the behavioral mass of target behavior.

Results reported in Chapter 4 provided evidence that extinction of behavior in one stimulus situation can hasten subsequent elimination of behavior during extinction in other correlated stimulus situations. It is not difficult to imagine practical situations in which problematic human behavior might occur in several correlated stimulus contexts. For example, a participant might engage in academically disruptive behavior in different classrooms, aggress towards others in his or her home or at school, etc. It is possible that reducing problem behavior by means of extinction in one of these contexts could produce therapeutically relevant reductions in problem behavior in other contexts if extinction



subsequently was introduced.

An important limitation to this potential application, however, is that extinction of problem behavior alone often is associated with undesirable and potentially dangerous collateral outcomes. For example, extinction might result in an initial escalation in the intensity or frequency of problem behavior or engagement in other topographies of problem behavior that are members of the same functional response class (see Lerman et al., 1999; Lieving, Hagopian, Long, & O'Connor, 2004; Petscher & Bailey, 2008). For these reasons, alternative-reinforcement based treatments often are used instead of or in conjunction with extinction to eliminate problem behavior in clinical settings. Thus, the practical utility of this finding in terms of treatment for problem behavior in clinical populations is debatable.

A final potential implication of the present work for practice is related to the inherent translational utility of the quantitative framework for understanding resistance to change offered by behavioral momentum theory. These models have been used to inform clinical applications and to identify relevant treatment factors that affect persistence of human behavior during and after behavioral interventions (e.g., Fuhrman et al., 2016; Mace et al., 2010; Nevin et al., 2016; Nevin & Shahan, 2011; Pritchard et al., 2014; Sweeney et al., 2014; Wacker et al., 2011). Unlike in controlled laboratory settings, however, reinforcer rates for humans' operant behavior are likely to vary across time to considerable degrees in naturalistic settings. The extensions of the momentum-based models described above might provide insights into the way such dynamic reinforcement histories ultimately affect response persistence. Inasmuch, these models could contribute

more precise tools for predicting and manipulating persistence to produce therapeutically relevant behavior change.

### **Future Directions**

The major conclusion from the experiment presented in Chapter 3 was that behavioral mass changes in the face of changing stimulus-reinforcer relations. This argument followed from differences in relative resistance to extinction produced by conditions where discriminative stimulus-reinforcer rate relations within the components of a multiple schedule changed after different number of sessions during baseline. As described in Chapters 1 and 2, behavioral mass is thought to promote persistence of behavior in the face of disruption, in general, and not only in the face of extinction contingencies. One important shortcoming of this work, then, is that effects of changing stimulus-reinforcer relations on resistance to change were only examined in extinction. As a result, at present it is not clear whether reinforcer rates that change over time affect resistance to change in a manner that is general across types of disruptors.

It would be important to establish whether or not changing stimulus-reinforcer relations have similar effects on resistance to change in the face of other commonly investigated behavioral disruptors (e.g., reinforcer satiation or presenting free reinforcers during inter-component intervals). If, on the one hand, the effects of stimulus-reinforcer relations that change over time on response persistence prove to be general across disruptors, stronger support for the notion that behavioral mass changes in the face of changing stimulus-reinforcer relations would be provided. On the other hand, failure to

systematically replicate these results with other disruptors would suggest that other behavioral mechanisms that are specific to extinction performance contributed to the results reported in Chapter 3.

Another potential area for empirical work might focus on determining relevant environmental factors that affect the relation between stimulus-reinforcer contingencies that change over time and response persistence. For example, if reinforcer-rate changes are relatively large (i.e., greater than the four-fold differences used Chapter 3), behavioral mass and resistance to change might be affected by these changes more quickly. Likewise, if reinforcer-rate changes are relatively small, mass might take a longer period of time to adjust following reinforcer-rate changes. These possibilities seem reasonable given that changes in reinforcer rates that are relatively large tend to affect behavior more immediately than changes in reinforcer rates that are relatively small (see Gallistel, 2012; Gallistel et al., 2001). Researchers might also aim to determine how changes to dimensions of reinforcement other than rate that have been shown to affect resistance to change (e.g., magnitude, delay, response-reinforcer contingency; see Craig, Browning, Nall, Marshall, & Shahan, 2017; Nevin, 1974; Nevin et al., 2001; Podlesnik & Shahan, 2008) affect persistence over time. Such work would help to determine the overall generality of these findings.

The experiment described in Chapter 4 also leaves open several areas for future research. First among these is more thorough analysis of the possible temporal dynamics of response strength during extinction. As reviewed above, this experiment failed to provide support for or to disconfirm the notion that behavioral mass decreases during

extinction. An alternative method that might offer first step towards answering this question was described in the Discussion section of this chapter. Briefly, the reinforcer rate associated with the alternative component of a multiple schedule could be manipulated during baseline instead of in a separate treatment condition prior to extinction testing. This type of procedure might allow for more specific interpretation of obtained target-component persistence in terms of the literature investigating behavioral-contrast effects on resistance to change (see Grace et al., 2012, 2003; Nevin, 1992b; Nevin & Grace, 1999). Regardless of the specific results generated from this procedure, they would be helpful in delimiting the potential behavioral processes responsible for the findings reported in Chapter 4.

Further, it is unknown at present if experience with extinction contingencies in the presence of stimuli associated with an alternative multiple-schedule component would affect persistence of target-component responding in the face of other forms of disruption. Conducting similar procedures with different disruptors would not only help to determine the generality of the effects reported in Chapter 4 but might also inform efforts to incorporate generalization-of-extinction effects into the behavioral-momentum based quantitative framework. For example, it was suggested earlier in the General Discussion that such generalization effects might occur because the disruptive impact of time ( $t$  in Equation 1) on target-component extinction performance becomes inflated. If exposure to extinction in an alternative stimulus situation subsequently impacted resistance to, say, prefeeding in a target stimulus situation, this approach to quantitatively modeling generalization of extinction would seem inappropriate: As reviewed in Chapter

1 (see also Nevin & Grace, 2000; Nevin & Shahan, 2011), the passage of time is thought not to influence resistance to change in the face of disruptors other than extinction.

Finally, translational work will be critical to determining the extent to which the findings reported in Chapters 3 and 4 may be generalized to human participants. Such work would also help to determine the clinical merit of the practical applications of these findings detailed in the previous section. It currently is unclear if the timeframe over which stimulus-reinforcer relations that change over time affect persistence is general across species, but relevant cross-species differences suggest this is likely not the case. For example, humans' temporal horizons (i.e., the amount of time between a behaviorally relevant event and the present over which that event may influence current behavior; see Bickel, Yi, Kowal, & Gatchalian, 2008; Jones, Landers, Yi, & Bickel, 2009) for inter-temporal decision making tend to be much longer than those of non-human animals (see Bickel & Marsch, 2000). Further, organism's perception of time and use of temporal information have been linked to body size, metabolic rate, and other factors that are notably dissimilar between humans and laboratory animals (see Healy, McNally, Ruxton, Cooper, & Jackson, 2013). Thus, a certain degree of caution may be warranted if clinicians or applied researchers aim to *directly* translate the specific procedures from the present experiments into practice. Though it is reasonable to believe that the same factors govern resistance to change of human and non-human animal behavior, it is also reasonable to expect that the specific time course over which stimulus-reinforcer relations come to affect resistance to change of human behavior could differ substantially from the time courses determined in the present series of experiments with pigeon subjects.

## Conclusions

The empirical work presented in this dissertation focused on extending the study of resistance to change to situations with changing reinforcer rates. Chapter 3 described an experiment that aimed to determine how stimulus-reinforcer relations that change across time prior to disruption affect resistance to change, and the study reported in Chapter 4 examined the influence of changing stimulus-reinforcer relations in one context on persistence in another correlated context. These experiments provided novel insights into the temporal dynamics of resistance to change. They also challenged the current understanding of resistance-to-change mechanisms offered by behavioral momentum theory. As it currently is understood, momentum theory could not account for the findings in either of these experiments. These interpretive complications might owe in part to the simplicity of its analogy between operant behavior and Newtonian mechanics.

Behavioral momentum theory is based on Newton's (1686) second law of motion:

$$\Delta v = \frac{-f}{m} . \quad (7)$$

That is, when acted on by an outside force that opposes motion ( $f$ ), the change in velocity ( $\Delta v$ ) of a moving object is directly proportional to the magnitude of the force applied and inversely related to the physical mass ( $m$ ) of the object. In this simple form, Equation 7 describes changes in objects' velocities under a restricted set of circumstances. For example, Equation 7 is not well suited for describing dynamic changes in velocity for objects that become more or less massive with time (e.g., Lichtenegger, 1984; Plastino & Muzzio, 1992). Under these "variable-mass systems," it is necessary to mathematically

characterize changes in physical mass over time to accurately determine point estimates of an object's momentum. Further, the magnitudes of forces that act on objects are rarely stable in the real world, requiring estimation of net forces over discrete units of time to infer momentum (see Semat & Katz, 1958).

The augmented model of extinction (i.e., Equation 1) and the other simple behavioral-momentum models reviewed in Chapter 1 appear to be similarly constrained to description of resistance to change under specific circumstances. Put another way, the experiments described in this dissertation demonstrate that behavioral equivalents of variable-mass and variable-force systems might exist in the context of resistance to change. In the same way that Equation 7 alone is not adequate to describe more complex mechanical situations in the physical world, the momentum-based equations of resistance to change might not be adequate to describe more complex determiners of resistance to change in the behavioral world. The model-building efforts described above represent an initial attempt to extend the momentum-based quantitative framework to these situations more fully.

In reference to statistical modeling of real-world phenomena, George Box (1979) famously observed that, "... all models are wrong but some are useful" (pp. 202). It is difficult to argue that behavioral momentum theory is anything less than useful. It has provided the basis for mathematical models of several behavioral outcomes (see Nevin, Davison, & Shahan, 2005; Nevin & Grace, 2000; Nevin & Shahan, 2011; Odum et al., 2005; Podlesnik & Shahan, 2010; Shahan & Sweeney, 2011). Scores of empirical studies have been conducted to test the predictions of momentum theory in the contexts of basic,

translational, and applied research. Further, as described previously, it has informed translational efforts aimed at increasing the immediate and long-term efficacy of behavioral interventions in human populations. However imprecise it might be under specific circumstances, then, behavioral momentum theory has been (and will likely continue to be) both conceptually and empirically generative.

It is well known today, however, that classical mechanics offers only an approximation to the physical laws of nature. Applications of classical mechanics are restricted to the macroscopic world, and quantum mechanics are used to describe physical systems on a microscopic level (for discussion, see Acedo, 2014; Sebens, 2015). Quantum mechanics, in turn, may be used to approximately describe many phenomena in the macroscopic world usually characterized by classical mechanics (though see, e.g., Allori & Zanghi, 2009, for discussion of the uncertain nature of classical limits in quantum mechanics). To the extent that governance of operant behavior may be related to governance of the physical world by analogy, it is possible that behavioral momentum theory at present offers only an approximate understanding of the behavioral processes that cause behavior to persist. Indeed, the challenges to behavioral momentum theory described in Chapter 2 call into question the generality of the *fundamental* mechanisms of response persistence offered by the theory (for similar discussion, see also Craig & Shahan, 2016a; Nevin et al., 2017; Shahan & Craig, 2017). Thus, pursuit of alternative conceptual analyses of persistence may be warranted, and the litmus test for any such analysis would be description of the well-documented relation between discriminative stimulus-reinforcer contingencies and resistance to change in multiple schedules.



In pursuing that goal, however, abandoning the insights into response persistence offered by behavioral momentum theory entirely might be a case of throwing the baby out with the bathwater. Despite its shortcomings, classical mechanics played a critical role in establishing our current understanding of how the physical world works. Only by identifying shortcomings of these basic tenets were researchers and theoreticians able to develop more general physical principles. Likewise, behavioral momentum theory has played a critical role in leading researchers to discover variables that affect persistence of operant behavior. Identifying higher-order dependent variables that affect response persistence, like those uncovered in the present experiments, could continue to shape our understanding of resistance-to-change mechanisms and operant behavior more generally.

## REFERENCES

- Acedo, L. (2014). Quantum mechanics of the solar system. *Latin-American Journal of Physics Education*, 8, 255-262.
- Ahearn, W. H., Clark, K. M., Gardenier, N. C., Chung, B. I., & Dube, W. V. (2003). Persistence of stereotype behavior: Examining the effects of external reinforcers. *Journal of Applied Behavior Analysis*, 36, 439-448.
- Akaike, H. (1973). Information theory and an extinction of the maximum likelihood principle. In B. N. Petrov & F. Csaki (Eds.) *Second international symposium on information theory* (pp. 267-281). Budapest, Hungary: Akademiai Kiado.
- Allori, V., & Zanghì, N. (2009). On the classical limit of quantum mechanics. *Foundations of Physics*, 39, 20-32.
- Aló, R. M., Abreu-Rodrigues, J., Souza, A. S., & Cançado, C. R. X. (2015). Resistance to change of fixed-ratio and differential-reinforcement-of-low-rate schedule performances. *Mexican Journal of Behavior Analysis*, 41, 3-31.
- Andrezejewski, M. E., Terry-Cain, S., & Bersh, P. J. (2004). Acquisition of discriminated operant responding: The effects of brief reinforcement delays. *The Psychological Record*, 54, 603-620.
- Bai, J. Y. H., Cowie, S., & Podlesnik, C. A. (2017). Quantitative analyses of local-level resurgence. *Learning & Behavior*, 45, 76-88.
- Baron, A., & Perone, M. (1998). Experimental design and analysis in the laboratory study of human operant behavior. In K. A. Lattal & M. Perone (Eds.), *Handbook of research methods in human operant behavior* (pp. 45-91). New York, NY: Plenum.
- Baum, W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, 22, 231-242.
- Baum, W. M. (2010). Dynamics of choice: A tutorial. *Journal of the Experimental Analysis of Behavior*, 94, 161-174.
- Baum, W. M. (2012). Extinction as discrimination: The molar view. *Behavioural Processes*, 90, 101-110.
- Baum, W. M., & Davison, M. (2014). Choice with frequently changing food rates and food ratios. *Journal of the Experimental Analysis of Behavior*, 101, 246-274.

- Bell, M. C. (1999). Pavlovian contingencies and resistance to change in a multiple schedule. *Journal of the Experimental Analysis of Behavior*, 72, 81-96.
- Bickel, W. K., & Marsch, L. A. (2000). The tyranny of small decisions: Origins, outcomes and proposed solutions. In W. K. Bickel & R. E. Vuchinich (Eds.), *Reframing health behavior change with behavioral economics* (pp. 341-391). Mahwah, NJ: Erlbaum.
- Bickel, W. K., Yi, R., Kowal, B. P., & Gatchalian, K. M. (2008). Cigarette smokers discount past and future rewards symmetrically and more than controls: Is discounting a measure of impulsivity? *Drug and Alcohol Dependence*, 96, 256-262.
- Blackman, D. E. (1968). Response rate, reinforcement frequency, and conditioned suppression. *Journal of the Experimental Analysis of Behavior*, 11, 503-516.
- Blough, D. S. (1969). Generalization gradient shape and summation in steady-state tests. *Journal of the Experimental Analysis of Behavior*, 12, 91-104.
- Bouton, M. E., Todd, T. P., Vurbic, D., & Winterbauer, N. E. (2011). Renewal after the extinction of free operant behavior. *Learning & Behavior*, 39, 57-67.
- Bouton, M. E., & Trask, S. (2016). Role of the discriminative properties of the reinforcer in resurgence. *Learning & Behavior*, 44, 137-150.
- Box, G. E. P. (1979). Robustness in the strategy of scientific model building. In R. L. Launer & G. N. Wilkinson (Eds.), *Robustness in statistics* (pp. 201-236). New York, NY: Academic.
- Cohen, S. L. (1996). Behavioral momentum of typing behavior in college students. *Behavior Analysis and Therapy*, 1, 36-51.
- Cohen, S. L. (1998). Behavioral momentum: The effects of temporal separation of rates of reinforcement. *Journal of the Experimental Analysis of Behavior*, 69, 29-47.
- Cohen, S. L., Riley, D. S. & Weigle, P. A. (1993). Tests of behavior momentum in simple and multiple schedules with rats and pigeons. *Journal of the Experimental Analysis of Behavior*, 60, 255-291.
- Cooper, J. O., Heron, T. E., & Heward, W. L. (2007). Definition and characteristics of applied behavior analysis. In *Applied behavior analysis* (2<sup>nd</sup> ed., pp. 2-24). Upper Saddle River, N.J.: Pearson Prentice Hall.
- Craig, A. R., Browning, K. O., Nall, R. W., Marshall, C. M., & Shahan, T. A. (2017). Resurgence and alternative-reinforcer magnitude. *Journal of the Experimental Analysis of Behavior*, 107, 218-233.

- Craig, A. R., Cunningham, P. J., & Shahan, T. A. (2015). Behavioral momentum and accumulation of mass in multiple schedules. *Journal of the Experimental Analysis of Behavior, 103*, 437-449.
- Craig, A. R., Lattal, K. A., & Hall, E. G. (2014). Pausing as an operant: Choice and discriminated responding. *Journal of the Experimental Analysis of Behavior, 101*, 230-245.
- Craig, A. R., Nevin, J. A., & Odum, A. L. (2014). Behavioral momentum and resistance to change. In McSweeney, F. K., & Murphy, E. S. (Eds.), *The Wiley-Blackwell handbook of operant and classical conditioning* (pp. 249-274). Oxford, UK: Wiley-Blackwell.
- Craig, A. R., & Shahan, T. A. (2016a). Behavioral momentum theory fails to account for the effects of reinforcement rate on resurgence. *Journal of the Experimental Analysis of Behavior, 105*, 375-392.
- Craig, A. R., & Shahan, T. A. (2016b). Experience with dynamic reinforcement rates decreases resistance to extinction. *Journal of the Experimental Analysis of Behavior, 105*, 291-306.
- Davison, M., & Jones, B. M. (1995). A quantitative analysis of extreme choice. *Journal of the Experimental Analysis of Behavior, 64*, 147-162.
- Davison, M., & Jones, B. M. (1998). Performance on concurrent variable-interval extinction schedules. *Journal of the Experimental Analysis of Behavior, 69*, 49-57.
- Devenport, J. A., & Devenport, L. D. (1993). Time-dependent decisions in dogs (*Canis familiaris*). *Journal of Comparative Psychology, 107*, 169-173.
- Devenport, J. A., Patterson, M. R., & Devenport, L. D. (2005). Dynamic averaging and foraging decisions in horses (*Equus caballus*). *Journal of Comparative Psychology, 119*, 352-358.
- Devenport, L. D., & Devenport, J. A. (1994). Time-dependent averaging of foraging information in least chipmunks and golden-mantled ground squirrels. *Animal Behavior, 47*, 787-802.
- Devenport, L. D., Hill, T., Wilson, M., & Ogden, E. (1997). Tracking and averaging in variable environments: A transition rule. *Journal of Experimental Psychology: Animal Behavior Processes, 23*, 450-460.
- Doughty, A. H., Cirino, S., Mayfield, K. H., Da Silva, S. P., Okouchi, H., & Lattal, K. A. (2005). Effects of behavioral history on resistance to change. *The Psychological Record, 55*, 315-330.

- Ferster, C. B., & Skinner, B. F. (1957). *Schedules of reinforcement*. Englewood Cliffs, NJ: Prentice-Hall.
- Feynman, R. P. (1994). *The character of physical law*. New York, NY: Modern Library.
- Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, *5*, 529-530.
- Fuhrman, A. M., Fisher, W. W., & Greer, B. D. (2016). A preliminary investigation on improving functional communication training by mitigating resurgence of destructive behavior. *Journal of Applied Behavior Analysis*, *49*, 1-16.
- Gallistel, C. R. (2012). Extinction from a rationalist perspective. *Behavioural Processes*, *90*, 66-80.
- Gallistel, C. R., Mark, T. A., King, A. P., & Latham, P. E. (2001). The rat approximates an ideal detector of changes in rates of reward: Implications for the law of effect. *Journal of Experimental Psychology: Animal Behavioral Processes*, *27*, 354-372.
- Gibbon, J. (1981). The contingency problem in autoshaping. In C. M. Locurto, H. S. Terrace, & J. Gibbon (Eds.), *Autoshaping and conditioning theory* (pp. 285-308). San Diego, CA: Academic.
- Grace, R. C., Arantes, J., & Berg, M. E. (2012). Resistance to change varies inversely with reinforcement context. *Behavioural Processes*, *90*, 343-349.
- Grace, R. C., McLean, A. P., & Nevin, J. A. (2003). Reinforcement context and resistance to change. *Behavioural Processes*, *64*, 91-101.
- Grace, R. C., & Nevin, J. A. (1997). On the relation between preference and resistance to change. *Journal of the Experimental Analysis of Behavior*, *67*, 43-65.
- Grace, R. C., Schwendiman, J. W., & Nevin, J. A. (1998). Effects of unsignaled delay of reinforcement on preference and resistance to change. *Journal of the Experimental Analysis of Behavior*, *69*, 247-261.
- Grimes, J. A., & Shull, R. L. (2001). Response-independent milk delivery enhances persistence of pellet-reinforced lever pressing by rats. *Journal of the Experimental Analysis of Behavior*, *76*, 179-194.
- Hanson, H. M. (1957). Discrimination training effect on stimulus generalization gradient for spectrum stimuli. *Science*, *125*, 888-889.
- Hanson, H. M. (1959). Effects of discrimination training on stimulus generalization. *Journal of Experimental Psychology*, *58*, 321-334.

- Harley, C. B. (1981). Learning the evolutionary stable strategy. *Journal of Theoretical Biology*, *89*, 611-633.
- Harper, D. N. (1996). Response-independent food delivery and behavioral resistance to change. *Journal of the Experimental Analysis of Behavior*, *65*, 549-560.
- Healy, K., McNally, L., Ruxton, G. D., Cooper, N., & Jackson, A. L. (2013). Metabolic rate and body size are linked with perception of temporal information. *Animal Behaviour*, *86*, 685-696.
- Higgins, S. T., & Petry, N. M. (1999). Contingency management: Incentives for sobriety. *Alcohol Research & Health*, *23*, 122-127.
- Hu, S. (2007). Akaike information criterion. *Center for Research in Scientific Computation*.
- Igaki, T., & Sakagami, T. (2004). Resistance to change in goldfish. *Behavioural Processes*, *66*, 139-152.
- Jessel, J., & Ingvarsson, E. T. (2016). Recent advances in applied research on DRO procedures. *Journal of Applied Behavior Analysis*, *49*, 991-995.
- Jones, B. A., Landes, R. D., Yi, R., & Bickel, W. K. (2009). Temporal horizon: Modulation by smoking status and gender. *Drug and Alcohol Dependence*, *104* (Supplement 1), S87-S93.
- Katz, J. L., & Higgins, S. T. (2003). The validity of the reinstatement model of craving and relapse to drug use. *Psychopharmacologia*, *168*, 21-30.
- Killeen, P. R. (1982). Incentive theory: II. Models for choice. *Journal of the Experimental Analysis of Behavior*, *38*, 217-232.
- Killeen, P. R. (1984). Incentive theory III: Adaptive clocks. In J. Gibbon & L. Allen (Eds.), *Timing and time perception* (pp. 515-527). New York, NY: New York Academy of Sciences.
- Killeen, P. R. (2015). The arithmetic of discounting. *Journal of the Experimental Analysis of Behavior*, *103*, 249-259.
- Koegel, R. L., & Rincover, A. (1977). Research on the difference between generalization and maintenance in extra-therapy responding. *Journal of Applied Behavior Analysis*, *10*, 1-12.
- Lattal, K. A. (1989). Contingencies on response rate and resistance to change. *Learning and Motivation*, *20*, 191-203.

- Lattal, K. A. (2010). Delayed reinforcement of operant behavior. *Journal of the Experimental Analysis of Behavior*, *93*, 129-139.
- Lattal, K. A., St. Peter, C., & Escobar, R. (2013). Operant extinction: Elimination and generation of behavior. In G. J. Madden, W. V. Dube, T. D. Hackenberg, G. P. Hanley, & K. A. Lattal (Eds.), *APA handbook of behavior analysis Vol. 2: Translating principles into practice* (pp. 77-107). Washington, DC: American Psychological Association.
- Lattal, K. A., & St. Peter Pipkin, C. (2009). Resurgence of previously reinforced responding: Research and application. *The Behavior Analyst Today*, *10*, 254-266.
- Lattal, K. M., & Lattal, K. A. (2012). Facets of Pavlovian and operant extinction. *Behavioural Processes*, *90*, 1-8.
- Leitenberg, H., Rawson, R. A., & Mulick, J. A. (1975). Extinction and reinforcement of alternative behavior. *Journal of Comparative and Physiological Psychology*, *88*, 640-652.
- Lerman, D. C., & Iwata, B. A. (1996). Developing a technology for the use of operant extinction in clinical settings: An examination of basic and applied research. *Journal of Applied Behavior Analysis*, *29*, 345-382.
- Lerman, D. C., Iwata, B. A., & Wallace, M. D. (1999). Side effects of extinction: Prevalence of bursting and aggression during the treatment of self-injurious behavior. *Journal of Applied Behavior Analysis*, *32*, 1-8.
- Lichtenegger, H. (1984). The dynamics of bodies with variable masses. *Celestial Mechanics*, *34*, 357-368.
- Lieving, G. A., Hagopian, L. P., Long, E. S., & O'Connor, J. (2004). Response-class hierarchies and resurgence of severe problem behavior. *The Psychological Record*, *54*, 621-634.
- Lionello-DeNolf, K. M., & Dube, W. V. (2011). Contextual influences on resistance to disruption in children with intellectual disabilities. *Journal of the Experimental Analysis of Behavior*, *96*, 317-327.
- Mace, F. C., Lalli, J. S., Shea, M. C., Lalli, E. P., West, B. J., Roberts, M., & Nevin, J. A. (1990). The momentum of human behavior in a natural setting. *Journal of the Experimental Analysis of Behavior*, *54*, 163-172.
- Mace, F. C., McComas, J. J., Mauro, B. C., Progar, P. R., Ervin, R., & Zangrillo, A. N. (2010). Differential reinforcement of alternative behavior increases resistance to extinction: Clinical demonstration, animal modeling, and clinical test of one solution. *Journal of the Experimental Analysis of Behavior*, *93*, 349-367.

- Maki, W. S., Moe, J. C., & Bierly, C. M. (1977). Short-term memory for stimuli, responses, and reinforcers. *Journal of Experimental Psychology: Animal Behavior Processes*, 3, 156-177.
- Marcucella, H. (1976). Signalled reinforcement and multiple schedules. *Journal of the Experimental Analysis of Behavior*, 26, 199-206.
- Marcucella, H., & Margolius, G. (1978). Time allocation in concurrent schedules: The effect of signaled reinforcement. *Journal of the Experimental Analysis of Behavior*, 29, 419-430.
- Mazur, J. E. (1995). Development of preference and spontaneous recovery in choice behavior with concurrent variable-interval schedules. *Animal Learning & Behavior*, 23, 93-103.
- Mazur, J. E. (1996). Past experience, recency, and spontaneous recovery in choice behavior. *Animal Learning & Behavior*, 24, 1-10.
- McLean, A. P., Grace, R. C., & Nevin, J. A. (2012). Response strength in extreme multiple schedules. *Journal of the Experimental Analysis of Behavior*, 97, 51-70.
- McSweeney, F. K. (1983). Positive behavioral contrast when pigeons press treadles during multiple schedules. *Journal of the Experimental Analysis of Behavior*, 39, 149-156.
- McSweeney, F. K., Dougan, J. D., Higa, J., & Farmer, V. A. (1986). Behavioral contrast as a function of component duration and baseline rate of reinforcement. *Animal Learning & Behavior*, 14, 173-183.
- Navakatikyan, M. A., Murrell, P., Bensemann, J., Davison, M., & Elliffe, D. (2013). Law of effect models and choice between many alternatives. *Journal of the Experimental Analysis of Behavior*, 100, 222-256.
- Nevin, J. A. (1974). Response strength in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 21, 389-408.
- Nevin, J. A. (1984a). Pavlovian determiners of behavioral momentum. *Learning and Behavior*, 12, 363-370.
- Nevin, J. A. (1984b). Quantitative analysis. *Journal of the Experimental Analysis of Behavior*, 42, 421-434.
- Nevin, J. A. (1992a). An integrative model for the study of behavioral momentum. *Journal of the Experimental Analysis of Behavior*, 57, 301-316.



- Nevin, J. A. (1992b). Behavioral contrast and behavioral momentum. *Journal of Experimental Psychology: Animal Behavior Processes*, *18*, 126-133.
- Nevin, J. A. (2002). Measuring behavioral momentum. *Behavioural Processes*, *57*, 198-287.
- Nevin, J. A. (2012). Resistance to extinction and behavioral momentum. *Behavioural Processes*, *90*, 89-97.
- Nevin, J. A., Craig, A. R., Cunningham, P. J., Podlesnik, C. A., Shahan, T. A., & Sweeney, M. M. (2017). Quantitative models of persistence and relapse from the perspective of behavioral momentum theory: Fits and misfits. *Behavioural Processes*, *141*, 92-99.
- Nevin, J. A., Davison, M., & Shahan, T. A. (2005). A theory of attending and reinforcement in conditional discriminations. *Journal of the Experimental Analysis of Behavior*, *84*, 281-303.
- Nevin, J. A., & Grace, R. C. (1999). Does the context of reinforcement affect resistance to change? *Journal of Experimental Psychology: Animal Behavior Processes*, *25*, 256-268.
- Nevin, J. A., & Grace, R. C. (2000). Behavioral momentum and the law of effect. *Behavioral and Brain Sciences*, *23*, 73-130.
- Nevin, J. A., Grace, R. C., Holland, S., & McLean, A. P. (2001). Variable-ratio versus variable interval schedules: Response rate, resistance to change, and preference. *Journal of the Experimental Analysis of Behavior*, *76*, 43-74.
- Nevin, J. A., Mace, F. C., DeLeon, I. G., Shahan, T. A., Shamlan, K. D., Lit, K., ... Craig, A. R. (2016). Effects of signaled and unsignaled alternative reinforcement on persistence and relapse in children and pigeons. *Journal of the Experimental Analysis of Behavior*, *106*, 34-57.
- Nevin, J. A., Mandell, C., & Atak, J. R. (1983). The analysis of behavioral momentum. *Journal of the Experimental Analysis of Behavior*, *39*, 49-59.
- Nevin, J. A., McLean, A. P., & Grace, R. C. (2001). Resistance to extinction: Contingency termination and generalization decrement. *Animal Learning & Behavior*, *29*, 176-191.
- Nevin, J. A., Milo, J., Odum, A. L., & Shahan, T. A. (2003). Accuracy of discrimination, rate of responding, and resistance to change. *Journal of the Experimental Analysis of Behavior*, *79*, 307-321.

- Nevin, J. A., & Shahan, T. A. (2011). Behavioral momentum theory: Equations and applications. *Journal of Applied Behavior Analysis, 44*, 877-895.
- Nevin, J. A., Tota, M. E., Torquato, R. D., & Shull, R. L. (1990). Alternative reinforcement increases resistance to change: Pavlovian or operant contingencies? *Journal of the Experimental Analysis of Behavior, 53*, 359-379.
- Nevin, J. A., & Wacker, D. P. (2013). Response strength and persistence. In G. J. Madden, W. V. Dube, T. D. Hackenberg, G. P. Hanley, & K. A. Lattal (Eds.), *APA handbook of behavior analysis, Vol. 2: Translating principles into practice* (pp. 109-128). Washington, DC: American Psychological Association.
- Nevin, J. A., Ward, R. D., Jimenez-Gomez, C., Odum, A. L., & Shahan, T. A. (2009). Differential outcomes enhance accuracy of delayed matching to sample but not resistance to change. *Journal of Experimental Psychology: Animal Behavior Processes, 35*, 74-91.
- Newton, I. (1686). *Philosophia naturalis principia mathematica*. London, UK: S. Pepys.
- Odum, A. L., Shahan, T. A., & Nevin, J. A. (2005). Resistance to change of forgetting functions and response rates. *Journal of the experimental Analysis of Behavior, 84*, 65-75.
- Peterson, G. B., Wheeler, R. L., & Trapold, M. A. (1980). Enhancement of pigeons' conditional discrimination performance by expectancies of reinforcement and nonreinforcement. *Animal Learning & Behavior, 8*, 22-30.
- Petscher, E. S., & Bailey, J. S. (2008). Comparing main and collateral effects of extinction and differential reinforcement of alternative behavior. *Behavior Modification, 32*, 468-488.
- Petscher, E. S., Rey, C., & Bailey, J. S. (2009). A review of empirical support for differential reinforcement of alternative behavior. *Research in Developmental Disabilities, 30*, 409-425.
- Plastino, A. R., & Muzzio, J. C. (1992). On the use and abuse of Newton's second law for variable mass problems. *Celestial Mechanics and Dynamical Astronomy, 53*, 227-232.
- Podlesnik, C. A., Bai, J. Y., & Elliffe, D. (2012). Resistance to extinction and relapse in combined stimulus contexts. *Journal of the Experimental Analysis of Behavior, 98*, 169-189.
- Podlesnik, C. A., & Shahan, T. A. (2008). Response-reinforcer relations and resistance to change. *Behavioral Processes, 77*, 109-125.

- Podlesnik, C. A., & Shahan, T. A. (2009). Behavioral momentum and relapse of extinguished operant responding. *Learning & Behavior, 37*, 357-364.
- Podlesnik, C. A., & Shahan, T. A. (2010). Extinction, relapse, and behavioral momentum. *Behavioural Processes, 84*, 400-411.
- Podlesnik, C. A., Jimenez-Gomez, C., Ward, R. D., & Shahan, T. A. (2006). Resistance to change of responding maintained by unsignaled delays to reinforcement: A response-bout analysis. *Journal of the Experimental Analysis of Behavior, 85*, 329-347.
- Pritchard, D., Hoerger, M., Mace, F. C., Penney, H., & Harris, B. (2014). Clinical translation of animal models of treatment relapse. *Journal of the Experimental Analysis of Behavior, 101*, 442-449.
- Pyszczynski, A. D., & Shahan, T. A. (2011). Behavioral momentum and relapse of ethanol seeking: Nondrug reinforcement in a context increases relative reinstatement. *Behavioural Pharmacology, 22*, 81-86.
- Reid, R. L. (1958). The role of the reinforcer as a stimulus. *British Journal of Psychology, 49*, 202-209.
- Rescorla, R. A. (1968). Probability of shock in the presence and absence of CS in fear conditioning. *Journal of Comparative and Physiological Psychology, 66*, 1-5.
- Rescorla, R. A. (2007). Spontaneous recovery after reversal and partial reinforcement. *Learning & Behavior, 35*, 191-200.
- Rescorla, R. A., & Skucy, J. C. (1969). Effect of response-independent reinforcers during extinction. *Journal of Comparative & Physiological Psychology, 67*, 381-389.
- Schaal, D. W., Odum, A. L., & Shahan, T. A. (2000). Pigeons may not remember the stimuli that reinforced their recent behavior. *Journal of the Experimental Analysis of Behavior, 73*, 125-139.
- Schepers, S. T., & Bouton, M. E. (2015). Effects of reinforcer distribution during response elimination on resurgence of an instrumental behavior. *Journal of Experimental Psychology: Animal Learning and Cognition, 41*, 179-192.
- Sebens, C. T. (2015). Quantum mechanics as classical physics. *Philosophy of Science, 82*, 266-291.
- Semat, H., & Katz, R. (1958). Momentum and impulse. In *Physics* (pp. 182-197). New York, NY: Rinehart & Company.

- Shahan, T. A., & Burke, K. A. (2004). Ethanol-maintained responding of rats is more resistant to change in a context with added non-drug reinforcement. *Behavioural Pharmacology, 15*, 279-285.
- Shahan, T. A., & Craig, A. R. (2017). Resurgence as choice. *Behavioural Processes, 141*, 100-127.
- Shahan, T. A., & Sweeney, M. M. (2011). A model of resurgence based on behavioral momentum theory. *Journal of the Experimental Analysis of Behavior, 95*, 91-108.
- Shettleworth, S., & Nevin, J. A. (1965). Relative rate of response and relative magnitude of reinforcement in multiple schedules. *Journal of the Experimental Analysis of Behavior, 8*, 199-202.
- Shull, R. L. (2005). The sensitivity of response rate to the rate of variable-interval reinforcement for pigeons and rats: A review. *Journal of the Experimental Analysis of Behavior, 84*, 99-110.
- Shull, R. L., & Grimes, J. A. (2006). Resistance to extinction following variable-interval reinforcement: Reinforcer rate and amount. *Journal of the Experimental Analysis of Behavior, 85*, 23-39.
- Skinner, B. F. (1938). *The behavior of organisms*. Englewood Cliffs, NJ: Prentice Hall.
- Stitzer, M., & Petry, N. (2015). Contingency management. In M. Galanter, H. D. Kleber, & K. T. Brady (Eds.), *The American Psychiatric Publishing textbook of substance abuse treatment* (5<sup>th</sup> ed., pp. 432-439). Arlington, VA: American Psychiatric Publishing.
- Sutherland, N. S., & Mackintosh, N. J. (1971). *Mechanisms of animal discrimination learning*. New York, NY: Academic.
- Sweeney, M. M., Moore, K., Shahan, T. A., Ahearn, W. H., Dube, W. V., & Nevin, J. A. (2014). Modeling the effects of sensory reinforcers on behavioral persistence with alternative reinforcement. *Journal of the Experimental Analysis of Behavior, 102*, 252-266.
- Sweeney, M. M., & Shahan, T. A. (2013). Effects of high, low, and thinning rates of alternative reinforcement on response elimination and resurgence. *Journal of the Experimental Analysis of Behavior, 100*, 102-116.
- Thrailkill, E. A., & Shahan, T. A. (2011). Resistance to change and relapse of observing. *Journal of the Experimental Analysis of Behavior, 97*, 281-304.

- Tiger, J. H., Wierzba, B. C., Fisher, W. W., & Benitez, B. B. (2017). Developing and demonstrating inhibitory stimulus control over repetitive behavior. *Behavioral Interventions*, *32*, 160-174.
- Wacker, D. P., Harding, J. W., Berg, W. K., Lee, J. F., Schieltz, K. M., Padilla, Y. C., ... Shahan, T. A. (2011). An evaluation of persistence of treatment effects during long-term treatment of destructive behavior. *Journal of the Experimental Analysis of Behavior*, *96*, 261-282.
- White, K. G. (1985). Characteristics of forgetting function in delayed matching to sample. *Journal of the Experimental Analysis of Behavior*, *44*, 15-34.
- White, K. G. (1991). Psychophysics of direct remembering. In M. L. Commons, J. A. Nevin, & M. C. Davison (Eds.), *Signal detection: Mechanisms, models, and applications* (pp. 221-237). Hillsdale, NJ: Erlbaum.
- White, K. G. (2001). Forgetting functions. *Animal Learning & Behavior*, *29*, 193-207.
- Winterbauer, N. E., & Bouton, M. E. (2012). Effects of thinning the rate at which the alternative behavior is reinforcement on resurgence of an extinguished instrumental response. *Journal of Experimental Psychology: Animal Behavior Processes*, *3*, 279-291.
- Winterbauer, N. E., Lucke, S., & Bouton, M. E. (2013). Some factors modulating the strength of resurgence after extinction of an instrumental behavior. *Learning and Motivation*, *44*, 60-71.
- Winterrowd, M. F., & Devenport, L. D. (2004). Balancing variable patch quality with prediction risk. *Behavioural Processes*, *67*, 39-46.
- Wyckoff, L. B. Jr. (1952). The role of observing responses in discrimination learning. Part I. *Psychological Review*, *59*, 431-442.
- Wynne, C. D., Staddon, J. E. R., & Delius, J. D. (1996). Dynamics of waiting in pigeons. *Journal of the Experimental Analysis of Behavior*, *65*, 603-618.

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Appendix D

Permission-to-Use Letter for Chapter 3

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**Craig Dissertation Collaboration**

1 message

---

**Paul Cunningham** <pcunningham729@gmail.com>  
Reply-To: Paul Cunningham <pcunningham729@gmail.com>  
To: Andrew Craig <craig.andrew.ryan@gmail.com>

Wed, Jul 26, 2017 at 4:09 PM

USU Graduate School,

My name is Paul Cunningham and I'm a graduate student in the Psychology department. My colleague, Andrew R. Craig, recently defended his dissertation that consisted, in part, on research for which I was a collaborator. Andy Craig and I (along with Timothy Shahan) submitted a manuscript to The Journal of the Experimental Analysis of Behavior titled "Behavioral Momentum and the Accumulation of Mass in Mutiple Schedules" which was used as part of Andy's dissertation. Andy has my permission to use this material for his dissertation.

Paul Cunningham

Appendix E

Stimulus Assignments for the Experiment Reported in Chapter 3

Subject											
392		874		361		938					
Condition	R-to-L Stim.	L-to-R Stim.	R-to-L Stim.	L-to-R Stim.	R-to-L Stim.	L-to-R Stim.	R-to-L Stim.	L-to-R Stim.			
20-Day	Red	Green	Green	Red	Red	Green	Green	Red			
1-Day	Turquoise	Red	Red	Turquoise	Turquoise	Red	White	Green			
5-Day	White	Turquoise	Turquoise	White	White	Turquoise	Turquoise	White			
3-Day	Yellow	Blue	Blue	Yellow	Yellow	Blue	Blue	Yellow			
2-Day	Red	White	White	Red	Red	White	White	Red			
5-Day (Rep.)	White	Turquoise	Turquoise	White	White	Turquoise	Turquoise	White			
20-Day (Rep.)	Yellow	Blue	Blue	Yellow	Yellow	Blue	Blue	Yellow			

Subject											
8405		7095		251		257					
Condition	R-to-L Stim.	L-to-R Stim.	R-to-L Stim.	L-to-R Stim.	R-to-L Stim.	L-to-R Stim.	R-to-L Stim.	L-to-R Stim.			
20-Day	Red	Green	Green	Red	-	-	Red	Green			
1-Day	Red	Turquoise	Green	White	-	-	White	Red			
5-Day	White	Turquoise	Turquoise	White	White	Turquoise	Turquoise	White			
3-Day	Yellow	Blue	Blue	Yellow	Yellow	Blue	Blue	Yellow			
2-Day	Red	White	White	Red	Red	White	White	Red			
5-Day (Rep.)	White	Turquoise	Turquoise	White	White	Turquoise	Turquoise	White			
20-Day (Rep.)	Yellow	Blue	Blue	Yellow	Blue	Yellow	Yellow	Blue			

Figure E.1. Stimulus assignments for the experiment reported in Chapter 3



Appendix F

Relative Resistance to Extinction Between Conditions Reported in Chapter 4

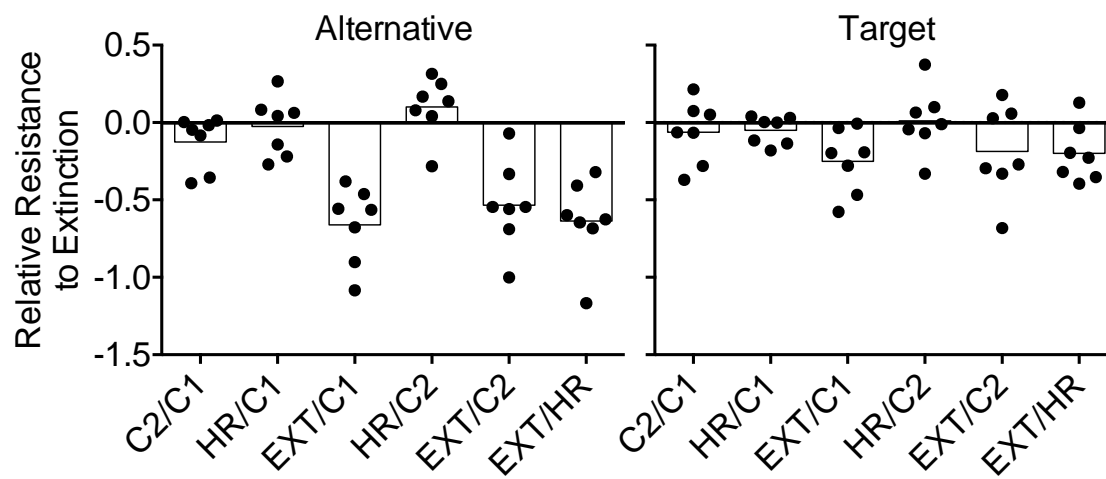


Figure F.1. Relative resistance to extinction between conditions reported in Chapter 4.

## CURRICULUM VITAE

ANDREW R. CRAIG

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

Phone: (724) 322-0542  
Fax: (435) 797-1448  
Email: craig.andrew.ryan@gmail.com

## EDUCATION

- 2017      Ph.D., Psychology  
Department of Psychology, Utah State University  
Dissertation Chairperson: Timothy A. Shahan, Ph.D.  
Dissertation: Extensions of behavioral momentum theory to conditions  
with changing reinforcer rates
- 2013      M.S., Psychology  
Department of Psychology, Utah State University  
Thesis Chairperson: Timothy A. Shahan, Ph.D.  
Thesis: A comparison of resistance to extinction following dynamic  
and static schedules of reinforcement
- 2011      B.S. (with honors), Psychology  
Department of Psychology, West Virginia University  
Honors Thesis: Time allocation during variable conjoint schedules of  
responding and not responding  
Thesis Chairperson: Kennon A. Lattal, Ph.D.

## AWARDS

- 2013      Walter R. Borg Scholarship and Research Productivity Award  
Department of Psychology, Utah State University
- 2011      Presidential Fellowship  
School of Graduate Studies, Utah State University

## EDITORIAL ACTIVITIES AND PROFESSIONAL ASSOCIATIONS

**Ad Hoc Reviewer Services***Behavioural Processes**The Journal of the Experimental Analysis of Behavior**The American Journal of Addictions***Organizational Associations**

Association for Behavior Analysis, International  
 Society for the Quantitative Analyses of Behavior

## RESEARCH

**Positions Held**

- 2011-2016 Graduate Research Assistant  
 Department of Psychology, Utah State University  
 Faculty Supervisor: Timothy A. Shahan, Ph.D.  
 Grant Work: RO1AA016786, “Behavioral Momentum of Alcohol Self-Administration”; R21DA026497, “Behavioral Momentum of Cocaine Self-Administration”; RO1HD064576, “Behavioral Persistence: Basic, Translational, and Clinical Studies”; 1R21DA037725-01, “Theory of Resurgence of Cocaine Seeking”
- 2012-2016 Manager, Behavior Laboratory  
 Department of Psychology, Utah State University  
 Faculty Supervisors: Timothy A. Shahan, Ph.D., and Amy L. Odum, Ph.D.
- 2012-2015 Head of Surgery, Intravenous Self-Administration Surgical Unit  
 Department of Psychology, Utah State University  
 Faculty Supervisors: Timothy A. Shahan, Ph.D., and Gregory J. Madden, Ph.D.
- 2010 Honorary Summer Researcher  
 Summer Undergraduate Research Experience, West Virginia University  
 Faculty Supervisors: Kennon A. Lattal, Ph.D., and Elizabeth G. E. Kyonka, Ph.D.

- 2010-2011 Undergraduate Research Assistant  
Department of Psychology, West Virginia University  
Faculty Supervisor: Elizabeth G. E. Kyonka, Ph.D.
- 2009-2011 Undergraduate Research Assistant  
Department of Psychology, West Virginia University  
Faculty Supervisor: Kennon A. Lattal, Ph.D.
- 2008-2009 Undergraduate Research Assistant  
Department of Psychology, West Virginia University  
Faculty Supervisor: Claire C. St. Peter, Ph.D., BCBA-D

## Publications

### Book chapters

- Craig, A. R., Nevin, J. A., & Odum, A. L. (2014). Behavioral momentum and resistance to change. In F. K. McSweeney & E. S. Murphey (Eds.), *The Wiley-Blackwell handbook of operant and classical conditioning* (pp. 249-274). Oxford, UK: Wiley-Blackwell.

### Articles in press

- Craig, A. R., Browning, K. O., & Shahan, T. A. (in press). Stimuli previously associated with reinforcement mitigate resurgence. *Journal of the Experimental Analysis of Behavior*.
- Nevin, J. A., Craig, A. R., Cunningham, P. J., Podlesnik, C. A., Shahan, T. A., & Sweeney, M. M. (2017). Quantitative models of persistence and relapse from the perspective of behavioral momentum theory: Fits and misfits. *Behavioural Processes, 141*, 92-99.
- Shahan, T. A., & Craig, A. R. (2017). Resurgence as choice. *Behavioural Processes, 141*, 100-127.
- Craig, A. R., Browning, K. O., Nall, R. W., Marshall, C. M., & Shahan, T. A. (2017). Resurgence and alternative-reinforcer magnitude. *Journal of the Experimental Analysis of Behavior, 107*, 218-233.
- Nevin, J. A., Mace, F. C., DeLeon, I. G., Shahan, T. A., Shamlan, K. D., Lit, K. ... Craig, A. R. (2016). Effects of signaled and unsignaled reinforcement of alternative behavior on persistence and relapse in children and pigeon. *Journal of the Experimental Analysis of Behavior, 106*, 34-57.

- Craig, A. R., & Shahan, T. A. (2016). Behavioral momentum theory fails to account for the effects of reinforcement rate on resurgence. *Journal of the Experimental Analysis of Behavior, 105*, 375-392.
- Craig, A. R., Nall, R. W., Madden, G. J., & Shahan, T. A. (2016). Higher rate alternative non-drug reinforcement produces greater suppression of cocaine seeking but more resurgence when removed. *Behavioral Brain Research, 306*, 48-51.
- Craig, A. R., & Shahan, T. A. (2016). Experience with dynamic reinforcement rates decreases resistance to extinction. *Journal of the Experimental Analysis of Behavior, 105*, 291-306.
- Craig, A. R., Cunningham, P. J., & Shahan, T. A. (2015). Behavioral momentum and accumulation of mass in multiple schedules. *Journal of the Experimental Analysis of Behavior, 103*, 437-449.
- Shahan, T. A., Craig, A. R., & Sweeney, M. M. (2014). Resurgence of sucrose and cocaine seeking in free-feeding rats. *Behavioral Brain Research, 279*, 47-51.
- Craig, A. R., Maxfield, A. D., Stein, J. S., Renda, C. R., & Madden, G. J. (2014). Do the adjusting- and increasing-delay tasks measure the same construct: Delay discounting? *Behavioural Pharmacology, 25*, 306-315.
- Craig, A. R., Lattal, K. A., & Hall, E. G. (2014). Pausing as an operant: Choice and discriminated responding. *Journal of the Experimental Analysis of Behavior, 101*, 230-245.
- Gallistel, C. R., Craig, A. R., & Shahan, T. A. (2014). Temporal contingency. *Behavioural Processes, 101*, 89-96.
- Craig, A. R. (2010). Self-administered behavior modification to reduce nail biting: Incorporating simple technology to ensure treatment integrity. *Behavior Analysis in Practice, 3*, 38-41.

### **Articles under review**

- Craig, A. R., Cunningham, P. J., Sweeney, M. M., Shahan, T. A., & Nevin, T. A. Delivering alternative reinforcement in a distinct context reduces its counter-therapeutic effects on relapse.
- Craig, A. R., & Shahan, T. A. (accepted pending revisions) Does behavioral mass change during extinction? Maybe. *Journal of the Experimental Analysis of Behavior*.

### **Articles in preparation**

- Craig, A. R., Cunningham, P. J., Browning, K. O., & Shahan, T. A. Both training and testing conditions modulate effects of reinforcement rates on resistance to change.
- Craig, A. R., Gallistel, C. R., & Shahan, T. A. Time is of the essence: Information theory and temporal contingency.
- Craig, A. R., Sweeney, M. M., & Shahan, T. A. Behavioral momentum and resistance to change: Effects of repeated extinction tests on response persistence.
- Craig, A. R., Cunningham, P. J., & Shahan, T. A. A critical role for reinforcement contexts in resistance to change.
- Nall, R. W., Craig, A. R., Browning, K. O., Madden, G. J., & Shahan, T. A. Duration of treatment does not impact resurgence of cocaine or alcohol seeking in rats.
- Cortés Patiño, D. M., Craig, A. R., & Shahan, T. A. Effects of alcohol concentration on the persistence of alcohol seeking.

### **Presentations**

#### **Invited addresses**

- Gallistel, C. R., Craig, A. R., & Shahan, T. A. (2016, May). Prospective and retrospective contingency in operantly conditioned behavior. Invited address for the B. F. Skinner Lecture Series presented at the 42<sup>nd</sup> annual meeting of the Association for Behavior Analysis, International, Chicago, IL.
- Shahan, T. A., & Craig, A. R. (2016, May). A choice-based model of resurgence. Invited address presented at the 39<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, Chicago, IL.

#### **Symposia chaired**

- Craig, A. R. (2014, May). Rewards are Key, but Their Timing is Everything! Recent Advances in Matching Theory, Delay Discounting, and Behavioral Momentum. Symposium conducted at the 40<sup>th</sup> annual meeting of the Association for Behavior Analysis, International, Chicago, IL.

#### **Symposia addresses**

- Craig, A. R., Cunningham, P. J., Sweeney, M. M., Shahan, T. A., & Nevin, J. A. (2017, May). Delivering alternative reinforcement in a distinct context reduces its contra-

- therapeutic effects on resurgence. In N. DeRosa (Chair), *Translational and Applied Research on Response Relapse*. Symposium presented at the 43<sup>rd</sup> annual meeting of the Association for Behavior Analysis, International, Denver, CO.
- Mace, F. C., Craig, A. R., DeLeon, I. G., Shahan, T. A., & Sheehan, T. (2017, May). Signaled alternative reinforcers in multiple schedules with varied reinforcer rates. In J. Nevin (Chair), *Behavioral Persistence: Basic, Translational, and Clinical Studies*. Symposium presented at the 43<sup>rd</sup> annual meeting of the Association for Behavior Analysis, International, Denver, CO.
- Shahan, T. A., Craig, A. R., Cunningham, P. J., & Sweeney, M. M. (2017, May). Examining relapse in an animal analog of contingency management. In J. Nevin (Chair), *Behavioral Persistence: Basic, Translational, and Clinical Studies*. Symposium presented at the 43<sup>rd</sup> annual meeting of the Association for Behavior Analysis, International, Denver, CO.
- Browning, K. O., Craig, A. R., & Shahan, T. A. (2016, May). Alternative-reinforcer magnitude effects on response suppression and resurgence. In C. St. Peter (Chair), *Resurgence and Relapse: From Bench to Bedside*. Symposium presented at the 42<sup>nd</sup> annual meeting of the Association for Behavior Analysis, International, Chicago, IL.
- Craig, A. R., Sweeney, M. M., Shahan, T. A., & Nevin, J. A. (2015, May). Effects of separating target- and alternative-reinforcement contexts on relapse following differential reinforcement of alternative behavior. In C. Podlesnik (Chair), *Translational Research on Persistence and Relapse*. Symposium conducted at the 41<sup>st</sup> annual meeting of the Association for Behavior Analysis, International, San Antonio, TX.
- Craig, A. R., Nall, R. W., Marshall, C., & Shahan, T. A. (2015, May). Do shifts in the magnitude or quality of alternative reinforcement produce resurgence? In C. St. Peter (Chair), *Factors Affecting Response Relapse and Resurgence*. Symposium conducted at the 41<sup>st</sup> annual meeting of the Association for Behavior Analysis, International, San Antonio, TX.
- Cunningham, P. J., Craig, A. R., Soares Filho, P., & Shahan, T. A. (2015, May). The role of temporal informativeness in observing: Conditioned reinforcement and information theory revisited. In T. Smith (Chair), *Conditioned Reinforcement: Gambling, Information, and Token Economies*. Symposium conducted at the 41<sup>st</sup> annual meeting of the Association for Behavior Analysis, International, San Antonio, TX.
- Odum, A. L., Craig, A. R., & Nevin, J. A. (2014, May). Persistently momentous: Basic research on behavioral momentum. In M. P. Lewon (Chair), *The Rat is Always*



Right: Why the Experimental Analysis of Behavior is Still Relevant. Symposium conducted at the 40<sup>th</sup> annual meeting of the Association for Behavior Analysis, International, Chicago, IL.

Craig, A. R., Sweeney, M. M., Shahan, T. A., & Nevin, J. A. (2014, May). Effects of alternative-reinforcement rate on extinction and relapse of behavior maintained by food and analog sensory consequences. In C. Podlesnik (Chair), *Translational Research in Behavioral Momentum Theory*. Symposium conducted at the 40<sup>th</sup> annual meeting of the Association for Behavior Analysis, International, Chicago, IL.

Craig, A. R., & Shahan, T. A. (2013, May). Temporal weighting of reward effects and resistance to extinction. In C. Podlesnik (Chair), *Translating Basic Research on Behavioral Momentum*. Symposium conducted at the 39<sup>th</sup> annual meeting of the Association for Behavior Analysis, International, Minneapolis, MN.

### Posters

Craig, A. R., Browning, K. O., & Shahan, T. A. (2017, May). Delivery of conditioned reinforcers suppresses resurgence. Poster presented at the 40<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, Denver, CO.

Nall, R. W., Craig, A. R., Browning, K. O., & Shahan, T. A. (2017, May). The effects of treatment duration on resurgence of cocaine seeking. Poster presented at the 40<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, Denver, CO.

Craig, A. R., & Shahan, T. A. (2016, May). Behavioral momentum theory fails to account for the effects of reinforcement rate on resurgence. Poster presented at the 39<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, Chicago, IL.

Craig, A. R., Shahan, T. A., & Gallistel, C. R. (2015, May). Time is of the essence: Information theory and temporal contingency. Poster presented at the 38<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, San Antonio, TX.

House, K. O., Craig, A. R., Cunningham, P. J., & Shahan, T. A. (2015, May). Difference in resistance to extinction between single and multiple schedules may be related to testing conditions. Poster presented at the 38<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, San Antonio, TX.

Nelson, S. A., Craig, A. R., Nall, R. W., Cunningham, P. J., Frye, C. C. J., & Shahan, T. A. (2015, May). Resurgence of alcohol seeking: Effects of length of exposure to

extinction plus alternative reinforcement. Poster presented at the 38<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, San Antonio, TX.

- Craig, A. R., Marshall, C., Nall, R. W., & Shahan, T. A. (2014, May). Resurgence following downshifts in reward magnitude: Evidence for a functional relation between relapse and shift size. Poster presented at the 37<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, Chicago, IL.
- Frye, C. C. J., Craig, A. R., Friedel, J. E., & Odum, A. L. (2014, May). Are the impulsive persistent? Investigating the relation between delay discounting and behavioral-momentum performance. Poster presented at the 37<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, Chicago, IL.
- Nall, R. W., Craig, A. R., & Shahan, T. A. (2014, May). Loss of alternative non-drug reinforcement produces resurgence of cocaine seeking in non-food-restricted rats. Poster presented at the 37<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, Chicago, IL.
- Cunningham, P. J., Soares Filho, P., Craig, A. R., & Shahan, T. A. (2014, May). Conditioned reinforcement and informativeness reconsidered. Poster presented at the 37<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, Chicago, IL.
- Nall, R. W., Craig, A. R., Cunningham, P. J., Marshall, C., & Shahan, T. A. (2014, April). Duration of extinction is negatively related to resurgence of ethanol seeking following loss of alternative non-drug reinforcement in rats. Poster presented at the 7<sup>th</sup> annual meeting of the Four Corners Association for Behavior Analysis, Park City, UT.
- Craig, A. R., & Shahan, T. A. (2013, May). Dynamic changes in baseline reinforcement rates hasten extinction. Poster presented at the 36<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, Minneapolis, MN.
- Marshall, C., Craig, A. R., & Shahan, T. A. (2013, May). A parametric analysis of the effects of reinforcer magnitude downshifts on resurgence. Poster presented at the 36<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, Minneapolis, MN.
- Marshall, C., Craig, A. R., & Shahan, T. A. (2013, May). Negative incentive contrast as a mechanism of resurgence. Poster presented at the 39<sup>th</sup> annual meeting of the Association for Behavior Analysis, International, Minneapolis, MN.

- Craig, A. R., & Shahan, T. A. (2012, May). A comparison of the effects of static and dynamic rates of reinforcement on resistance to extinction. Poster presented at the 35<sup>th</sup> annual meeting of the Society for the Quantitative Analyses of Behavior, Seattle, WA.
- Craig, A. R., & Lattal, K. A. (2011, May). Time allocation during variable-conjoint schedules of responding and not-responding. Poster presented at the 37<sup>th</sup> annual meeting of the Association for Behavior Analysis, International, Denver, CO.
- Craig, A. R., Kuroda, T., & Lattal, K. A. (2010, November). Resistance to extinction in a multiple variable-ratio, yoked-interval schedule of reinforcement. Poster presented at the 27<sup>th</sup> annual meeting of the Southeastern Association for Behavior Analysis, Asheville, NC.

#### TEACHING

- |                 |   |
|-----------------|---|
| 2017,<br>Summer | Graduate Teaching Assistant<br>Department of Psychology, Utah State University<br>Course Title: EDUC/PSY 6600, Research Design & Analysis I<br>Instructor: Sarah Schwartz, M.S.     |
| 2017,<br>Summer | Graduate Teaching Assistant<br>Department of Psychology, Utah State University<br>Course Title: EDUC/PSY 7610, Research Design & Analysis II<br>Instructor: Daniel Laxman, Ph.D.    |
| 2017, Spring    | Graduate Teaching Assistant<br>Department of Psychology, Utah State University<br>Course Title: EDUC/PSY 6600, Research Design & Analysis I<br>Instructor: Sarah Schwartz, M.S.     |
| 2017, Spring    | Graduate Teaching Assistant<br>Department of Psychology, Utah State University<br>Course Title: EDUC/PSY 7610, Research Design & Analysis II<br>Instructor: Thomas Ledermann, Ph.D. |
| 2016, Fall      | Graduate Teaching Assistant<br>Department of Psychology, Utah State University<br>Course Title: EDUC/PSY 6600, Research Design & Analysis I<br>Instructor: Thomas Ledermann, Ph.D.  |

- 2016, Fall      Graduate Teaching Assistant  
                    Department of Psychology, Utah State University  
                    Course Title: EDUC/PSY 7610, Research Design & Analysis II  
                    Instructors: Jacqueline Miller, Ph.D., and Daniel J. Laxman, Ph.D.
- 2011, Spring    Undergraduate Teaching Assistant  
                    Department of Biology, West Virginia University  
                    Course Title: Biology 117, Introductory Physiology  
                    Instructor: Ahnya M. Redman, Ph.D.
- 2010, Fall      Undergraduate Teaching Assistant  
                    Department of Biology, West Virginia University  
                    Course Title: Biology 115, Principles of Biology  
                    Instructor: Ahnya M. Redman, Ph.D.
- 2008, Spring   Undergraduate Teaching Assistant  
                    Department of Psychology, West Virginia University  
                    Course Title: Psychology 101, Introduction to Psychology  
                    Instructor: Claire C. St. Peter, Ph.D., BCBA-D