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Preference, Resistance to Change, and Qualitatively Different Reinforcers

Christopher Aaron Podlesnik
Utah State University

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PREFERENCE, RESISTANCE TO CHANGE, AND QUALITATIVELY
DIFFERENT REINFORCERS

by

Christopher A. Podlesnik

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

Clint Field, Ph.D.
Committee Member

Amy L. Odum, Ph.D.
Committee Member

Timothy A. Slocum, Ph.D.
Committee Member

Scott C. Bates, Ph.D.
Committee Member

Byron R. Burnham, Ed.D.
Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2008

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ABSTRACT

Preference, Resistance to Change, and Qualitatively
Different Reinforcers

by

Christopher A. Podlesnik, Doctor of Philosophy

Utah State University, 2008

Major Professor: Dr. Timothy A. Shahan
Department: Psychology

Preference for one stimulus context over another and resistance to disruption within those contexts are a function of the conditions of reinforcement arranged within those contexts. According to behavioral momentum theory, these measures are converging expressions of the concept of response strength. Most studies have found that preference in concurrent chains and resistance to change are greater in contexts presenting higher rates or larger magnitudes of reinforcement. The present series of experiments attempted to extend behavioral momentum theory by examining whether differences in reinforcer type affect relative response strength with rats lever pressing for different types of food. In Experiment 1 of Chapter 2, several nonuniform disrupter types were examined that provided free access to a food type that was the same as one reinforcer type. Responding decreased more in the context presenting the same type of reinforcer as the disrupter, suggesting that many traditional disrupters (e.g., satiation) are inappropriate for examining how reinforcer type impacts response strength. Therefore,

extinction was used throughout the remainder of the experiments to more uniformly disrupt responding across contexts. In Experiment 2 of Chapter 2, resistance to extinction was assessed when food pellets and a sucrose solution maintained responding across contexts. Moreover, relative reinforcer type was manipulated by changing the sucrose concentration across conditions. Relative response rates were systematically affected by changing sucrose concentration, but relative resistance to extinction was not. In Experiment 3 of Chapter 2, qualitative difference between reinforcers was enhanced and preference also was assessed to provide a converging measure of response strength. Preference and relative response rates were systematically affected, but relative resistance to extinction again was not. Finally, in Chapter 3, relative reinforcer rate and type were manipulated while assessing preference and resistance to extinction using the matching law. Preference, but not resistance to extinction, consistently was affected by changes in reinforcer rate and type. Systematic deviations in sensitivity and bias, however, suggested that different reinforcer types interacted with reinforcer rate. Overall, these findings suggest that the overall context of reinforcement, including interactions between different reinforcer types, should be considered when assessing preference and relative resistance to change.

(160 pages)

ACKNOWLEDGMENTS

I thank my advisor, Tim Shahan. He has provided guidance and insight throughout my years as a graduate student. I thank the members of my dissertation committee, Scott Bates, Clint Field, Amy Odum, and Tim Slocum, for their helpful comments and suggestions. Thank you to Corina Jimenez-Gomez, my wife, friend, and colleague, who has been there every step of the way and has seen the best and worst in me. I could not imagine having done all this without you. Thanks to Ryan Ward, friend and colleague, who has been there since day one of graduate school. Adam Kynaston and Scott Barrett, two undergraduate students, deserve thanks for helping conduct many experiments. Finally, thank you to my parents for their support, encouragement, and freedom to succeed and mess up on my own. That way, I had no one to blame but myself. It has made all the difference.

Chris Podlesnik

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CHAPTER I

INTRODUCTION

The concept of *response strength* is an old one (e.g., Sherrington, 1906), and has been fundamental in several theoretical approaches to understanding behavior (e.g., Herrnstein, 1970; Hull, 1943; Nevin & Grace, 2000a; Pavlov, 1927; Skinner, 1938). Skinner suggested that the fundamental unit of analysis for the science of behavior is the *discriminated operant*, which is composed of an antecedent discriminative stimulus (S^D), a response, and a reinforcing consequence. According to Skinner, the primary measure of response strength is the rate at which a response occurs (see also Herrnstein). A response occurring at a higher rate purportedly is of greater strength than a response occurring at a lower rate. Nevin (1974) criticized this account of response strength on the grounds that response rate, like response latency or duration, is a conditionable dimension of behavior. Following Morse (1966), Nevin noted that reinforcement has two distinct effects on responding—shaping and strengthening effects. Reinforcement may occur at equal rates contingent upon two responses; however, the shaping effects of contingencies may cause those responses to occur at much different rates. For instance, reinforcement can be available at the same rate on two reinforcement schedules; however, one schedule may present reinforcers only following high response rates (i.e., a differential-reinforcement-of-high-rates schedule), while the other schedule may present reinforcers only following low response rates (i.e., a differential-reinforcement-of-low-rates schedule). Because both responses may be at stable and asymptotic performance, it is unclear that the different response rates are indicative of their underlying strength.

Resistance to Change

To resolve these difficulties with using response rate as a measure of response strength, Nevin (1974) suggested that response strength may be better characterized as the persistence of response rates when some disruptive variable (e.g., extinction, satiation) is introduced relative to stable predisruption response rates. This measure, called *resistance to change*, typically has been examined using multiple schedules of reinforcement. Figure 1-1 shows a typical multiple schedule in which two component S^D s signal independent schedules of reinforcement that alternate frequently within a single experimental session (Ferster & Skinner, 1957). Multiple-schedule components typically are separated by a short timeout, referred to as an intercomponent interval (ICI), to reduce the interaction of schedules across components. Multiple schedules are particularly convenient for assessing resistance to change because the frequent alternation of components allows for the effects of conditions of disruption to be examined on responding in two or more contexts within the same session. Thus, resistance to change of responding in one component can be compared directly to resistance to change in one or more other components. Disrupters typically used to examine resistance to change include introducing response-independent (i.e., free) reinforcer presentations during the ICI, removing reinforcer presentations (i.e., extinction), and satiation by feeding the subject before the experimental session (hereafter pre-session feeding; see Nevin & Grace, 2000a, for a review).

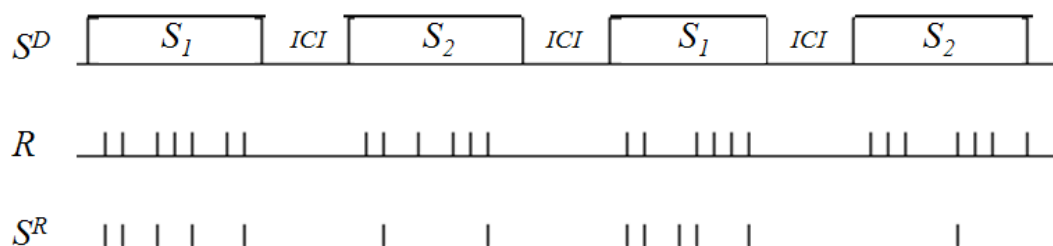


Figure 1-1. Schematic of a multiple schedule of reinforcement. Two mutually-exclusive components are signaled by different stimuli, S_1 and S_2 . Responding (R) in the components is occasionally reinforced (S^R) by separate and independent schedules of reinforcement. Components are separated by intercomponent intervals ($ICIs$), in which all component stimuli are turned off.

Nevin (1974) examined a number of variables that affect relative resistance to change of pigeons' keypecking for food. In one experiment, a two-component multiple schedule arranged a variable-interval (VI) 60-s schedule in one component (60 reinforcers per hr) and a VI 180-s schedule of reinforcement in the other component (20 reinforcers per hr). With VI schedules, each reinforcer is presented contingent on the first response after one of a series of intervals has elapsed (Ferster & Skinner, 1957). This series of intervals varies around some specified mean value (e.g., 60 s or 180 s). An advantage of VI schedules of reinforcement over other schedules is that reinforcement rates are similar across a wide range of response rates. Once response rates were stable across daily sessions, Nevin introduced free food presentations during the ICI according to a variable-time (VT) schedule to disrupt responding in both components. Variable-time schedules, like VI schedules, present reinforcers on a varied series of intervals of a specific mean, but response independently (Zeiler, 1968). Although response rates in both components decreased as the rate of free food increased during the ICI, response rates decreased less relative to baseline in the high reinforcer rate VI 60-s component than in

the lower reinforcer rate VI 180-s component. Similarly, in another experiment, Nevin found that when equal VI 60-s schedules were in effect across two multiple-schedule components, responding was more resistant to free ICI food in a component presenting 7.5-s access to food than in a component presenting 2.5 s of access. These findings suggest that higher rates or magnitudes of reinforcement produce responding that is more resistant to change than lower rates or magnitudes of reinforcement.

Behavioral Momentum Theory

The relation between relative resistance to change and relative rate of intermittent reinforcement has been shown to be quite general across species and procedures (see Nevin, 1992; Nevin & Grace, 2000a, for reviews), and has been conceptualized by an analogy with physical momentum (Nevin, Mandell, & Atak, 1983). Physical momentum is the product of velocity and mass. As velocity and mass are separable aspects of physical momentum, according to behavioral momentum theory, response rate and resistance to change are considered two separable aspects of the discriminated operant (see Nevin, Tota, Torquato, & Shull, 1990). Response rates are analogous to the *velocity* of a moving object and governed by the relation between responding and reinforcement (i.e., operant response-reinforcer relation; see Herrnstein, 1970), whereas resistance to change is analogous to *mass* and governed by the rate of reinforcement in the presence of an S^D (i.e., Pavlovian stimulus-reinforcer relation; see Nevin, 1992). Behavioral mass is inferred from resistance to change and is equivalent to the traditional notion of response strength (Nevin et al., 1983; Nevin & Grace, 1999).

Operant Response-Reinforcer Relation

Behavioral momentum theory assumes that the operant response-reinforcer relation governs stable baseline response rates under VI schedules of reinforcement according to *the matching law* (Herrnstein, 1961),

$$\frac{B_1}{B_1 + B_2} = \frac{r_1}{r_1 + r_2}, \quad (1)$$

in which B refers to responses and r refers to reinforcers across two alternatives. Thus, in a *concurrent-choice situation*, the proportion of responses allocated across two concurrently available alternatives equals the proportion of reinforcers presented across the two alternatives. Equation 1 can be rearranged to account for a single response alternative in the presence of a discriminative context (Herrnstein, 1970),

$$B = \frac{kr}{r + r_o}, \quad (2)$$

in which B is the target response rate in the presence of an S^D , k is a free parameter representing asymptotic response rates (i.e., the sum of all possible behavior [$B_1 + B_2$ in Equation 1] in the presence of an S^D), r is the reinforcement rate for the target response, and r_o is a free parameter representing all reinforcement other than for the target response (i.e., r_2 , scratching, exploring, etc.). Thus, changes in target response rate (B) are a hyperbolic function of reinforcement rate for the target response (r). As r increases or decreases, B increases toward or decreases away, respectively, from asymptotic response rates (i.e., k). Although Equation 1 has extensive generality in describing stable response rates on interval schedules as a function of reinforcement rate (see Davison & McCarthy, 1988; Williams, 1988, for reviews), it fails to adequately describe the effects of different

reinforcement histories on relative resistance to change (see Nevin et al., 1990, for a discussion). Behavioral momentum theory, on the other hand, does account for the effects of reinforcement histories on relative resistance to change.

Pavlovian Stimulus-Reinforcer Relation

Two major assumptions of behavioral momentum theory are that relative resistance to change is governed by the relative rate of reinforcement in the presence of S^D s (i.e., Pavlovian stimulus-reinforcer relations), and that resistance to change is independent of differences in baseline response rates (i.e., operant response-reinforcer relations). Two experiments by Nevin and colleagues (1990) give particularly strong empirical support for these assumptions. In Experiment 1, pigeons responded for food on a two-component multiple schedule in which equal VI 60-s schedules were presented in each component. Food reinforcers also were presented response independently according to a VT schedule in one component. Although baseline response rates were lower in the component presenting additional response-independent reinforcement (by increasing r_o in Equation 2), responding was more resistant to pre-session feeding and extinction in the component with added food. Similarly, in Experiment 2, additional reinforcement was presented in one component concurrently on an adjacent key according to a VI schedule. Response rates also were lower and resistance to change was greater in the component with added response-*dependent* reinforcement. Because response rates were lower and resistance to change was greater in components with added food in both experiments, these results suggested that resistance to change is a function of Pavlovian stimulus-reinforcer relations and independent of any differences in operant response-reinforcer

relations. These findings have been replicated using a number of different procedures and species, including rats (Grimes & Shull, 2001; Harper, 1999a, b; Mauro & Mace, 1996; Shahan & Burke, 2004; Shull, Gaynor, & Grimes, 2002), goldfish (Igaki & Sakagami, 2004), and humans (Ahearn, Clark, Gardenier, Chung, & Dube, 2003; Cohen, 1996; Mace et al., 1990).

Modeling Resistance to Change

Equations. Like the effects of intermittent reinforcement rate on VI-schedule performance (Herrnstein, 1970), the effects of reinforcement rate in the presence of a stimulus context on resistance to change also have been described using quantitative modeling. Behavioral momentum theory states that the resistance to change of a response to a disrupting event is proportional to the magnitude of that event and inversely proportional to the rate of reinforcement in the presence of an S^D (Nevin & Grace, 2000a),

$$\log\left(\frac{B_x}{B_o}\right) = \frac{-x}{r^a}, \quad (3)$$

in which B_x is response rates during disruption and B_o is response rates during stable baseline prior to disruption. The proportion of baseline response rates during disruption is transformed to logarithms (logs) to express equal ratios (i.e., B_x / B_o) as equal differences. The value x represents units of the disrupter and is negative to account for the typical response-rate decreasing effects of disrupters. The rate of reinforcement in the presence of an S^D is identified by r . The free parameter a represents sensitivity of changes in

response rate from baseline to disruption to the reinforcement rate in the presence of an S^D .

The left side of Equation 3 is dimensionless and, in addition, no obvious physical unit of measurement can be applied across different types of disrupters (such as grams of food during pre-session feeding versus time in extinction). Therefore, Nevin (1992) suggested that resistance to change be assessed as a relative measure between two stimulus contexts (e.g., multiple-schedule components). To express resistance to change as a relative measure, the difference in resistance to change across two stimulus contexts is examined as a power function of relative reinforcement rate across those contexts (Grace & Nevin, 1997):

$$\log\left(\frac{B_{x1}}{B_{o1}}\right) - \log\left(\frac{B_{x2}}{B_{o2}}\right) = a \log\left(\frac{r_1}{r_2}\right) + \log b . \quad (4)$$

The subscripts in Equation 4 represent the two independent stimulus contexts and the other variables are as in Equation 3. Equation 4 affords several advantages over Equation 3: (a) All ratios are rendered dimensionless, which precludes the need for scaling units of r to units of x ; (b) Because the same disruptive force (x) typically is imposed across components, the terms for disruption are canceled out; (c) It results in a power function relating relative resistance to change to relative reinforcement rate (see Nevin, 1992); and (d) Free parameters (described below) account for deviations from a one-to-one correspondence between changes in relative reinforcement rates and relative resistance to change. These advantages allow for relative resistance to change to be described in a

manner analogous to traditional concurrent-choice performance derived from the matching law (i.e., Equation 1).

The matching law and resistance to change. The *generalized matching law* is derived from Equation 1 and has been used widely to quantify how changes in concurrently available sources of reinforcement (e.g., reinforcer rate, magnitude) affect choice performance (see Davison & McCarthy, 1988, for a review). The generalized matching law examines changes in the *log response ratio* as a function of changes in the *log reinforcer ratio* (see Baum, 1974):

$$\log\left(\frac{B_1}{B_2}\right) = a \log\left(\frac{r_1}{r_2}\right) + \log b . \quad (5)$$

The subscripts represent two concurrently available alternatives for responses (B) and reinforcers (r). Unlike Equation 1, Equation 5 can account for deviations from one-to-one correspondence between relative responding (i.e., $\log [B_1 / B_2]$) and relative reinforcement (i.e., $\log [r_1 / r_2]$) with sensitivity (a) and bias ($\log b$) parameters obtained using least squares linear regression fits. The a parameter is the slope of the function and provides a measure of the sensitivity of response ratios to changes in reinforcement ratios. In Figure 1-2, changes in the response ratio equal to changes in the reinforcer ratio produce a sensitivity measure of 1.0 (solid line), whereas less extreme changes in the response ratio are indicated by a slope < 1.0 (dashed line). The $\log b$ parameter is the y-intercept of the function and accounts for greater responding on one alternative relative to

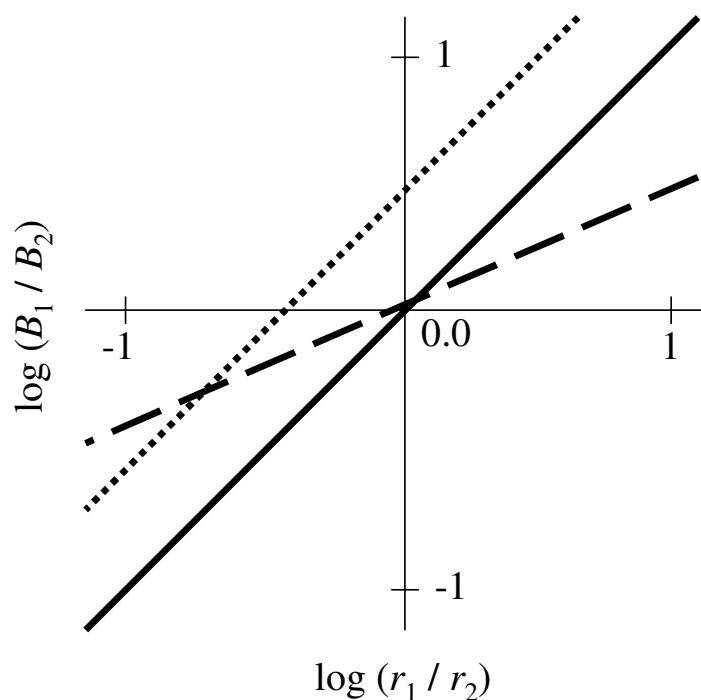


Figure 1-2. Deviations from strict matching described by the generalized matching law (Equation 6). The solid line shows strict matching with the sensitivity parameter (a) equal to 1.0 and the bias parameter ($\log b$) equal to 0.0. The dashed line indicates sensitivity that is less extreme (i.e., $a < 1.0$) than predicted by the reinforcer ratio (i.e., $a = 1.0$). The dotted line shows a bias for B_1 over B_2 (i.e., $\log b > 0.0$).

the other across all reinforcement ratios, or bias. A difference in reinforcer magnitude across alternatives when relative reinforcer rates are varied has been shown to produce bias for alternatives producing reinforcers of larger magnitude (e.g., McLean & Blampied, 2001). A $\log b$ equal to 0.0 (solid line) indicates no systematic bias for one alternative over another. In Figure 1-2, an upward shift of the function ($\log b > 0.0$) would indicate a bias for the first alternative (dotted line). A basic assumption of the generalized matching law is parameter independence between sensitivity and bias. That is, manipulations that affect the sensitivity (a) parameter should not affect the bias ($\log b$) parameter and vice versa.

As previously mentioned, the sensitivity (a) and bias ($\log b$) parameters from Equation 5 have been used similarly to describe changes in relative resistance to change as a function of changes in relative reinforcement rates (Equation 4). Sensitivity (a) of relative resistance to change to changes in relative reinforcement rates in studies using multiple schedules typically has been estimated at about 0.5 (Nevin, 2002; Nevin, McLean, & Grace, 2001). Thus, relative resistance to change tends to be less extreme than predicted by the reinforcer ratio alone. Bias ($\log b$) in relative resistance to change has been shown to be affected by differences in relative reinforcer magnitude when examined across a range of reinforcer rates (e.g., Grace, Bedell, & Nevin, 2002). Further, as with typical findings with concurrent-choice performance (cf. McLean & Blampied, 2001; but see Todorov, 1973), Grace and colleagues showed that the biasing effect of reinforcer magnitude was independent of the sensitivity of relative resistance to change produced by changes in relative reinforcement rates. Thus, Equation 4 has been shown to account quantitatively for the systematic effects of various experimental manipulations in relative resistance to change. In addition, Equation 4 allows for manipulations that affect relative resistance to change to be compared to other quantitative measures of response strength (that will be discussed next).

Resistance to Change and Preference

Nevin (1979) noted that experimental manipulations that typically have been shown to affect relative resistance to change within stimulus contexts also tended to similarly affect preference for one stimulus context over another. Grace and Nevin (2000) provided empirical support for this observation (see also Grace & Nevin, 1997; Grace et

al., 2002; Grace, Schwendiman, & Nevin, 1998; Nevin & Grace, 2000b; Nevin, Grace, Holland, & McLean, 2001). Using pigeons as subjects, they assessed both relative resistance to change and preference with a concurrent-chains procedure. The advantage to studying preference using a concurrent-chains procedure rather than in a simple concurrent-choice situation is that the measure of preference between two stimulus contexts can be examined independent of any shaping effects of the contingencies that maintain responding in those contexts. Figure 1-3 diagrams the concurrent-chains procedure frequently used by Grace and Nevin (see also Grace et al., 2002). Two concurrently available response keys are present during the *initial links*. Both keys are lit white and freely available for the pigeon to peck; however, only one key is randomly selected at a time to provide access to a different context in which food reinforcement is available (i.e., *terminal link*). If the left key is selected, for instance, responding on that key turns off both white keylights according to a VI schedule and provides access to a red key. If the right key is selected, responding turns both white keylights off according to an equal VI schedule and leads to access to a green key. Because the red and green terminal links are mutually exclusive, they have been considered analogous to multiple-schedule components. The equal VI schedules in the initial links ensure that responding the two initial-link keys provides access to both terminal-link options equally as often, regardless of the general distribution of responding across the initial-link keys. When relatively more responding occurs to one initial-link key over the other, it suggests there is “preference” for the terminal-link stimulus paired with that key.

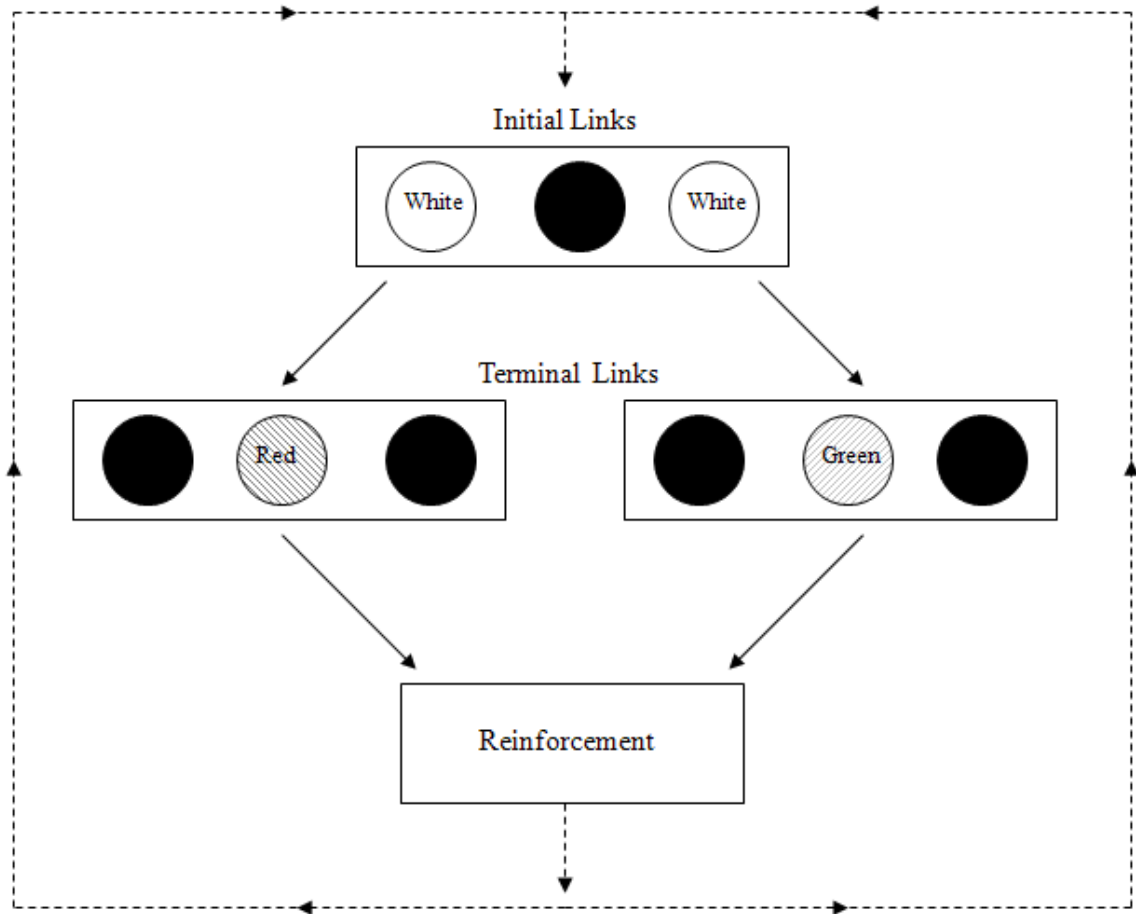


Figure 1-3. Schematic of a cycle of a concurrent-chains procedure. In the initial links, both side keys are lighted white and the center key is dark. Responding on the side keys occasionally produces entry into one of the mutually-exclusive terminal links signaled by the red and green keys. Responding in the terminal links is occasionally reinforced with food. Following termination of the terminal links, the initial links are re-presented.

Grace and Nevin (2000) manipulated relative rate of reinforcement across the two concurrent-chain terminal links. Thus, the *overall* reinforcement rate across the red and green terminal links was the same; however, the *ratio* of reinforcement rates across the red and green terminal links changed across conditions. Once responding was stable in the initial and terminal links in a given condition, relative resistance to change of terminal

link responding was assessed by simultaneously (a) making the transition from the initial links to terminal links response independent, and (b) presenting response-independent food during the initial links. In general, responding tended to be more resistant to change *in*, and preference was greater *for*, the terminal link that presented a relatively higher rate of reinforcement. In addition, like relative resistance to change, preference was shown to be a power function of relative reinforcement rate across terminal-link stimuli. This function relating preference and relative reinforcement rate can be expressed using a modified version of the generalized-matching law (Grace, 1994; Grace & Nevin, 1997):

$$\log\left(\frac{B_{iL}}{B_{iR}}\right) = a \log\left(\frac{r_{iL}}{r_{iR}}\right) + \log b, \quad (6)$$

in which B_{iL} and B_{iR} are total initial-link responses on the left and right keys, respectively (i.e., log preference ratio), and r_{iL} and r_{iR} are the reinforcer rates produced in the corresponding terminal links (i.e., log reinforcer ratio). Similar to Equations 4 and 5, the parameter a represents sensitivity of relative initial-link responding to relative terminal-link reinforcement rates and the parameter $\log b$ represents bias for one initial link over another. Also, similar to Equations 4 and 5, Equation 6 assumes that sensitivity to changes in the log reinforcer ratio is independent of manipulations that affect bias and vice versa. Grace and colleagues (2002) demonstrated parameter independence for both relative resistance to change and preference when the effects of differences in relative reinforcer magnitude were independent of the effects of changes in relative reinforcement rates.

The findings from Grace and Nevin (1997, 2000) suggest that relative resistance to change and preference are similarly affected by manipulations of reinforcer variables, as originally suggested by Nevin (1979). If relative resistance to change and preference are both power functions of relative reinforcement rate, it follows that relative resistance to change and preference must be related by a power function (Grace & Nevin, 1997),

$$\log\left(\frac{B_{x1}}{B_{o1}}\right) - \log\left(\frac{B_{x2}}{B_{o2}}\right) = a \log\left(\frac{B_{iL}}{B_{iR}}\right), \quad (7)$$

in which the left side of Equation 7 is the difference of log proportion baseline response rates across multiple-schedule components or terminal links (i.e., relative resistance to change; see Equation 4). On the right side of Equation 7, the log preference ratio (i.e., B_{iL} / B_{iR}) appears as in the left side of Equation 6. The sensitivity parameter (a) is a ratio of sensitivity parameters from Equation 4 (relative resistance to change) and Equation 6 (preference), but appears as a single value represented by the slope of the function. No bias parameter ($\log b$) appears in Equation 7 because it has no theoretical justification. Using Equation 7, Grace and colleagues (2002) fit the results of all existing experiments to date that have examined the relation between relative resistance to change and preference (Grace & Nevin, 2000; Grace et al., 2002; Nevin & Grace, 2000b; Nevin, Grace, et al., 2001). They found the slope of this function to be approximately 0.29. This relation across a number of procedures and experiments suggest that relative resistance to change and preference provide converging measures of a unitary construct. Grace and colleagues suggested that this construct could be conceptualized as the learning that occurs about the prevailing reinforcement conditions in the presence of a stimulus context

commonly known as response *strength* or *value* (see Nevin & Grace, 2000a, for a discussion).

Qualitatively Different Reinforcers

Although the effects of different reinforcement rates and magnitudes in preference and resistance to change have provided support for behavioral momentum theory, there has been relatively little investigation of these measures when responding is maintained by reinforcers that differ in type, or quality. Reinforcer quality is defined as “a property of reinforcers that does not lie on a single, clearly defined dimension” (Davison & McCarthy, 1988, p. 93) and, therefore, is nominally scaled. Because reinforcer rate and magnitude have predictable effects on relative resistance to change and preference, the effects of different reinforcer types logically also should have predictable effects. Unlike reinforcer rate or magnitude, examining the effects of qualitatively different reinforcers is complicated by the fact that, by definition, quality does not lie on a continuum and cannot be manipulated quantitatively (see Davison & McCarthy; Killeen, 1972, for discussions). Therefore, parametric assessments of the effects of relative reinforcer type on relative resistance to change and preference cannot be established (nor for any other measure for that matter). Nonetheless, understanding the effects of qualitatively different reinforcers on resistance to change and preference is important for generalizing basic findings to natural contexts. Hirsch and Bauman (1987) have suggested that experiments that arrange the availability between only the same reinforcer type are comparable to studying consumer behavior in a store that sells only a single product. Further, some applied

investigators (e.g., Mace, Neef, Shade, & Mauro, 1996; Neef, Mace, & Shade, 1993; Neef, Mace, Shea, & Shade, 1992; Neef, Shade, & Miller, 1994) have shown that qualitative differences between reinforcers can be more effective in determining allocation of socially relevant behavior in humans than more frequently examined continuous variables (e.g., reinforcer rate). Thus, understanding the role of qualitatively different reinforcers in preference and resistance to change is necessary to expand our understanding of variables that affect response strength and the generality of behavioral momentum theory.

The effects of different types of reinforcers have been examined in a number of experimental situations. These include studies of discrimination performance (see Urcuioli, 2005, for a review), the underlying associative mechanisms of learning (see Colwill & Rescorla, 1986, for a review), the economics of substitutes and compliments of different reinforcer types (see Green & Freed, 1993, for a review), the role of alternative non-drug reinforcers on drug-maintained responding (see Carroll, Bickel, & Higgins, 2001, for a review), response deprivation (Allison, 1993), response topography (e.g., Ploog & Zeigler, 1997), reinforcer satiation and habituation (see McSweeney, 2004, for a review), temporal discounting (e.g., Green & Estle, 2003), and others. Due to the extensive range in which different types of reinforcers have been examined, a full review of how qualitatively different reinforcers affect behavior is beyond the scope of this literature review. Therefore, the remainder of the review will focus on how the effects of qualitatively different reinforcers have been examined within the framework of behavioral momentum theory.

Qualitatively Different Reinforcers and Behavioral Momentum Theory

Although the study of qualitatively different reinforcers in preference using typical concurrent-chain procedures has not been investigated, the effects of qualitatively different reinforcers in resistance to change have received some attention. Two studies have shown that adding a response-independent reinforcer that differs qualitatively from those that maintain lever pressing of rats decreases baseline response rates but increases resistance to extinction (Grimes & Shull, 2001; Shahan & Burke, 2004). Grimes and Shull found that resistance to change of food-maintained responding was increased in a multiple-schedule component with added free presentations of sweetened-condensed milk. Similarly, Shahan and Burke found that resistance to change of ethanol-maintained responding was increased in a component presenting additional response-independent food. These results are consistent with the findings from studies that have found increases in resistance to change in a component presenting additional reinforcers that were identical to those maintaining responding across components (e.g., Nevin et al.; Shull et al., 2002). Although these studies show that adding reinforcers increases resistance to change regardless of whether or not they differ in type, these studies did not examine whether a difference in reinforcer type itself differentially affects relative resistance to change.

Mace, Mauro, Boyajian, and Eckert (1997) examined how different reinforcer types affect resistance to change. In one condition, rats were provided daily with 15-min of free access to bottles of a sucrose solution and a citric-acid solution that were concurrently available. After 10 sessions, rats preferred the sucrose solution, as indexed

by relatively larger amounts of sucrose consumed by the end of testing. Next, a two-component multiple schedule was arranged with equal VI 60-s schedules in each component. Lever pressing was reinforced with the sucrose solution in one component and the citric-acid solution in the other. Although baseline response rates were similar in both components, responding was more resistant to a single session of extinction in the sucrose component for all rats. Thus, reinforcers that differ qualitatively, as indexed by a simple choice test, can produce corresponding differences in resistance to change.

The extent to which the role of reinforcer type has been examined within the framework of behavioral momentum theory has been limited. As mentioned, the studies that have enhanced resistance to change by adding qualitatively different reinforcers to one component (Grimes & Shull, 2001; Shahan & Burke, 2004) provide little insight into how differences in reinforcer type per se affects resistance to change. In addition, the study by Mace and colleagues (1997) was limited in several major ways. First, extinction was the only disrupter used by Mace and colleagues. Given that different reinforcer types maintained responding, the effects of different disrupter types likely would be modulated by the reinforcer types maintaining behavior. Experiment 1 of Chapter 2 addressed this issue. Second, there was no manipulation of relative reinforcer type to examine whether changes in relative reinforcer type might affect relative resistance to change. Experiments 2 and 3 of Chapter 2 addressed this issue. Third, preference for the different reinforcer types did not use methods typical of those used within the behavioral momentum framework. Examining the effects of relative reinforcer type on preference with concurrent-chains procedures would allow for the assessment both of preference and

resistance to change and compare those findings with the known relation between those measures. Experiment 3 of Chapter 2 and Chapter 3 addressed this issue. Finally, the effects of changes in relative reinforcer rate along with differences in relative reinforcer type allow for quantifying the effects of qualitatively different reinforcers on preference and resistance to change using modified versions of the generalized matching law (see Equations 4 & 6). Chapter 2 addressed this issue by using methods devised by Miller (1976) to scale different reinforcer types using the bias parameter from the generalized matching law.

CHAPTER 2
THE EFFECTS OF QUALITATIVELY DIFFERENT REINFORCERS
ON PREFERENCE AND RESISTANCE TO CHANGE¹

Abstract

Resistance to disruption of discriminated operant responding typically is greater in stimulus contexts arranging higher rates or larger magnitudes of identical reinforcer types. The present series of experiments examined resistance to disruption when qualitatively different reinforcers were arranged on equal variable-interval schedules across stimulus contexts. In Experiments 1 and 2, food pellets and sucrose solutions were presented in two components of a multiple schedule. In Experiment 1, disrupters were introduced nonuniformly across components by providing free access to one reinforcer type prior to or during sessions. Responding systematically decreased more relative to baseline in the component associated with a reinforcer that was the same as the disrupter. In Experiment 2, extinction was used as a disrupter and the qualitative difference in reinforcer type was manipulated across conditions by changing the sucrose concentration. Relative baseline response rates changed systematically with changes in sucrose concentration, but relative resistance to extinction did not. In Experiment 3, the qualitative difference in reinforcer type was made greater and preference and resistance to extinction were assessed using a concurrent-chains procedure. Relative baseline response rates and preference changed with changes in relative reinforcer type, but

¹Coauthored with Timothy A. Shahan

consistent with Experiment 2 relative resistance to extinction did not. Overall, these findings suggest that relative resistance to change depends upon the disrupter type when qualitatively different reinforcers maintain responding. In addition, relative resistance to extinction appears to be less sensitive to qualitative differences in reinforcers than are baseline response rates and preference.

Introduction

The *discriminated operant* is considered the fundamental unit of operant behavior and is composed of a discriminative-stimulus (S^D) context, a response, and a reinforcing consequence (Skinner, 1938). A number of studies have shown that with training, animals learn associations between each of the components of the discriminated operant (see Colwill, 1993; Colwill & Rescorla, 1986; Rescorla, 1992, for reviews), and the strength of these associations come to motivate or modulate the rate and persistence of operant behavior (e.g., Nevin & Grace, 2000a; Rescorla & Solomon, 1967; Trapold & Overmier, 1972). According to behavioral momentum theory, the rate and persistence of responding are a function of two separable aspects of the discriminated operant (see Nevin & Grace, for a review). The operant relation between responding and reinforcement (i.e., response-reinforcer relation) governs response rates, but resistance to disruption is governed by the Pavlovian relation between an S^D context and the rate of reinforcement presented in that context (i.e., stimulus-reinforcer relation). When responding is maintained in separate stimulus contexts and a disrupter (e.g., extinction, satiation) is introduced uniformly to responding in each context, responses that decrease

less relative to baseline response rates are considered more resistant to change than responses that decrease relatively more. With uniform disrupters, the magnitude of the disrupter is the same across contexts. Thus, any differences in resistance to disruption across contexts should reflect only differences in the response strengthening effects of the baseline conditions of reinforcement (see Nevin, 1974, for a discussion).

Consistent with behavioral momentum theory, many studies have shown that resistance to change tends to be greater in stimulus contexts associated with higher rates or larger magnitudes of reinforcement (e.g., Ahearn et al., 2003; Cohen, 1996; Harper, 1999a, 1999b; Jimenez-Gomez & Shahan, 2007; Mace et al., 1990; Nevin et al., 1990; Podlesnik & Shahan, 2008; Shull et al., 2002; see Nevin, 1992; Nevin & Grace, 2000a, for reviews). For instance, in Nevin and colleagues, pigeons pecked lighted keys for food reinforcement on separate variable-interval (VI) 60-s schedules in two components of a multiple schedule. In one component, additional food was presented response independently on a variable-time (VT) schedule of reinforcement. The added response-independent food degraded the response-reinforcer relation in that component by weakening the contingency between responding and reinforcement, but enhanced the stimulus-reinforcer relation in that component by increasing the overall rate of food presentation in that component. Although baseline response rates were lower in the component with added food, responding in that component was more resistant to disruption by pre-session feeding (i.e., satiation) and extinction. These findings suggest that relative resistance to change is governed by the overall rate of reinforcement in a

stimulus context, even if the additional reinforcement is not dependent on the target response.

Two studies extended the findings of Nevin and colleagues (1990) by showing that reinforcers added response independently to one context can increase resistance to change even when those reinforcers differed qualitatively from those maintaining responding. Grimes and Shull (2001) found that rats' baseline rates of lever pressing for food were lower but more resistant to extinction in a multiple-schedule component with added response-independent sweetened-condensed milk presentations. Shahan and Burke (2004) found that rats' baseline rates of lever pressing for alcohol were lower but more resistant to extinction in a multiple-schedule component with added response-independent food pellets. Although these studies show that added reinforcers differing qualitatively from that maintaining responding can increase resistance to change, these findings do not indicate whether differences in reinforcer type or quality affect relative resistance to change.

Mace and colleagues (1997) directly examined whether responding maintained by qualitatively different reinforcers affected resistance to change (see also Schmidt, McCaleb, & Merrill, 1977). In one condition, water-deprived rats were provided daily with 15 min of free access to concurrently available bottles of a 0.075% sucrose solution and a 0.075% citric-acid solution. After 10 sessions, rats preferred the sucrose solution, as indexed by relatively larger amounts consumed by the end of testing.¹ Next, lever pressing resulted in the presentation of the sucrose solution in one component of a multiple schedule and the citric-acid solution in the other component on separate VI 60-s

schedules. Although baseline response rates were similar in the two components, resistance to extinction was greater in the sucrose component than in the citric-acid component. If the magnitude of disruption with extinction was uniform across contexts, then relative resistance to extinction was a function of the different response strengthening effects of the different reinforcer types. Moreover, these results suggest that qualitative differences in reinforcer type affect relative response strength like quantitative differences in reinforcer rate or magnitude (see Nevin, 1999; Nevin & Grace, 2000a, for related discussions).

Unlike with different reinforcement rates, when qualitatively different reinforcers maintain responding across stimulus contexts, the effects of extinction and pre-session feeding may no longer be directly comparable (see Nevin, 1995, for a related discussion). While extinction might continue to be a uniform disrupter and its effects primarily reflecting the relative strengthening effects of the different reinforcer types (cf. Nevin, McLean, et al., 2001), the disruptive magnitude of pre-session feeding likely is no longer uniform across contexts. Any differences in relative resistance to pre-session feeding would primarily reflect the nonuniform disruptive effects of pre-session feeding—not just the relative strengthening effects of the different reinforcer types. Thus, nonuniform disrupters should decrease responding more when the disrupter is the same as the reinforcer type that maintains responding. Such results would be consistent with findings from studies that devalue one reinforcer type through satiation or pairing with illness (e.g., Balleine, 1992; Balleine & Dickinson, 1998; Colwill & Rescorla, 1985a, 1990; Dickinson, Campos, Varga, & Balleine, 1996; Ploog & Zeigler, 1997; Williams, 1989;

Willis, Hartesvelt, Loken, & Hall, 1974; see Colwill & Rescorla, 1986, for a review; but see Balleine, 2001). These studies use nonuniform disrupters to show that animals learn during training to associate particular reinforcers with the S^D context and/or the response producing that reinforcer.

The purpose of the present series of experiments was to use the procedures and theoretical framework of behavioral momentum theory to examine how uniform and nonuniform disrupters affect discriminated operant behavior maintained by qualitatively different reinforcers. Experiment 1 compared the effects of several nonuniform disrupters while relative reinforcer type was held constant to assess whether responding decreased as a function of disrupter type. Differences in relative resistance to the nonuniform disrupters also would function to show that food pellets and sucrose solutions were functionally different when maintaining responding in Experiments 2 and 3. Experiments 2 and 3 examined the effects of extinction as a uniform disrupter when relative reinforcer type was manipulated across stimulus contexts. In addition, Experiment 3 assessed the effect of changes in relative reinforcer type on an additional measure of relative response strength—preference in concurrent chains schedules.

Experiment 1

Introduction

The purpose of the present experiment was to examine whether relative resistance to disruption of responding maintained by qualitatively different reinforcers was impacted differently when the disrupter was the same or different than the reinforcer

maintaining responding. Lever pressing of rats was maintained on separate VI 60-s schedules of reinforcement in a multiple schedule with food pellets presented in one component and a 15% sucrose solution in the other component. Several nonuniform disrupters were examined that provided free access to either food pellets or the sucrose solution: (a) prior to the session (i.e., pre-session food or sucrose), while food and sucrose continued to be presented during the session; (b) prior to extinction sessions; and (c) throughout the session inside the operant chamber (i.e., contrafreeloading; see Inglis, Forkman, & Lazarus, 1997; Osborne, 1977, for reviews). Based on studies of reinforcer devaluation (e.g., Colwill & Rescorla, 1985a), it was predicted that responding would be less resistant to change on the lever that produced the reinforcer type that was the same as those freely provided.

Method

Subjects. Four Long Evans rats obtained from Charles River (Portage, MI, USA) were maintained at approximately 80% of their adult weights (± 10 g). Rats were approximately 120 days old and experimentally naïve at the start of the experiment. Running weights were 365 g, 376 g, 376 g, and 361 g for N53, N54, N55, and N56, respectively, and were maintained by postsession feeding of Harlan Teklad (Madison, WI, USA) 8604 Rat Diet as necessary. When not in experimental sessions, rats were housed individually in a temperature-controlled colony with a 12:12 hr light/dark cycle (lights on at 7 a.m.). All rats had free access to water in their home cages.

Apparatus. Four Med Associates® (St. Albans, VT, USA) operant conditioning chambers were used. Each chamber was approximately 30 cm long, 24 cm wide, and 21

cm high, and housed in a sound-attenuating cubicle. The front panel of each chamber was equipped with two response levers centered 13 cm apart, a horizontal array of red, yellow, and green LEDs above each lever, a 28-V DC houselight at the top center of the panel, and a Sonalert (2900 ± 500 Hz, 75-85 dB). Between the two levers was a rectangular opening (6.5 cm wide by 4.2 cm high) centered with its bottom edge 2 cm above a grid floor and divided in half vertically. The left side of the opening provided access to a solenoid-operated dipper that delivered 0.1 ml of a 15% sucrose solution. The right side of the opening provided access to 45-mg Noyes® food pellets (Formula A/I) that were accompanied by an audible “click” upon delivery. One pellet was presented per reinforcer in all conditions. During each dipper or food presentation, the lever LEDs and houselight were darkened and a light inside the corresponding side of the opening was turned on for 3 s. Timing of other events was suspended during reinforcement. Extraneous noise was masked by a chamber ventilation fan and white noise. Control of experimental events and data recording was conducted with Med Associates® (St. Albans, VT, USA) interfacing and programming. Sucrose solutions were prepared as percent weight per volume with distilled water and table sugar and stored at room temperature.

Procedure. Across daily sessions, food pellets or sucrose were made available response independently on a variable-time (VT) 60-s schedule. At the start of each session, the lever LEDs over one lever also were turned on and pressing that lever produced food or sucrose on a fixed-ratio (FR) 1 schedule. The LEDs over the other lever were off for the duration of that session. The response-independent and response-

dependent presentations were always the same reinforcer type within a training session. For rats N53 and N55, a steady tone and houselight with the lever LEDs flashing on and off every 0.1 s signaled that responding on the right lever would produce food pellets. A pulsing tone, flashing houselight, and flashing lever LEDs turning on and off every 0.5 s signaled that responding on the left lever would produce sucrose. The lever and stimulus assignments were reversed for rats N54 and N56. These training sessions ended after 60 min or when 200 reinforcer presentations occurred, whichever came first. Rats N53 and N54 were trained with food during the first and third training sessions and with sucrose on the second and fourth training sessions. The order of training sessions was reversed for rats N55 and N56. After the four training sessions, the VT schedule was turned off and a two-component multiple schedule was introduced.

In the multiple schedule, food pellets were presented in one component (hereafter Food component) and sucrose was presented in the other component (hereafter Sucrose component) on VI schedules. Across sessions, the VI schedules increased in both components from VI 1-s to VI 60-s schedules, at which point baseline conditions began. All VI schedules included 13 intervals selected without replacement and constructed as described by Fleshler and Hoffman (1962). Lever and stimulus assignments in the components were the same as during training sessions. Sessions began with a 20-s blackout before the first component and all components were separated by a 20-s intercomponent interval (ICI) during which all stimuli were turned off. The Food or Sucrose component was chosen randomly following the initial blackout and strictly alternated for the rest of the session. Each component was 60 s in duration and sessions

ended after a total of 40 components were presented. If a reinforcer was available but not obtained, it was presented after the first response the next time that component was presented. Sessions occurred 7 days per week at approximately the same time.

Prior to beginning any condition of disruption, baseline conditions were maintained until responding was stable as judged by visual inspection with no increasing or decreasing trends for at least six consecutive sessions. Responding was disrupted in several ways. During pre-session food (PF) or pre-session sucrose (PS), a 12 cm diameter by 2 cm deep porcelain dish was placed in the home cage 2 hr prior to the start of the session for 3 consecutive days. On PF days, approximately 45 g of food pellets were placed in the dish. On PS days, 125 ml of 15% sucrose solution was placed in the dish. In other disruption conditions, PF and PS occurred for 3 consecutive days prior to sessions of extinction (EXT). Other than extinction during the session, PF+EXT and PS+EXT were identical to the PF and PS disrupters. Both PF+EXT and PS+EXT conditions were replicated once after all other disrupters were completed. Responding also was disrupted for three consecutive sessions using a contrafreeloading procedure, in which either 45 g of food pellets (i.e., CFL F) or 125 ml of sucrose (i.e., CFL S) was available in the back of the operant chamber in a porcelain dish. Given that no rat finished all the food pellets or sucrose during any of the disruption conditions, they can be considered conditions of disruption by “free access” to food or sucrose. The order of conditions of disruption for all rats is presented in Table 2-1. Six consecutive sessions of extinction also occurred as the fifth disrupter for all rats (see Table 2-1); however, these findings will be presented with Experiment 2, in which other resistance-to-extinction data are examined.

Results

Figure 2-1 shows response rates in the Food and Sucrose components across successive conditions of baseline prior to each disrupter. For rats N53 and N55, response rates consistently were higher in the Food component. For the first three baselines for N54, response rates were higher in the Food component than in the Sucrose component, after which response rates decreased in the Food component and were similar thereafter in the two components. There were no systematic differences in response rates for N56. Appendix 1 presents the number of baseline sessions prior to disruption, number of sessions during disruption, and response rates in the Food and Sucrose components during baseline and disruption. Reinforcement rates were slightly lower than scheduled but similar in the Food component ($M = 0.93$ per min; $SD = 0.03$) and Sucrose component ($M = 0.92$ per min; $SD = 0.03$).

Inactive lever response rates also are shown in Figure 2-1 to demonstrate that the rats discriminated between the components. Inactive-lever response rates in the Food component are presented as solid lines and inactive-lever response rates in the Sucrose component are presented as dashed lines. Thus, when the lever is active in the Food component the line is solid and when the same lever is inactive in the Sucrose component the line is dashed. When the lever is active in the Sucrose component the line is dashed and when the same lever is inactive in the Food component the line is solid. Response rates consistently were higher when the levers were active than when inactive, indicating that responding was under control by the discriminative stimuli. Mean discrimination indices support this conclusion (Rat N53: $M = 0.88$, $SD = 0.03$; Rat N54: $M = 0.80$, $SD =$

0.10; Rat N55: $M = 0.90$, $SD = 0.04$; Rat N56: $M = 0.86$, $SD = 0.05$). Discrimination indices were calculated as the proportion of responses on one lever when a component was active in the numerator and responses on that lever when the component was active and inactive in the denominator.

Figure 2-2 shows an analysis of resistance to disruption in the component in which the reinforcer was *different* than the nonuniform disrupter (e.g., Food component with PS disrupter; y-axis) as a function of the component in which the reinforcer was the *same* as the nonuniform disrupter (e.g., Sucrose component with PS disrupter; x-axis). Each data point represents the logarithm (log) of the mean proportion of baseline response rates for the three sessions of each disruption condition. The relative magnitude of disruption is indexed by how far the symbols decrease from 0.0 down along the y-axis and to the left along the x-axis. Therefore, points falling above the diagonal line indicate that responding decreased relatively more in the component that produced the same reinforcer type as the nonuniform disrupter. Filled symbols indicate disruption by providing access to food and open symbols indicate disruption by providing access to sucrose.

Overall, data points fell above the diagonal line in 31 out of 32 instances across rats, with the only exception being from the first PS+EXT for N53. These data indicate that responding typically was disrupted more in the component that produced the reinforcer that was the same as the disrupter. There were never food pellets remaining in the pellet troughs following disruption sessions, indicating that pellets were eaten when they were earned (cf. Ploog & Zeigler, 1997). Such verification of consumption was not

possible with the sucrose reinforcers. When comparing access to food versus sucrose as disrupters, in all cases, access to food decreased responding more in both components than access to sucrose. This is indicated by the solid data points falling further down along the y-axis and to the left along the x-axis than the corresponding open data points. In addition, disruption with PF+EXT and CFL F typically produced greater amounts of disruption in both components than PF. Similarly, disruption with PS+EXT and CFL S typically produced greater amounts of disruption in both components than PS. Finally, relative resistance to PF+EXT and PS+EXT tended to increase from the first to the second PF+EXT and PS+EXT. The exception was PS+EXT for N55; those data points overlap. Overall, the nonuniform disrupters decreased responding more when they were the same as the reinforcer than when they were different than the reinforcer.

Discussion

The present experiment showed that nonuniform disrupters decreased responding more relative to baseline in a context presenting a reinforcer that was the same type as the disrupter than in a context presenting a different reinforcer type. In general, these findings replicated previous studies in which responding decreased more when associated with a reinforcer type that was devalued by satiation or pairing with illness (e.g., Colwill & Rescorla, 1985a, 1986, 1990), or when responding decreased more in one context associated with a reinforcer type that was the same as that presented response independently in two contexts (e.g., Colwill & Rescorla, 1986; Williams, 1989). Within the context of behavioral momentum theory, these data could be viewed as reflecting that

the magnitude of disruption (i.e., force) was greater when the disrupter and reinforcer type were the same than when the disrupter and reinforcer type were different.

Although the overall patterns of disruption were similar across the nonuniform disrupters, there were some subtle differences across disrupters. First, disrupters that provided access to food impacted responding in both the Food and Sucrose components more than the complimentary disrupters that provided access to sucrose. These results suggest that free access to food functioned as a more effective disrupter of both Food and Sucrose lever pressing than free access to sucrose. According to behavioral momentum theory, free access to food served as a stronger force, or larger magnitude disrupter of responding, across both stimulus contexts than did free access to sucrose.

Second, the overall amount of disruption of responding in the two components also differed with the food and sucrose disrupters. For instance, PF+EXT and CFL F consistently decreased responding more in both components than PF. Similarly, PS+EXT and CFL S consistently decreased responding more in both components than PS. With PF and PS, the disrupters were introduced prior to the session only and likely decreased responding by diminishing the value of those reinforcers through satiation (or habituation; see Murphy, McSweeney, & Kowal, 2003). On the other hand, CFL F, CFL S, PF+EXT, and PS+EXT might have disrupted responding in more than one way. With CFL F and CFL S, free access to one reinforcer type throughout a session could have differentially decreased the value of the two reinforcer types through satiation or habituation, and/or degraded the response-reinforcer relations in both contexts by providing an alternative source of reinforcement (see Herrnstein, 1970; cf. Williams,

1989). With PF+EXT and PS+EXT, two disrupters were combined and introduced both prior to the session (i.e., PF or PS) and during the session (i.e., EXT). Combining different disrupters has been shown to produce greater decreases in responding compared to the effects of the constituents alone (see Nevin, 2002, for a discussion).

Finally, differences also were found within disrupters. In 7 out of 8 instances, differences in relative resistance to disruption across the Food and Sucrose components with PF+EXT and PS+EXT increased with the replication of those disrupters. The overall greater number of baseline training sessions from the start of the experiment prior to the replication could have been responsible. The two reinforcer types might have become better associated with the responses and/or stimulus contexts with increased training (see Colwill & Rescorla, 1985b). Alternatively, some learning about the disrupters themselves might have occurred from the first to the second presentation of those disrupters (see Balleine, 2001; Anger & Anger, 1976, for examples). Given that PF+EXT and PS+EXT were the only disrufter types that were replicated, it is unclear whether similar results would have been found with the other disrupters.

The CFL data from the present experiment might have some relevance to understanding contrafreeloading in general. To our knowledge, the present experiment was the first to assess contrafreeloading with one reinforcer type while two reinforcer types maintained responding within the same session. The present results show that seeking alternative food sources (i.e., the response-dependent source) occurs less frequently when the free source is the same as the potential alternative, response-dependent source.

Experiment 2

Introduction

Nonuniformly disrupting responding produced differential decreases in responding across components in Experiment 1. These findings also showed that the food pellets and sucrose solutions functioned as qualitatively different reinforcers. Given that the differences in reinforcer type have been demonstrated to have functional differences, the different response-strengthening effects of food pellets versus sucrose solutions can be assessed. Therefore, Experiment 2 assessed the effects of a more uniform disrupter, extinction, on responding maintained by qualitatively different reinforcers. Mace and colleagues (1997) found that responding for a sucrose solution (a more-preferred reinforcer) was more resistant to extinction than responding for a citric-acid solution (a less-preferred reinforcer). We extended Mace and colleagues by assessing relative resistance to extinction following manipulations of relative reinforcer type across conditions. Specifically, food pellets maintained responding in one component of a multiple schedule and either a 15% sucrose solution or a 5% sucrose solution maintained responding in the other component. Because the food pellet and volume of the sucrose solutions were held constant across conditions, any changes in relative resistance to extinction across conditions should be a function of the differences in relative reinforcer type (i.e., between food pellets and the 15% sucrose solution versus food pellets and the 5% sucrose solution).

Method

Subjects and apparatus. The same subjects and apparatus from Experiment 1 were used.

Procedure. Table 2-1 shows the order of conditions for Experiment 2. Following the last nonuniform disrupter in Experiment 1, all rats were returned to the same multiple schedule as in Experiment 1 with VI 60-s schedules of reinforcement of food pellets in the Food component and 15% sucrose in the Sucrose component [hereafter, the 15%(1) condition]. Once response rates reached stability, lever pressing in both components was extinguished for six consecutive sessions. Note that the first extinction occurred during the fifth consecutive baseline of Experiment 1 for all rats. Next, the sucrose concentration was changed to a 5% sucrose concentration in the Sucrose component, while the Food component remained the same (hereafter, the 5% condition). Two exposures to extinction occurred with at least six sessions of stable baseline responding prior to each extinction condition. Finally, the sucrose concentration was changed back to 15% sucrose in the Sucrose component [hereafter, the 15%(2) condition] and two more exposures to extinction occurred following stability in response rates prior to each extinction.

Results

Figure 2-3 shows response rates in the Food and Sucrose components across successive conditions of baseline prior to each extinction. Response rates were higher in the Food component in both conditions for rats N53 and N55, whereas response rates only were higher in the Food component during the 5% sucrose condition for rats N54 and N56. Response rates in the Food component did not differ systematically across

conditions; however, response rates tended to be lower in the Sucrose component when maintained by 5% sucrose than by 15% sucrose. As in Experiment 1, response rates consistently were higher when the levers were active than when inactive, indicating that responding was under discriminative control. Mean discrimination indices were calculated as in Experiment 1 (Rat N53: $M = 0.83$, $SD = 0.19$; Rat N54: $M = 0.79$, $SD = 0.11$; Rat N55: $M = 0.86$, $SD = 0.13$; Rat N56: $M = 0.88$, $SD = 0.07$). Appendix 2 includes mean baseline response rates, the number of sessions of baseline prior to disruption, and response rates during individual sessions of disruption. Reinforcement rates were similar across components for the 15%(1) condition (Food: $M = 0.91$ per min; $SD = 0.04$; Sucrose: $M = 0.91$ per min; $SD = 0.05$), the 5% condition (Food: $M = 0.93$ per min; $SD = 0.05$; Sucrose: $M = 0.91$ per min; $SD = 0.07$), and the 15%(2) condition (Food: $M = 0.93$ per min; $SD = 0.04$; Sucrose: $M = 0.92$ per min; $SD = 0.02$).

The left panel of Figure 2-4 shows the log ratio of baseline response rates in the Food and Sucrose components. Values falling above 0.0 indicate that relative response rates were greater in the Food component and values falling below 0.0 indicate that relative response rates were greater in the Sucrose component. For all four rats, response rates were more similar in the two components (closer to 0.0) when responding in the Sucrose component was maintained by 15% sucrose than when responding was maintained by 5% sucrose. These findings suggest that the 15% sucrose was a more effective reinforcer relative to food pellets than the 5% sucrose.

The right panel of Figure 2-4 shows the difference between log mean proportion of baseline response rates in the Food and Sucrose components (see Grace & Nevin,

1997) from the six sessions of extinction. Values falling above and below the origin indicate greater and less resistance to extinction, respectively, in the Food component than in the Sucrose component. There were no systematic differences in relative resistance to extinction when the sucrose concentration was changed from 15% to 5% and back to 15% sucrose. Further, there were no systematic differences in the two resistance to extinction tests at each sucrose concentration. Overall, relative resistance to extinction was greater in the Food component (i.e., difference > 0) in 16 out of 24 instances.

To examine relative resistance to change in the same format as in Experiment 1 (see Figure 2-2), and to assess the magnitude of disruption by extinction, Figure 2-5 shows log mean proportion of baseline response rates in the Food component (x -axis) against log mean proportion of baseline response rates in the Sucrose component (y -axis). Consistent with the right panel of Figure 2-4, there were no consistent differences in relative resistance to extinction across components or conditions. In addition, there was no systematic difference in the magnitude of disruption across conditions. In Figure 2-6, the relative resistance to extinction also was assessed for the first session in the top panel and for the first three sessions in the bottom panel as a function of relative resistance to extinction across all six sessions. This was done to see whether the general pattern of results differed if examined as in Mace and colleagues (1997; one session) or as in Experiment 1 (three sessions). Data points are from individual extinction tests for each rat. Data points falling along the diagonal line indicate that there were no differences in relative resistance to extinction between six sessions and one or three sessions. Given that

the data points do not systematically deviate from the diagonal line in either panel, these data suggest that the pattern of disruption was similar when analyzed after one, three, or six sessions. Overall, these data show that relative baseline response rates were systematically affected by changes in sucrose concentration, but relative resistance to extinction was not.

Discussion

Response rates were higher in the Food component relative to in the Sucrose component for all rats when the sucrose concentration was 5% than when it was 15%. These findings are consistent with previous studies that have found that response rates of rats tend to increase with increases in sucrose concentration (e.g., Conrad & Sidman, 1956; Heyman & Monaghan, 1994; Shahan, 2002). Shanab and Gersh (1976) examined different groups of rats lever pressing for 8%, 16%, or 32% sucrose solutions and 45-mg food pellets across components of a multiple schedule. They found higher response rates for food pellets than for sucrose across all groups of rats with identical deprivation conditions (i.e., 80% of free-feeding weight). Unlike in Shanab and Gersh, response rates for food pellets were not greater than those for sucrose across both sucrose concentrations for all rats in the present experiment. This discrepancy might be due to different rat strains or procedural details (e.g., use of ICI, VI schedule value, component length, etc.). Nonetheless, the relative baseline response rates from Experiment 2 suggest that the 15% sucrose solution was a more effective reinforcer relative to food pellets than was the 5% sucrose solution.

Despite the differences in relative baseline response rates with changes in sucrose concentration, resistance to extinction was not systematically affected by the changes in sucrose concentration. Moreover, relative resistance to extinction was not always consistent between successive conditions of extinction when the sucrose concentration was held constant. The only other study to examine resistance to extinction of responding maintained by qualitatively different reinforcers in a multiple schedule is Mace and colleagues (1997). They found that baseline rates of lever pressing for sucrose or citric-acid solutions did not differ across components, yet resistance to extinction was greater in the component presenting the sucrose solution.

One possible reason that relative resistance to extinction changed systematically as a function of reinforcer type in Mace and colleagues (1997) but not in the present experiment is that the reinforcers were not different enough in the present experiment. There may have been no differential strengthening effects of the sucrose concentrations relative to food, whereas the sucrose and citric-acid reinforcers in Mace and colleagues did. If this was the case, the changes in sucrose concentration across conditions in the present experiment might not have been great enough for relative resistance to extinction to detect any potentially different strengthening effects. Importantly, Mace and colleagues also used a converging preference measure to determine that the sucrose solution was a more effective reinforcer than the citric-acid solution. Differences in reinforcer effectiveness in the present experiment could only be made on the basis of changes in baseline response rates when sucrose concentration was manipulated. Therefore, differences in baseline response rates could have been a function of variables

other than the strengthening effects of reinforcement (see Morse, 1966; Nevin, 1974, for discussions).

Experiment 3

Experiment 2 showed that changing relative reinforcer quality across conditions systematically affected baseline response rates in two components of a multiple schedule but not relative resistance to extinction. Given that response rates can be affected by both the shaping and strengthening effects of reinforcement (see Nevin, 1974, for a discussion), it is not clear that the changes in relative response rates in Experiment 2 necessarily reflected changes in relative response strength when the sucrose concentration was manipulated. Experiment 3 attempted to improve on Experiment 2 in two ways. First, the qualitative difference was increased between the reinforcers across conditions. Instead of changing sucrose concentration, as in Experiment 2, food pellets were maintained across three conditions, while a 50% sweetened-condensed milk solution and a 10% sucrose solution alternated across conditions. Second, in addition to assessing baseline response rates and resistance to extinction, preference for the different reinforcer types was assessed using a concurrent-chains procedure (cf. Nevin & Grace, 2000a). Given that preference and relative resistance to change have been shown to be related and both are considered expressions of response strength (see Grace et al., 2002, for a summary of these findings), preference and relative resistance to extinction should be affected similarly by the changes in reinforcer type. Thus, preference and resistance to

extinction provide potentially converging measures of whether changing relative reinforcer type affects relative response strength.

Method

Subjects. Four Long Evans rats were obtained, maintained, and housed in the same way as described for the rats in Experiments 1 and 2. Running weights were 300 g, 312 g, 299 g, and 317 g, for Rats N93, N94, N95, and N96, respectively. All rats had prior experience with a similar procedure prior to the beginning of the experiment.

Apparatus. Two Med Associates® (St. Albans, VT, USA) operant conditioning chambers were used. Each chamber was approximately 30 cm long, 24 cm wide, 21 cm high, and housed in a sound-attenuating cubicle. The back panel of each chamber was equipped with two response levers centered 13 cm apart and a horizontal array of red, yellow, and green LEDs above each lever. The front panel of each chamber was equipped with a 28-V DC houselight at the top center of the panel, a Sonalert (2900 ± 500 Hz, 75-85 dB), and three rectangular openings (3.2 cm wide by 4.1 cm high) centered with 5 cm between each opening, 2 cm from each side of the chamber, and the bottom edges 2 cm above a grid floor. Only the center and right openings were used. The right opening provided access to a solenoid-operated dipper that delivered 0.1 ml of either a sucrose solution or a sweetened-condensed milk solution. The center opening provided access to 45-mg Bio-Serv food pellets (Product# F0165). One pellet was presented as reinforcement. During dipper and food presentations, lever LEDs and the houselight were darkened while a light inside the activated opening was turned on for 3 s. Pellet deliveries were accompanied by an audible brief “double click.” Timing of other events was

suspended during reinforcement. A chamber ventilation fan masked extraneous noise. Control of experimental events and data recording was conducted with Med Associates® (St. Albans, VT, USA) interfacing and programming. The 10% sucrose solutions were prepared as described in Experiment 2. The 50% sweetened-condensed milk solutions were prepared as percent volume per volume with distilled water and Meadow Gold® sweetened-condensed milk. Sweetened-condensed milk (hereafter milk) solutions were stored in a refrigerator between sessions.

Procedure. Responding in the initial links of concurrent-chains schedules provided access to two mutually exclusive terminal links. In one terminal link, responding was reinforced with food pellets. In the other terminal link, responding was reinforced with one of two liquids, either a milk solution or a sucrose solution. Milk was presented during Conditions 1 and 3, while sucrose was presented during Condition 2. Resistance to extinction of terminal-link responding was assessed in each condition.

Rats N93 and N94 were run in the two chambers immediately before rats N95 and N96. Because all rats had experience with the concurrent-chains procedure, they began the experiment on the final procedure. Each session ended after 24 cycles of a concurrent-chains procedure or 60 min, whichever came first. A cycle began in the initial links of the concurrent chains with the houselight off and both lever lights illuminated. Responding in the initial links provided access to one of two mutually exclusive terminal links. On each cycle, terminal-link entries were randomly assigned to either the left or right lever, with the restriction that exactly 12 terminal-link entries occurred to each side per session. Terminal-link entries to the left and right terminal links were scheduled on

separate arithmetic VI 25-s schedule (see Grace & Nevin, 2000, for interval construction). There were 12 intervals for each arithmetic VI schedule. Therefore, exactly 12 terminal-link entries occurred on the left and right levers. A terminal link entry occurred when: (a) that lever was selected; (b) the VI schedule had elapsed; (c) a response occurred on the corresponding lever; and (d) a 1.5-s changeover delay had elapsed since the last response on the lever on which the terminal-link entry was not arranged. Timing of the initial-link VI schedules did not begin until one response occurred to either lever (cf. Grace & Nevin).

Entries into the terminal links were signaled by either: (a) a steady tone and houselight with one lever light flashing on and off every 0.1 s, or (b) a pulsing tone, flashing houselight, and flashing lever light turning on and off every 0.5 s. In the terminal links, responding on the left lever produced access to the liquid solution (sucrose or milk) and responding on the right lever produced access to food pellets on independent VI 20-s schedules without replacement according to Fleschler and Hoffman (1962). Both terminal links were always a constant 60 s in duration, excluding reinforcer time. If a reinforcer was available but not obtained, it was presented after the first response the next time that terminal link was presented. After a terminal link ended, the initial links were immediately introduced again. For rats N94 and N95, the steady tone and houselight were paired with the liquid reinforcer terminal link and the pulsing tone and flashing houselight were paired with the food reinforcer terminal link. The assignments were reversed for rats N93 and N96.

Each condition included 30 baseline sessions followed by six sessions of disruption with extinction. After extinction, the baseline schedules in the initial and terminal links were reinstated and the type of liquid reinforcer was changed from milk in Condition 1 to sucrose in Condition 2 and back to milk in Condition 3. Resistance to extinction of terminal-link responding was assessed by making transitions from the initial links to terminal links response independent on a VT 25-s schedule, and discontinuing reinforcement in both terminal links (see Grace & Nevin, 2000). Sessions occurred 7 days per week at approximately the same time.

Results

Response rates were assessed in the initial links during baseline and in the terminal links during baseline and disruption. Appendix 3 presents mean response rates in the initial and terminal links from the last six sessions of baseline and each session of disruption. The top panel of Figure 2-7 shows preference for each rat as the log ratio of mean Food-to-Liquid initial-link response rates from the last six sessions of baseline prior to disruption. Thus, positive values indicate greater responding in the initial link providing access to the Food terminal link. In all cases except Phase 3 (i.e., the second food and milk comparison) for N94, the Food terminal link was preferred over the Liquid terminal link. Moreover, for all rats, preference for the Food terminal link over the Liquid terminal link was greater when sucrose rather than milk was presented in the Liquid terminal link. Terminal link reinforcers per min were similar both across components and conditions (Condition 1—Food: $M = 2.68$, $SD = 0.12$; Liquid: $M = 2.80$, $SD = 0.08$;

Condition 2—Food: $M = 2.73$, $SD = 0.11$; Liquid: $M = 2.68$, $SD = 0.12$; Condition 3—Food: $M = 2.85$, $SD = 0.07$; Liquid: $M = 2.81$, $SD = 0.09$).

The overall rate of access to the terminal links (i.e., all terminal link entries/total initial-link time) was greater when milk was presented in the Liquid terminal link (Condition 1: $M = 1.94$, $SD = 0.12$; Condition 3: $M = 1.99$, $SD = 0.10$) than when sucrose was presented in the Liquid terminal link (Condition 2: $M = 1.67$, $SD = 0.10$). These differences in terminal-link entry rate likely do not explain the changes in preference across phases when milk and sucrose were presented in the Liquid terminal link. All major models of concurrent-chain performance (e.g., Grace, 1994; Mazur, 2001; Squires & Fantino, 1971) predict that preference should become increasingly indifferent as the terminal-link entry rate decreases (i.e., as initial links increase). Thus, if preference was driven exclusively by terminal-link entry rate, preference for the Food terminal link should have become *less extreme* when sucrose was presented in the Liquid terminal link, rather than more extreme.

The bottom panel of Figure 2-7 shows response rates in the Food and Liquid terminal links across the three conditions. Across rats, there were no systematic differences in response rates across the Food and Liquid terminal links. Response rates were higher in the Food terminal link for rats N93 and N95, but response rates did not always differ across Food and Liquid terminal links for rats N94 and N96. Although response rates were not consistently different across conditions in the Food terminal link across rats, response rates consistently were lower in the Liquid terminal link when sucrose was presented. Response rates consistently were lower on both levers when

inactive compared to when active in the terminal links. Mean discrimination indices were calculated as in Experiments 1 and 2 (Rat N93: $M = 0.94$, $SD = 0.07$; Rat N94: $M = 0.99$, $SD = 0.01$; Rat N95: $M = 0.99$, $SD = 0.00$; Rat N96: $M = 0.97$, $SD = 0.02$).

The second panel from the top of Figure 2-7 shows relative terminal-link response rates as the log ratio of mean Food-to-Liquid terminal-link response rates from the last six sessions of baseline prior to disruption for each rat. For Rats N93 and N95, relative response rates consistently were greater in the Food terminal link across all phases. For Rat N94, response rates were higher in the Liquid terminal link across all phases. For rat N96, response rates tended to be similar across terminal links when milk was presented in the Liquid terminal link and slightly greater in the Food terminal link when sucrose was presented. Comparing the baseline terminal-link response ratios when sucrose and milk were presented, the ratios always were greater when sucrose was presented than when milk was presented. Thus, relative to food, the milk solution was a more effective reinforcer of terminal link responding than the sucrose solution.

The third panel from the top of Figure 2-7 shows relative resistance to extinction as the difference between log mean proportion of baseline response rates in the Food and Liquid terminal links (see Equation 3). Relative resistance to extinction varied across rats. Unlike preference and baseline terminal link response rates, resistance to extinction did not systematically change with changes in reinforcer type in the Liquid terminal link for rats N93 and N95. Instead, relative resistance to extinction in the Liquid terminal link increased across conditions for both rats. Further, resistance to extinction consistently was greater in the Food terminal link for N93 and in the Liquid terminal link for N95. For

rats N94 and N96, however, relative resistance to extinction changed with changes in reinforcer type in the Liquid terminal link. Similar to the effects of milk versus sucrose on preference and terminal link response rates, milk produced greater relative resistance to extinction in the Liquid terminal link than sucrose. Therefore, resistance to extinction varied systematically with reinforcer type in some cases (Rats N94 and N96), but not in others (Rats N93 and N95).

Figure 2-8 shows log mean proportion of baseline response rates in the Food terminal link (y -axis) against the log mean proportion of baseline response rates in the Liquid terminal link (x -axis) across all rats and conditions. The overall magnitude of disruption across both terminal links relative to baseline increased from the first exposure to extinction to the second and third exposures to extinction. There were no systematic differences in the overall magnitude of disruption, however, following the second and third exposures to extinction. Note that the second exposure to extinction for N93 (gray circle) is not visible because it overlaps with the third exposure to extinction for N93 (white circle). Figure 2-9 plots relative resistance to extinction from the first session and from the mean of the first three sessions of extinction as a function of relative resistance to extinction from all sessions. Each data point is from an individual extinction test. As in Experiment 2, the data points did not systematically deviate from the dashed diagonal line. Therefore, the pattern of disruption when assessed across all six sessions was similar to when assessed across a single session as in Mace and colleagues (1997) or as the mean from three sessions as in Experiment 1.

According to behavioral momentum theory, preference and relative resistance to change both are considered expressions of the underlying central construct of response strength (Nevin & Grace, 2000b). Variables that affect preference should similarly affect relative resistance to change and vice versa. Figure 2-10 shows the relation between relative resistance to extinction on the y -axis and preference on the x -axis for each rat across conditions. Linear regression slopes were negative for N93 (-0.14) and positive for rats N94 (0.31), N95 (0.49), and N96 (0.19). (Because the difference in slope between regression and structural-relation lines [see Isaac, 1970] did not exceed 0.04 [N95], regression analyses were used for convenience.) At least two important points should be noted. First, three data points per rat were not sufficient for a strong test of the parameters of the model relating resistance to change and preference. Thus, the slopes of the regression lines can only be considered suggestive of the relation between resistance to change and preference. Second, the regression slope was positive for N95 even though the values for preference always were positive and the values for relative resistance to extinction were always negative (see Figure 2-7). Therefore, even the positive relations between relative resistance to extinction and preference do not reflect an easily interpretable relation between those measures when reinforcer type changed across conditions.

Discussion

Experiment 3 attempted to improve on Experiment 2 by increasing the qualitative difference in relative reinforcer type across contexts and also by assessing whether preference changed as a result of those changes in relative reinforcer type. Consistent

with Experiment 2, Experiment 3 showed that changes in relative reinforcer type systematically affected relative baseline response rates, but relative resistance to extinction was not systematically affected. In addition, preference also was systematically affected by changes in relative reinforcer type. According to behavioral momentum theory, resistance to change and preference both are considered expressions of relative response strength (Nevin & Grace, 2000a). Therefore, if manipulating relative reinforcer type affected relative response strength, both relative resistance to extinction and preference should be similarly affected. Given the inconsistency in the effects of reinforcer type on preference and relative resistance to extinction, it remains unclear whether changes in reinforcer type affected relative response strength in the present experiments. One possibility supported by previous findings is that, unlike preference, relative resistance to extinction was not sensitive enough to detect the differences in response strength (see Nevin & Grace, 2000b; Nevin, Grace, et al., 2001).

General Discussion

Experiment 1 showed that nonuniformly disrupting responding with free access to one reinforcer type prior to or during sessions decreased responding relative to baseline consistently more in the context producing the same reinforcer type as the disrupter. Experiments 2 and 3 found that the effects of extinction as a uniform disrupter were not systematic across two contexts presenting qualitatively different reinforcers. Specifically, when relative reinforcer type was manipulated, baseline response rates (Experiments 2 &

3) and preference (Experiment 3) changed systematically, but relative resistance to extinction did not.

One question that follows from these findings is why the nonuniform disrupters systematically disrupted responding across contexts but the uniform disrupter (extinction) did not. According to behavioral momentum theory, relative resistance to change is a function of the relative value of reinforcement across contexts and the relative force of disruption applied across contexts (Grace et al., 2002; Nevin, 1992; Nevin & Grace, 2000a). Thus, when rate of reinforcement is equal across stimulus contexts and relative reinforcer type differs:

$$\log\left(\frac{B_{x1}}{B_{o1}}\right) - \log\left(\frac{B_{x2}}{B_{o2}}\right) = a_q \log\left(\frac{q_1}{q_2}\right) + \log\left(\frac{f_1}{f_2}\right). \quad (1)$$

With two stimulus contexts indicated by the subscripts, response rates during disruption (B_x) relative to baseline response rates (B_o) are a function of the reinforcer type, or quality (q), and the magnitude or force (f) of disruption (cf. Grace & Nevin, 1997). The free parameter a_q indicates the sensitivity of relative resistance to change to relative reinforcer type.

With extinction, if $f_1 = f_2$ in Equation 1, relative resistance to extinction should solely be a function of the relative response-strengthening effects of the baseline reinforcer types. Resistance to the nonuniform disrupters, conversely, should have been a function of both the response-strengthening effects of the baseline reinforcer types and the relative force of nonuniform disruption. When uniform and nonuniform disrupters were combined during PF+EXT and PS+EXT in Experiment 1, the effects of those

disrupters more closely resembled the effects of the other nonuniform disrupters than extinction alone. The most likely explanation according to Equation 1 is that the difference in force (f) across contexts was greater than any differences in the response-strengthening effects of the different reinforcer types. If this account is correct, then systematically decreasing the magnitude of the nonuniform disrupters should produce increasingly unsystematic results similar to those found in Experiment 2 with extinction alone.

The above interpretation suggests that resistance to extinction was not affected by relative reinforcer type because either: (a) The qualitative difference between reinforcer types was not large enough to impact relative response strength (i.e., $q_1 \approx q_2$ in Equation 1); or (b) The different reinforcer types impacted relative response strength but relative resistance to extinction was not sensitive to those differences in reinforcer type (i.e., $a_q \approx 0$ in Equation 1). The finding that relative baseline response rates (Experiments 2 & 3) and preference (Experiment 3) were sensitive to changes in relative reinforcer type suggests the latter explanation. Low sensitivity of relative resistance to extinction to differences in reinforcer type is supported by previous findings that relative resistance to disruption has been less sensitive to changes in relative *reinforcer rate* than measures of preference in concurrent-chains procedures (e.g., Grace et al., 2002; Grace & Nevin, 1997, 2000; Nevin & Grace, 2000b; Nevin, Grace, et al., 2001). Moreover, relative resistance to extinction in particular has been found to be less sensitive to changes in relative reinforcer rate than resistance to other disrupters (e.g., Nevin & Grace; Nevin, Grace, et al.). Increasing the qualitative difference in reinforcer type across contexts or

using other disrupters that can be introduced uniformly across contexts (e.g., punishment, conditioned suppression, increased effort; see Nevin, 1979, 1995; Schmidt et al., 1977) might be sufficient to detect possible differences in relative response strength.

Even if relative resistance to extinction consistently is less sensitive to changes in conditions of reinforcement than other measures of relative response strength, it is not clear that the lack of sensitivity can be attributed to the same factors when reinforcer type differs as when reinforcer rate differs. When resistance to extinction has not been greater in stimulus contexts presenting higher rates of reinforcement (i.e., the partial-reinforcement-extinction effect), those findings have been attributed to a *generalization decrement* in contexts presenting lower reinforcement rates (e.g., Grace, McLean, & Nevin, 2003; Nevin & Grace, 1999; Nevin, McLean, et al., 2001). Because extinction produces greater changes in reinforcement rate in rich contexts, behavioral momentum theory suggests that those changes are discriminated and function as larger magnitude disrupters in rich contexts (i.e., $f_1 \neq f_2$; Nevin & Grace, 2000a). To account for the present extinction results, transitioning to extinction following a baseline presenting different reinforcer types also must be discriminated as a greater change in one stimulus context. This is unlikely given that: (a) the influence of generalization decrement has been eliminated in studies of resistance to extinction by presenting equal rates of different reinforcer magnitudes across stimulus contexts (e.g., Nevin, McLean, et al.; Shull & Grimes, 2006); and (b) different reinforcers have been shown to affect choice behavior in the same way as differences in relative reinforcer magnitude (e.g., Hamblin & Miller, 1977; Hollard & Davison, 1971; Miller, 1976). If responding maintained by different

reinforcer magnitudes is not impacted by a generalization decrement, then neither should responding maintained by different reinforcer types.

How can the unsystematic resistance to extinction with different reinforcer types from the present experiment be reconciled with the systematic findings from Mace and colleagues (1997)? One possibility is the differences in the conditions of deprivation and reinforcers that were used. The rats in Mace and colleagues were water deprived and responded for two liquid reinforcers (i.e., 0.075% sucrose and 0.075% citric-acid solutions). These weak solutions ostensibly were water with different flavors, with the citric-acid solution likely being less palatable relative to the sucrose solution or even aversive (see Sclafani, 1991). Conversely, the rats in the present experiments were food deprived and responded for one solid reinforcer (i.e., food pellets) and one liquid reinforcer (i.e., milk or sucrose solutions). Unlike the liquid reinforcers used by Mace and colleagues, there were a number of factors that made the food pellets and the milk and sucrose solutions qualitatively different (e.g., palatability, texture, caloric density, etc.). It is unclear how these differences in deprivation conditions and reinforcer types impact underlying response strength.

Differences in deprivation conditions and reinforcer types likely also differentially affect the degree to which reinforcers are *substitutable*. Substitutability is a continuum of possible interactions between reinforcer types, with substitutability being greatest with identical reinforcers (see Green & Freed, 1993, for a discussion). Most previous studies within a behavioral momentum framework have examined the effects of different rates or magnitudes of the same reinforcer type (i.e., highly substitutable

reinforcers). Based on the findings from Hursh (1978), the different reinforcers used across the present experiments and Mace and colleagues (1997) could differentially impact relative resistance to extinction. Hursh found that the interaction between different reinforcer types can profoundly affect the pattern of choice responding on concurrent VI schedules of reinforcement. Relative rates of monkeys' lever pressing were directly related to changes in relative reinforcer rate (i.e., matching) when responding for two identical food sources were compared. However, when responding for two less substitutable reinforcers, food and water, were compared, relative response rates were inversely related to relative reinforcer rate (i.e., antimatching). At least two findings from the present experiments suggest that a low degree of reinforcer substitutability cannot completely account for the unsystematic resistance-to-extinction data from Experiments 2 and 3. First, responding for both food pellets and 15% sucrose solutions decreased when nonuniformly disrupted with free access to either food or sucrose in Experiment 1. These findings suggest that those reinforcers were at least partial substitutes (cf. Bauman, Raslear, Hursh, Shurtleff, & Simmons, 1996) when those reinforcers were presented during baseline prior to extinction in Experiment 2. Second, if the degree of substitutability influenced relative resistance to extinction, it also should have influenced relative response rates and concurrent-chain preference.

Nonetheless, the fact that differences in relative reinforcer type affect reinforcer substitutability suggest that determining how differences in reinforcer type affect relative response strength could be rather complicated. Regarding behavioral momentum theory in general, interactions between qualitatively different reinforcers suggest that it is

incomplete to conceptualize different reinforcers based solely on their response-strengthening effects. Therefore, obtaining quantitative estimates of substitutability between different reinforcer types prior to assessing response rates, preference, and resistance to change could provide insight into how interactions between reinforcers might affect those measures (see Green & Rachlin, 1991, for a method for estimating substitutability; see also Belke, Pierce, & Duncan, 2006).

Authors' Notes

These experiments were part of the first author's doctoral dissertation in Psychology at Utah State University and he thanks the committee members Scott Bates, Clint Field, Amy Odum, and Tim Slocum. The authors would like to thank Corina Jimenez-Gomez for her thoughtful comments during the preparation of this manuscript. Portions of these data were presented at the 2006 annual meeting of the Society for the Quantitative Analyses of Behavior.

Footnotes

¹In the Winter 2006 Issue of the *Journal of Applied Behavior Analysis*, an erratum for the two-bottle choice data from Mace and colleagues (1997) states, “The citric acid data series for Rats MV-46 and MV-47 (Figure 2-6) were duplicated in error. Because the raw data are now unavailable, firm conclusions regarding these two animals cannot be made.” (p. 468)

²It should be noted that assessing resistance to extinction from a single session in the present study is not entirely equivalent to assessing resistance to extinction from a single session in Mace and colleagues (1997). Mace and colleagues continued extinction until no responding occurred in either component for 12 min, whereas extinction was assessed using the same number of components as during baseline in the present experiment. There often were only small decreases or in some case increases in response rates during the first session of extinction in the present experiment, but large decreases by the end of the extinction session in Mace and colleagues. Nonetheless, given the high correlation between these measures of resistance to extinction in the present experiment, the inconsistent results from the present experiment cannot be attributed to differences in the scale at which resistance to extinction was assessed.

Table 2-1. *Conditions and Disrupters. Order of disrupters and sucrose solution used in each condition for all rats across Experiments 1 and 2. Disrupters were extinction (EXT), pre-session food (PF), pre-session sucrose (PS), pre-session food plus extinction (PF+EXT), pre-session sucrose plus extinction (PS+EXT), contrafreeloading food (CFL F), and contrafreeloading sucrose (CFL S).*

Experiment	Solution	Rat			
		N53	N54	N55	N56
1	15% sucrose	PF+EXT	PF+EXT	PF+EXT	PF+EXT
		PS+EXT	PS+EXT	PS+EXT	PS+EXT
		PF	PF	PS	PS
		PS	PS	PF	PF
		EXT*	EXT*	EXT*	EXT*
		CFL S	CFL F	CFL S	CFL F
		CFL F	CFL S	CFL F	CFL S
		PS+EXT	PS+EXT	PF+EXT	PF+EXT
		PF+EXT	PF+EXT	PS+EXT	PS+EXT
		2	15% sucrose	EXT	EXT
EXT	EXT			EXT	EXT
5% sucrose	EXT		EXT	EXT	EXT
	EXT		EXT	EXT	EXT
15% sucrose	EXT		EXT	EXT	EXT
	EXT		EXT	EXT	EXT

*Presented with Experiment 2.

Appendix A. *Number of Baseline (BL) Sessions in Each Condition of Experiment 1.*

Conditions are presented in the order they occurred. Baselines are indicated by the following disrupter (pre-session food [PF], pre-session sucrose [PS], pre-session food plus extinction [PF+EXT], pre-session sucrose plus extinction [PS+EXT], contrafreeloading food [CFL F], and contrafreeloading sucrose [CFL S]). Baseline response rates are the mean rates from the final six sessions of baseline prior to disruption. Response rates from individual sessions of disruption are presented. SD s are in italics.

Rat	Condition	Sessions	Responses per min		Rat	Condition	Sessions	Responses per min	
			Food	Sucrose				Food	Sucrose
N53	PF+EXT BL	50	119.67 <i>13.15</i>	43.66 <i>9.02</i>	N54	PF+EXT BL	49	62.53 <i>13.43</i>	34.68 <i>3.53</i>
	PF+EXT	1	13.25	6.70		PF+EXT	1	8.70	6.60
	PF+EXT	1	7.35	2.15		PF+EXT	1	2.05	1.00
	PF+EXT	1	7.75	1.00		PF+EXT	1	0.60	0.70
	PS+EXT BL	7	136.93 <i>13.53</i>	33.99 <i>4.56</i>		PS+EXT BL	7	64.41 <i>6.33</i>	36.04 <i>1.55</i>
	PS+EXT	1	65.05	17.70		PS+EXT	1	36.35	15.60
	PS+EXT	1	52.65	8.90		PS+EXT	1	22.95	8.15
	PS+EXT	1	58.50	15.00		PS+EXT	1	21.50	8.45
	PF BL	12	126.08 <i>5.15</i>	44.47 <i>6.19</i>		PF BL	6	73.11 <i>7.99</i>	32.47 <i>2.47</i>
	PF	1	64.60	24.05		PF	1	4.45	8.20
	PF	1	75.10	32.05		PF	1	11.05	13.65
	PF	1	73.35	29.40		PF	1	8.10	10.25
	PS BL	12	111.94 <i>6.46</i>	55.40 <i>4.82</i>		PS BL	6	43.45 <i>9.41</i>	32.08 <i>3.58</i>
	PS	1	118.55	39.05		PS	1	31.50	16.55
	PS	1	110.10	34.50		PS	1	52.70	15.35
	PS	1	124.30	35.45		PS	1	43.10	17.55
	Contra S BL	21	90.63 <i>12.88</i>	32.17 <i>6.70</i>		Contra F BL	6	23.44 <i>6.77</i>	37.76 <i>5.19</i>
	Contra S	1	80.40	11.90		Contra F	1	1.65	10.20
	Contra S	1	74.40	8.75		Contra F	1	1.45	9.40
	Contra S	1	39.55	4.60		Contra F	1	3.35	13.65

(table continues)

Rat	Condition	Sessions	Responses per min		Rat	Condition	Sessions	Responses per min	
			Food	Sucrose				Food	Sucrose
	Contra F BL	7	90.48 <i>7.21</i>	28.73 <i>8.26</i>		Contra S BL	6	17.68 <i>4.22</i>	26.20 <i>2.85</i>
	Contra F	1	7.50	4.25		Contra S	1	7.50	7.45
	Contra F	1	4.05	2.95		Contra S	1	9.25	6.15
	Contra F	1	3.05	2.40		Contra S	1	13.30	7.40
	PS+EXT BL	7	74.87 <i>10.52</i>	21.58 <i>5.67</i>		PS+EXT BL	6	24.88 <i>8.58</i>	28.98 <i>3.51</i>
	PS+EXT	1	44.75	9.90		PS+EXT	1	15.00	7.80
	PS+EXT	1	46.85	7.60		PS+EXT	1	15.90	8.20
	PS+EXT	1	37.00	6.00		PS+EXT	1	10.55	7.65
	PF+EXT BL	18	101.83 <i>14.97</i>	24.43 <i>6.79</i>		PF+EXT BL	6	27.02 <i>4.39</i>	29.94 <i>2.73</i>
	PF+EXT	1	14.30	8.60		PF+EXT	1	0.80	3.10
	PF+EXT	1	8.35	3.75		PF+EXT	1	0.55	4.00
	PF+EXT	1	5.40	2.50		PF+EXT	1	1.15	2.90
N55	PF+EXT BL	49	97.49 <i>11.17</i>	19.88 <i>3.24</i>	N56	PF+EXT BL	50	96.83 <i>9.92</i>	92.40 <i>6.91</i>
	PF+EXT	1	6.05	2.95		PF+EXT	1	9.25	11.85
	PF+EXT	1	1.75	1.60		PF+EXT	1	7.90	6.05
	PF+EXT	1	1.55	2.20		PF+EXT	1	0.05	1.25
	PS+EXT BL	6	97.86 <i>7.97</i>	18.68 <i>4.50</i>		PS+EXT BL	7	78.34 <i>13.26</i>	71.12 <i>6.34</i>
	PS+EXT	1	22.00	3.80		PS+EXT	1	19.80	20.80
	PS+EXT	1	32.40	2.35		PS+EXT	1	30.30	17.45
	PS+EXT	1	35.05	3.90		PS+EXT	1	21.20	11.15
	PS BL	8	112.10 <i>9.61</i>	29.02 <i>4.43</i>		PS BL	10	83.88 <i>7.57</i>	83.09 <i>10.87</i>
	PS	1	76.15	12.30		PS	1	81.30	47.00
	PS	1	107.25	23.20		PS	1	91.75	44.60
	PS	1	103.50	21.55		PS	1	110.55	52.80
	PF BL	6	99.41 <i>7.17</i>	26.12 <i>5.51</i>		PF BL	7	98.05 <i>7.27</i>	71.48 <i>3.79</i>
	PF	1	42.25	14.50		PF	1	19.85	43.90
	PF	1	50.95	18.20		PF	1	47.20	61.65
	PF	1	25.45	15.20		PF	1	33.65	49.45
	Contra S BL	6	103.53 <i>8.54</i>	41.25 <i>3.63</i>		Contra F BL	6	92.88 <i>6.07</i>	87.37 <i>10.69</i>
	Contra S	1	45.50	7.95		Contra F	1	2.95	8.30
	Contra S	1	37.35	6.35		Contra F	1	1.80	7.80
	Contra S	1	28.50	3.60		Contra F	1	1.70	12.80

(table continues)

Rat	Condition	Sessions	Responses per min		Rat	Condition	Sessions	Responses per min	
			Food	Sucrose				Food	Sucrose
	Contra F BL	8	121.06 <i>10.87</i>	41.33 <i>6.96</i>		Contra S BL	9	92.22 <i>9.61</i>	79.30 <i>4.99</i>
	Contra F	1	3.20	3.65		Contra S	1	18.40	15.15
	Contra F	1	0.75	2.40		Contra S	1	63.95	19.30
	Contra F	1	3.10	4.25		Contra S	1	52.80	9.55
	PF+EXT BL	11	111.22 <i>13.43</i>	40.53 <i>9.84</i>		PF+EXT BL	9	89.35 <i>9.11</i>	97.13 <i>9.58</i>
	PF+EXT	1	0.95	4.15		PF+EXT	1	4.15	4.35
	PF+EXT	1	1.60	1.65		PF+EXT	1	1.30	4.30
	PF+EXT	1	0.55	1.25		PF+EXT	1	1.25	2.20
	PS+EXT BL	24	112.00 <i>14.10</i>	39.45 <i>6.99</i>		PS+EXT BL	7	83.26 <i>8.09</i>	91.86 <i>12.05</i>
	PS+EXT	1	26.75	4.70		PS+EXT	1	48.30	19.10
	PS+EXT	1	33.05	11.30		PS+EXT	1	35.90	17.25
	PS+EXT	1	32.55	7.15		PS+EXT	1	10.70	9.45

Appendix B. *Number of Baseline (BL) Sessions in Each Condition of Experiment 2.*

Conditions are presented in the order they occurred at each sucrose concentration (% Sucrose). Baselines are indicated by the following extinction (EXT) condition. Baseline response rates are the mean rates from the final six sessions of baseline prior to disruption. Response rates from individual sessions of disruption are presented. SD s are in italics.

% Sucrose	Condition	Rat	Sessions	Responses per min		Rat	Sessions	Responses per min	
				Food	Sucrose			Food	Sucrose
15% (1)	EXT 1 BL	N53	12	113.15 <i>3.93</i>	33.49 <i>7.20</i>	N54	9	27.78 <i>2.55</i>	32.76 <i>1.82</i>
	EXT 1		1	56.50	16.65		1	25.80	22.30
	EXT 1		1	47.85	11.65		1	23.10	18.35
	EXT 1		1	28.50	4.05		1	12.35	14.15
	EXT 1		1	33.90	4.75		1	9.25	9.25
	EXT 1		1	35.75	2.85		1	6.50	8.45
	EXT 1		1	16.60	1.05		1	0.10	2.75
	EXT 2 BL		6	110.98 <i>10.48</i>	23.53 <i>3.52</i>		19	29.27 <i>7.20</i>	28.97 <i>3.97</i>
	EXT 2		1	78.30	22.10		1	26.25	27.35
	EXT 2		1	43.90	7.05		1	10.15	13.05
	EXT 2		1	59.40	13.95		1	14.85	13.45
	EXT 2		1	35.05	11.15		1	6.05	8.70
	EXT 2		1	44.85	10.30		1	5.05	7.15
	EXT 2		1	47.50	6.85		1	2.05	5.90
	5%	EXT 1 BL		30	123.94 <i>9.76</i>	12.58 <i>3.01</i>		30	36.31 <i>6.10</i>
EXT 1			1	115.80	7.95		1	28.95	15.15
EXT 1			1	98.20	5.05		1	16.25	9.95
EXT 1			1	45.25	3.70		1	9.20	8.75
EXT 1			1	54.70	3.90		1	10.65	7.35
EXT 1			1	44.70	3.25		1	7.75	3.80
EXT 1			1	33.70	2.90		1	4.85	2.65
EXT 2 BL			6	94.19 <i>8.89</i>	8.63 <i>2.08</i>		8	24.12 <i>3.39</i>	18.18 <i>1.41</i>

(table continues)

% Sucrose	Condition	Rat	Sessions	Responses per min		Rat	Sessions	Responses per min	
				Food	Sucrose			Food	Sucrose
	EXT 2		1	92.75	7.20		1	37.05	13.75
	EXT 2		1	77.60	6.05		1	17.40	9.00
	EXT 2		1	49.35	3.15		1	14.50	6.70
	EXT 2		1	37.60	3.55		1	11.00	6.70
	EXT 2		1	19.85	2.10		1	8.85	5.25
	EXT 2		1	25.55	2.90		1	5.80	4.40
15% (2)	EXT 1 BL		70	80.92	27.88		73	40.68	40.06
				6.22	5.05			14.73	5.91
	EXT 1		1	65.65	10.50		1	35.35	24.30
	EXT 1		1	42.70	5.05		1	29.95	18.25
	EXT 1		1	15.80	1.60		1	25.30	16.80
	EXT 1		1	9.75	0.90		1	15.90	12.40
	EXT 1		1	4.65	0.95		1	17.50	12.35
	EXT 1		1	6.75	1.80		1	9.30	3.80
	EXT 2 BL		62	101.78	25.00		63	32.57	35.05
				8.33	3.82			7.63	2.54
	EXT 2		1	71.20	20.00		1	53.30	38.10
	EXT 2		1	54.00	10.15		1	25.90	17.75
	EXT 2		1	33.75	8.05		1	18.40	15.85
	EXT 2		1	20.10	3.40		1	13.65	10.55
	EXT 2		1	19.95	3.50		1	8.85	11.30
	EXT 2		1	24.30	2.45		1	8.10	8.55
15% (1)	EXT 1 BL	N55	7	116.43	36.10	N56	6	77.27	69.10
				9.90	3.37			2.90	7.79
	EXT 1		1	66.00	21.25		1	68.70	55.75
	EXT 1		1	60.40	11.20		1	44.95	34.20
	EXT 1		1	41.70	10.90		1	37.60	30.75
	EXT 1		1	35.80	7.90		1	24.80	25.75
	EXT 1		1	24.45	6.90		1	6.90	6.95
	EXT 1		1	21.85	5.20		1	11.35	10.45
	EXT 2 BL		12	104.86	42.53		24	91.38	92.11
				11.85	2.31			9.93	4.69
	EXT 2		1	77.25	33.25		1	88.10	83.75
	EXT 2		1	27.80	14.95		1	54.95	52.75
	EXT 2		1	14.50	7.90		1	22.30	29.80
	EXT 2		1	2.00	4.35		1	23.15	24.85
	EXT 2		1	1.50	2.35		1	15.30	16.50
	EXT 2		1	1.95	4.00		1	2.15	4.70
5%	EXT 1 BL		30	107.30	23.93		31	87.10	61.08
				8.10	5.12			11.93	2.44

(table continues)

% Sucrose	Condition	Rat	Sessions	Responses per min		Rat	Sessions	Responses per min	
				Food	Sucrose			Food	Sucrose
	EXT 1	1	71.25	13.70		1	70.70	45.10	
	EXT 1	1	63.05	15.40		1	35.25	33.30	
	EXT 1	1	24.10	4.05		1	10.30	15.30	
	EXT 1	1	19.55	5.40		1	4.85	6.60	
	EXT 1	1	17.35	4.95		1	6.50	4.25	
	EXT 1	1	6.90	2.60		1	4.35	6.70	
	EXT 2 BL	6	94.51	22.98		23	78.65	56.21	
			9.86	6.89			5.24	6.27	
	EXT 2	1	54.10	14.90		1	81.60	44.90	
	EXT 2	1	34.35	7.75		1	23.55	12.40	
	EXT 2	1	30.30	5.65		1	39.80	26.80	
	EXT 2	1	8.85	4.40		1	20.55	14.95	
	EXT 2	1	8.20	3.30		1	6.60	6.95	
	EXT 2	1	9.05	3.05		1	9.35	7.95	
15% (2)	EXT 1 BL	52	78.96	45.89		72	103.75	86.33	
			7.31	5.15			8.85	4.82	
	EXT 1	1	70.35	31.50		1	111.05	78.05	
	EXT 1	1	44.90	16.75		1	60.85	50.30	
	EXT 1	1	13.75	5.85		1	34.85	30.05	
	EXT 1	1	4.15	6.55		1	24.95	22.40	
	EXT 1	1	11.60	6.10		1	10.40	15.45	
	EXT 1	1	1.85	3.10		1	8.10	10.65	
	EXT 2 BL	63	81.73	39.81		63	83.45	87.38	
			4.64	5.22			4.50	9.67	
	EXT 2	1	47.80	18.10		1	60.70	56.20	
	EXT 2	1	22.75	9.40		1	22.50	23.95	
	EXT 2	1	20.95	7.80		1	9.00	9.45	
	EXT 2	1	2.20	1.65		1	14.15	16.75	
	EXT 2	1	3.80	5.45		1	11.20	14.15	
	EXT 2	1	5.20	6.35		1	0.65	0.80	

Appendix C. Conditions in Experiment 3. Thirty baseline (BL) sessions occurred in each condition of Experiment 3. Conditions are presented in the order they occurred.

Baselines are indicated by the liquid reinforcer (Milk [1], Sucrose, or Milk [2]). Baseline response rates are the mean rates from the final six sessions of baseline prior to disruption. Response rates from individual sessions of disruption with extinction (EXT) are presented. SDs are in italics.

Condition	Rat	Responses per min									
		Initial links		Terminal links		Rat	Initial links		Terminal links		
		Food	Liquid	Food	Liquid		Food	Liquid	Food	Liquid	
Milk (1) BL	N93	88.28	8.83	108.20	58.89	N94	64.51	41.30	81.68	149.12	
		<i>8.60</i>	<i>1.85</i>	<i>6.80</i>	<i>6.50</i>		<i>9.29</i>	<i>1.95</i>	<i>8.62</i>	<i>4.90</i>	
EXT		50.99	9.90	88.43	30.92		30.40	51.79	89.68	116.85	
EXT		19.40	2.30	24.92	13.09		9.70	18.20	24.42	28.92	
EXT		15.40	1.90	17.17	7.25		17.50	14.70	32.92	21.67	
EXT		6.30	1.60	6.00	1.42		7.80	3.90	10.50	3.92	
EXT		5.10	1.20	7.83	0.00		1.70	1.30	4.33	3.42	
EXT		7.20	1.10	12.09	6.42		0.70	2.70	2.42	3.25	
Sucrose BL		93.09	3.28	157.71	33.59		83.54	6.45	91.80	96.03	
		<i>8.28</i>	<i>1.24</i>	<i>11.85</i>	<i>5.10</i>		<i>28.67</i>	<i>1.90</i>	<i>12.93</i>	<i>37.12</i>	
EXT		75.69	1.20	113.60	20.25		27.60	2.90	79.51	36.92	
EXT		15.60	0.80	23.75	5.58		26.40	1.90	31.34	12.67	
EXT		20.30	1.60	9.92	3.08		10.70	3.10	26.17	10.75	
EXT		7.50	0.20	9.92	3.83		3.20	1.10	10.09	1.83	
EXT		7.10	0.20	6.92	1.50		0.70	0.40	1.08	2.25	
EXT		0.90	0.00	6.50	0.50		1.20	0.40	3.92	2.42	
Milk (2) BL		81.98	7.96	162.28	61.94		30.09	58.22	122.60	183.53	
		<i>10.00</i>	<i>2.89</i>	<i>6.49</i>	<i>9.64</i>		<i>3.22</i>	<i>20.60</i>	<i>14.42</i>	<i>7.40</i>	
EXT		63.69	6.80	112.94	28.00		13.30	20.10	56.59	124.27	
EXT		28.70	3.10	40.34	21.75		11.10	17.30	35.59	64.51	
EXT		10.90	1.50	4.58	4.92		9.80	13.20	26.59	35.42	
EXT		6.30	3.30	11.75	6.42		2.10	1.90	8.08	19.09	
EXT		4.60	0.60	0.17	2.75		6.60	5.40	13.59	8.25	
EXT		0.00	0.00	2.67	0.00		4.20	4.60	6.42	12.17	
Milk (1) BL	N95	65.56	9.95	123.77	51.51	N96	65.35	26.25	112.33	107.79	
		<i>5.98</i>	<i>2.28</i>	<i>9.68</i>	<i>3.79</i>		<i>11.86</i>	<i>4.98</i>	<i>5.73</i>	<i>2.98</i>	
EXT		48.59	6.50	98.77	43.09		26.00	9.00	59.18	64.76	
EXT		13.70	3.60	26.50	13.84		7.40	0.70	21.34	14.75	
EXT		11.90	1.60	11.25	7.67		8.80	3.30	16.84	12.75	
EXT		4.50	0.50	5.75	6.00		15.40	2.20	12.92	7.67	
EXT		1.00	0.60	2.08	3.33		1.50	0.60	5.83	2.75	
EXT		6.20	1.80	12.50	6.25		12.00	3.50	7.50	8.58	
Sucrose BL		67.57	3.69	123.68	46.54		79.68	11.33	114.70	96.08	
		<i>2.90</i>	<i>1.24</i>	<i>4.82</i>	<i>3.73</i>		<i>4.07</i>	<i>2.50</i>	<i>4.54</i>	<i>5.33</i>	

(table continues)

Condition	Responses per min									
	Rat	Initial links		Terminal links		Rat	Initial links		Terminal links	
		Food	Liquid	Food	Liquid		Food	Liquid	Food	Liquid
EXT	4.00	0.70	16.75	9.42	21.90	1.70	29.75	23.42		
EXT	5.40	0.60	11.59	2.92	11.40	1.60	27.84	9.58		
EXT	7.80	1.80	12.92	3.58	6.40	1.50	12.50	7.42		
EXT	3.00	0.20	2.17	5.25	2.30	0.60	17.50	5.50		
EXT	0.10	0.00	2.50	1.50	1.80	0.40	10.25	7.67		
EXT	0.40	0.00	0.33	0.83	0.20	0.30	1.17	1.00		
Milk (2) BL	48.69	26.41	130.14	76.12	44.59	28.74	114.08	113.77		
	4.52	3.11	11.68	5.51	5.78	1.73	4.34	5.47		
EXT	24.00	6.90	14.34	29.92	15.60	6.40	36.59	25.42		
EXT	1.90	2.10	0.33	4.83	9.60	4.10	13.34	15.84		
EXT	1.40	1.50	6.17	5.67	2.90	3.60	12.75	6.17		
EXT	16.80	6.70	7.67	20.25	2.20	1.10	3.50	10.59		
EXT	7.30	3.10	1.50	7.08	2.80	1.20	8.75	5.67		
EXT	0.00	0.00	0.17	4.50	0.30	0.40	1.17	1.50		

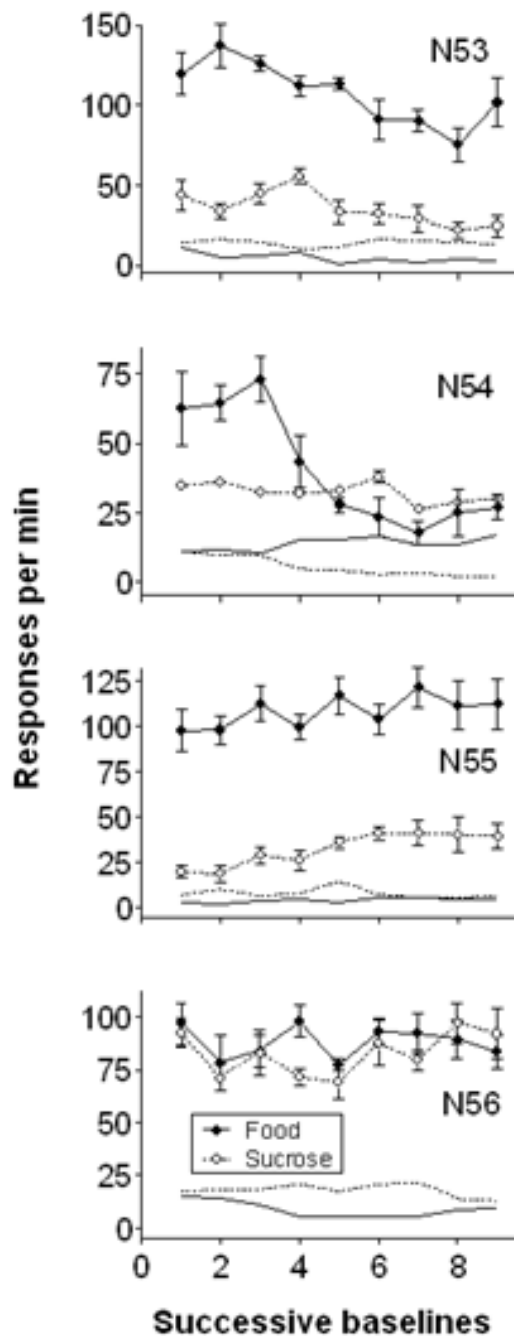


Figure 2-1. Baseline response rates in Experiment 1. Response rates in the Food and Sucrose components across successive exposures to the baseline condition. Data points represent the means of the last 6 sessions of exposure to the conditions. Error bars represent ± 1 SD. Response rates on the inactive levers are indicated by the line corresponding to the Food component (solid line) and Sucrose component (dotted line). Note that y-axis starts at -5.

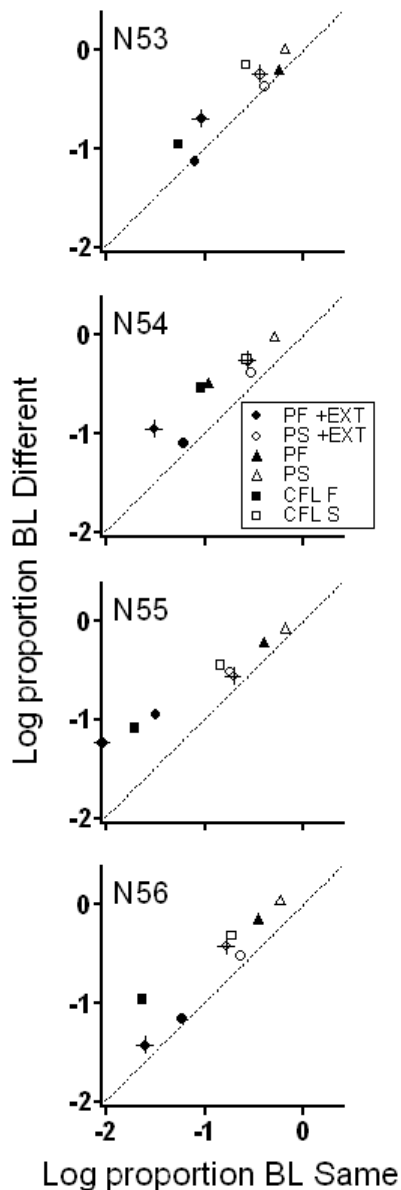


Figure 2-2. Relative resistance to change in Experiment 1. Data points represent means from each 3-session condition of disruption (pre-session food plus extinction [PF+EXT], pre-session sucrose plus extinction [PS+EXT], pre-session food [PF], pre-session sucrose [PS], contrafreeloading food [CFL F], and contrafreeloading sucrose [CFL S]). Replications of PF+EXT and PS+EXT are indicated by plus (+) symbols transposed on the open and closed circles, respectively. The log of mean proportion of baseline response rates in the component that produced the reinforcer that was Different than the disrupter (y-axis) relative to log mean proportion of baseline response rates in the component that produced the reinforcer that was the Same as the disrupter (x-axis). The dotted diagonal line indicates where data points fall if disruption is equal in both components.

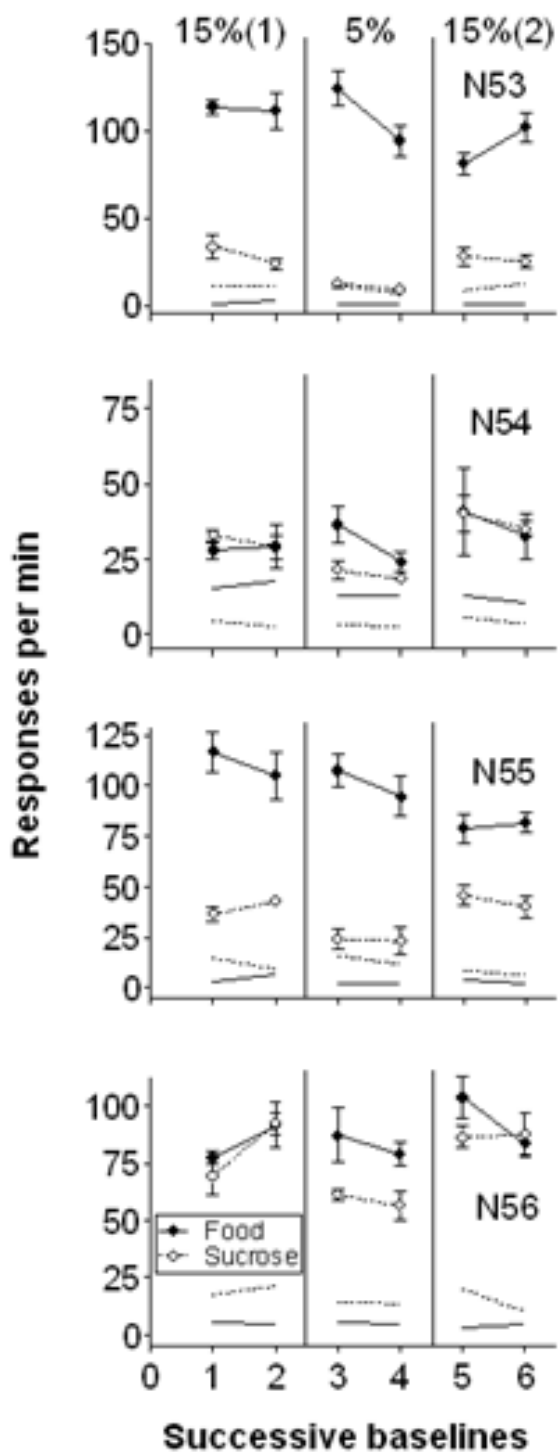


Figure 2-3. Baseline response rates in Experiment 2. Response rates in the Food and Sucrose components across successive exposures to the baseline conditions. Data are presented as in Figure 2-1.

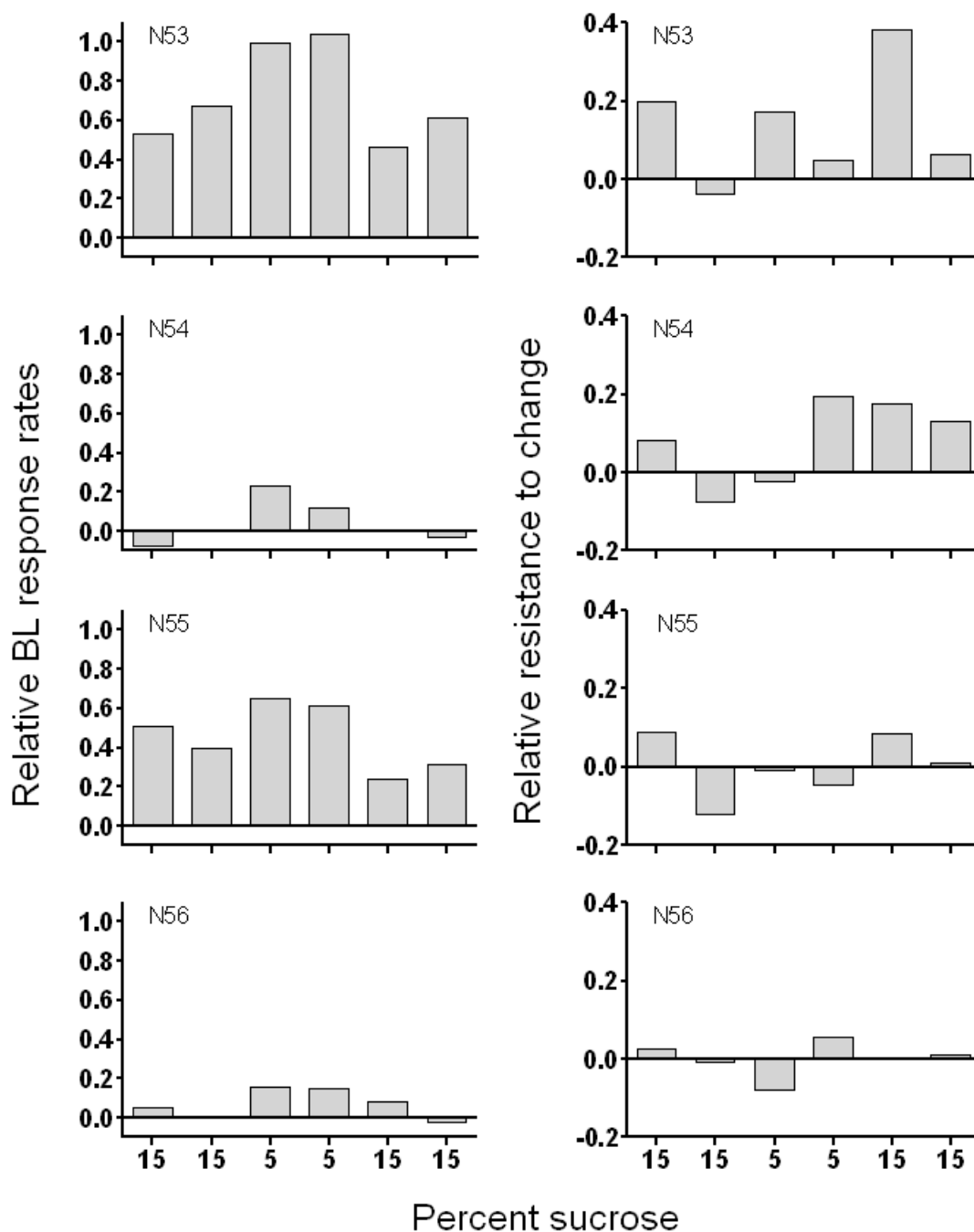


Figure 2-4. Relative response rates and relative resistance to change in Experiment 2. The left panel presents the log ratio of mean response rates in the Food and Sucrose components for all rats as a function of the sucrose concentration presented in the Sucrose component. The right panel presents the difference of log mean proportion baseline response rates in the Food and Sucrose components for all rats as a function of the sucrose concentration presented in the Sucrose component.

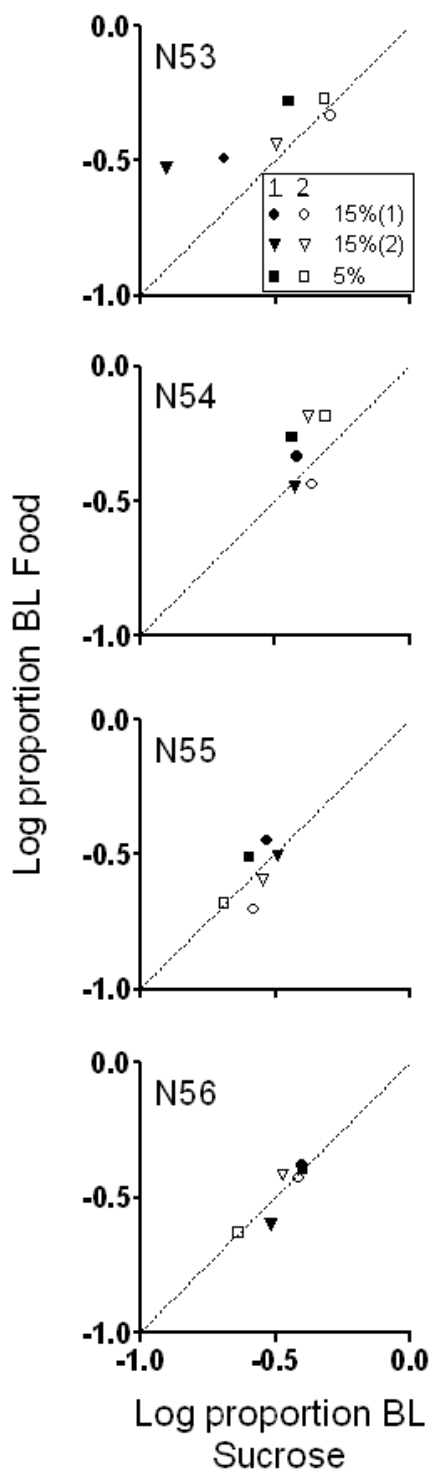


Figure 2-5. Relative resistance to change in Experiment 2. The log of mean proportion of baseline response rates in the Sucrose component (y-axis) relative to log mean proportion of baseline response rates in the Food component (x-axis). Data are presented separately for each condition and for each exposure to extinction within a condition.

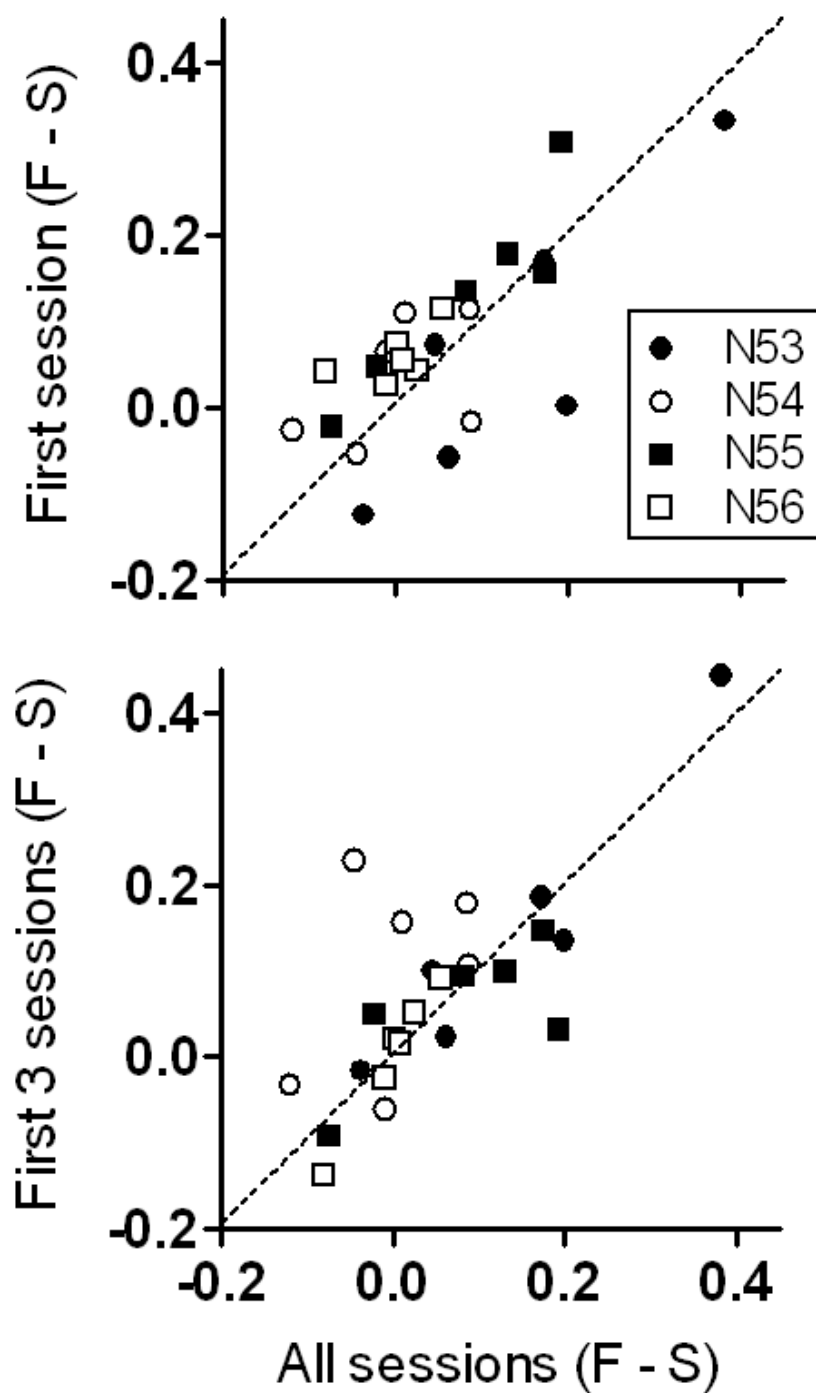


Figure 2-6. Relative resistance to change as a function of number of sessions in Experiment 2. Relative resistance to change for six sessions versus the first session (top panel) and first three sessions (bottom panel).

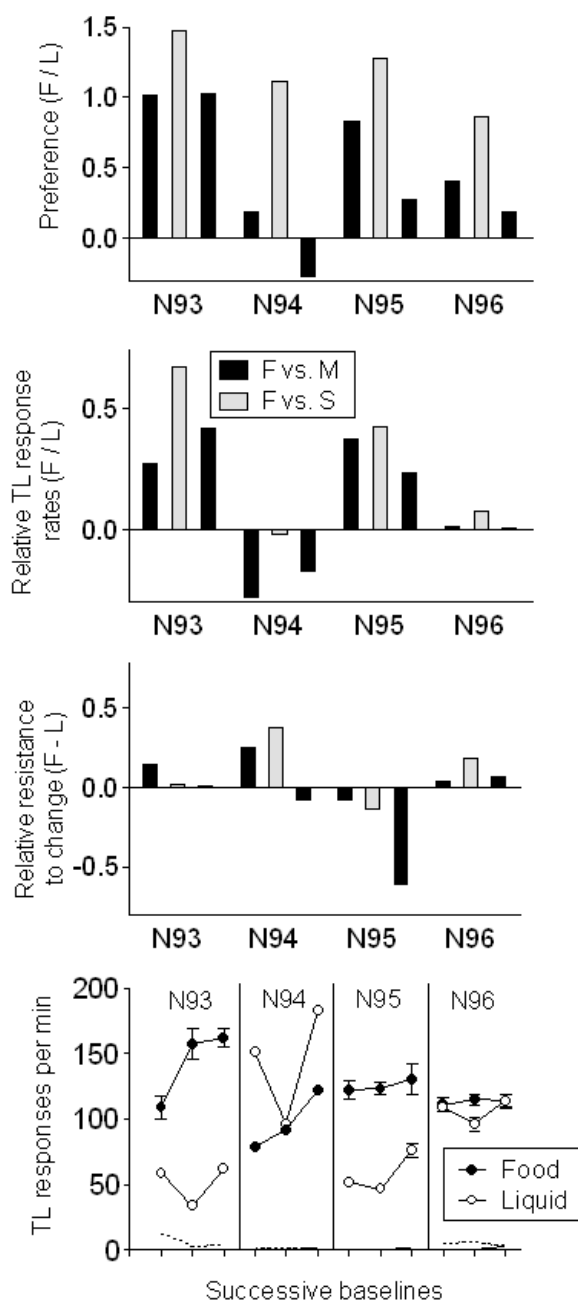


Figure 2-7. Preference, relative response rates, and relative resistance to change in Experiment 3. The top panel shows the log ratio of mean Food and Liquid initial-link response rates for all rats. The second panel shows the log ratio of mean Food and Liquid terminal-link response rates for all rats. The third panel shows the difference of the log mean proportion baseline response rates between the Food- and Liquid-terminal links for all rats. The black bars indicate when milk (M) was presented in the Liquid terminal link and the gray bars indicate when sucrose (S) was presented in the Liquid terminal link. The bottom panel shows terminal-link (TL) baseline response rates.

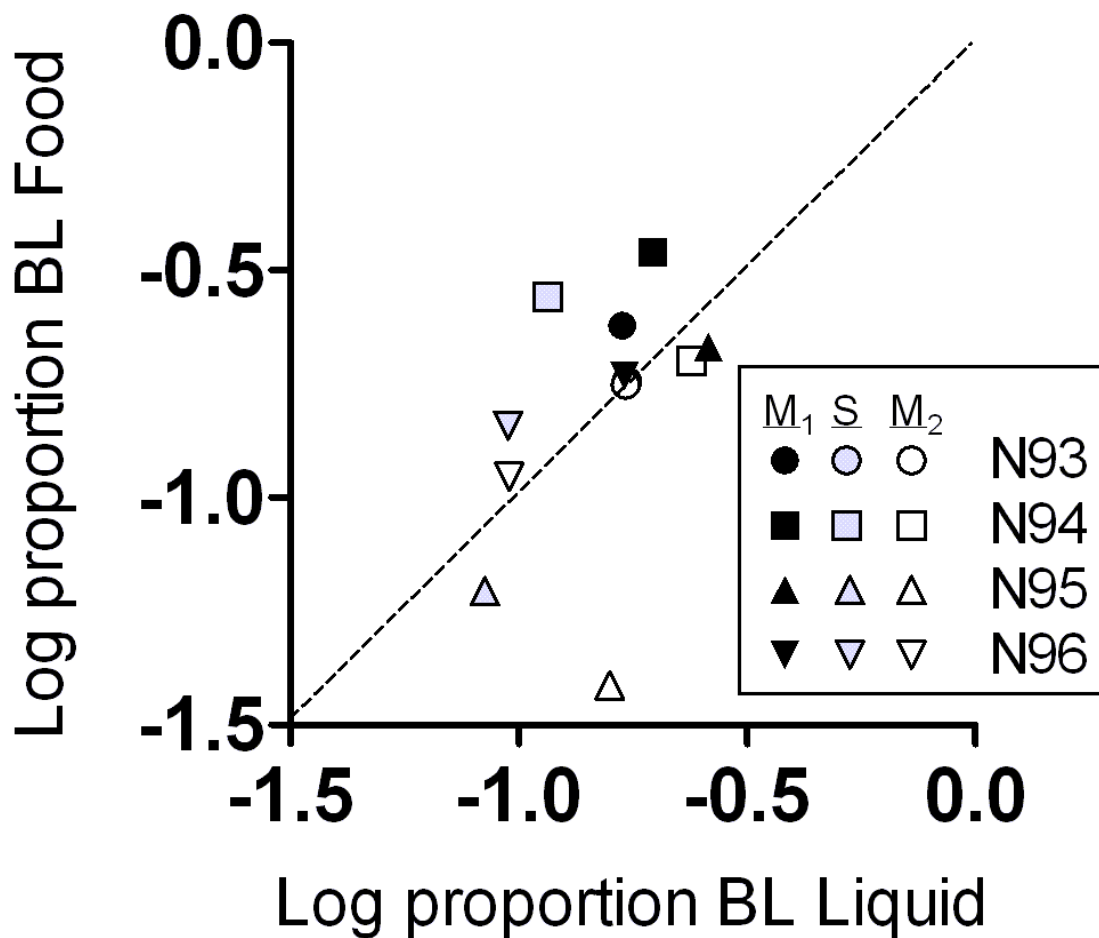


Figure 2-8. Relative resistance to change in Experiment 3. The log of mean proportion of baseline response rates in the Liquid component (y-axis) relative to log mean proportion of baseline response rates in the Food component (x-axis). Data are presented separately for each condition and for each exposure to extinction within a condition.

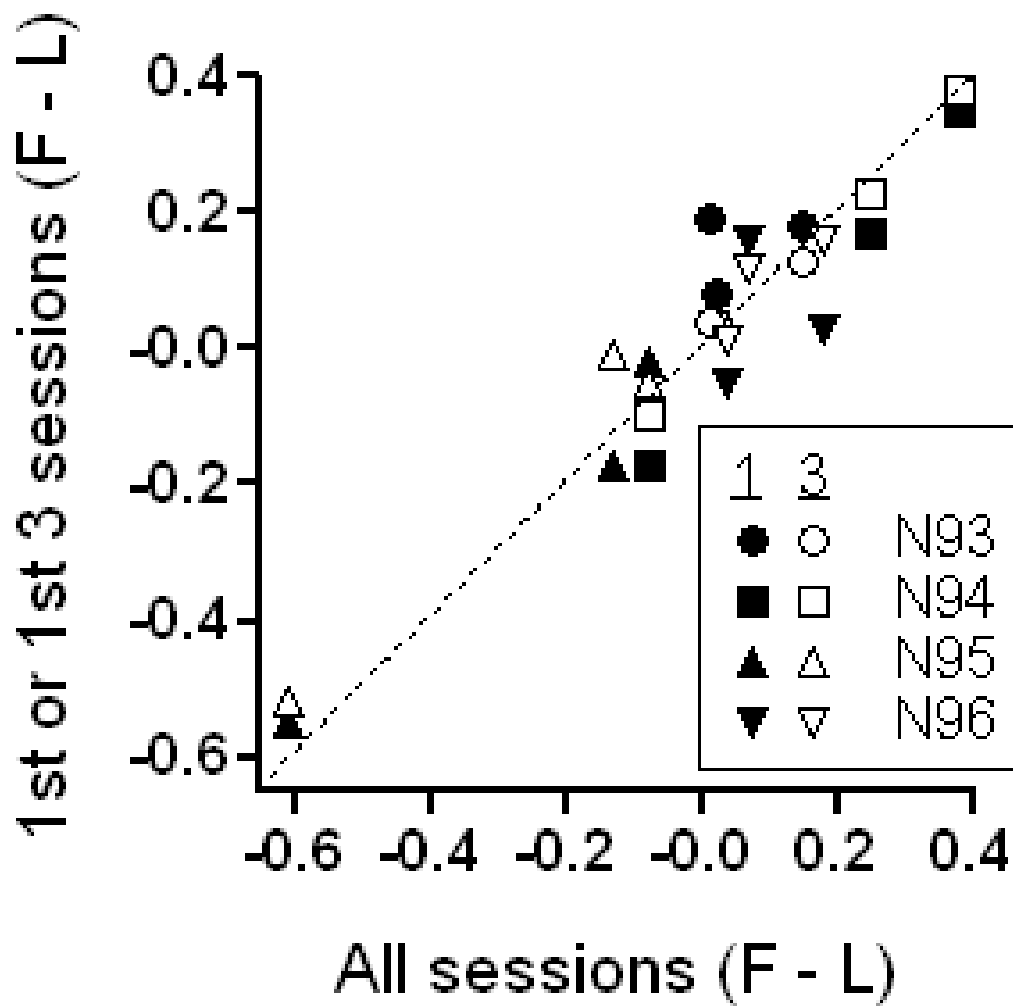


Figure 2-9. Relative resistance to change as a function of number of sessions in Experiment 3. Relative resistance to change for six sessions versus the first session (closed symbols) and first three sessions (open symbols).

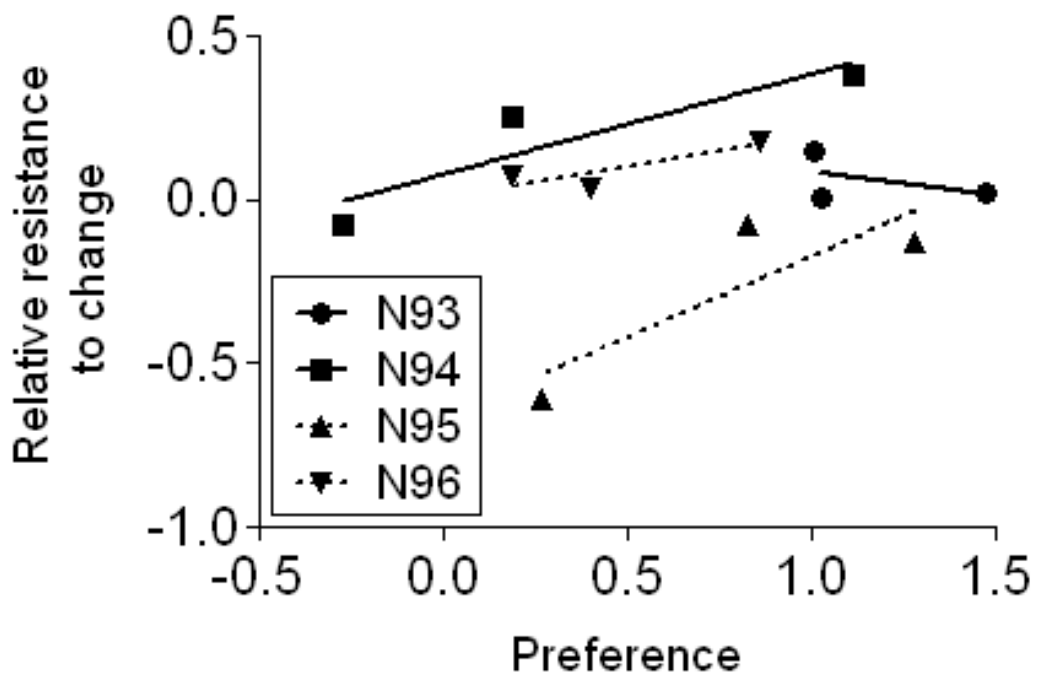


Figure 2-10. Structural relation in Experiment 3. The difference of the log mean proportion baseline response rates between the Food- and Liquid-terminal links plotted as a function of the log ratio of mean Food and Liquid initial-link response rates. Least squares linear-regression lines were fitted to the data of each rat. See text for additional information.

CHAPTER 3
SCALING QUALITATIVELY DIFFERENT REINFORCERS WITH
PREFERENCE AND RESISTANCE TO CHANGE²

Abstract

According to behavioral momentum theory, preference for one stimulus context over another and relative resistance to disruption within contexts should be related as a function of the conditions of reinforcement presented within those contexts. Previous studies have shown that preference and resistance to change were greater when higher rates or larger magnitudes of identical reinforcer types were presented. The present experiment examined preference and resistance to extinction with rats lever pressing for varying rates of qualitatively different reinforcers in the terminal links of a concurrent-chains procedure. Across conditions, food pellets functioned as a standard reinforcer to compare the biasing effects of different reinforcer types (i.e., sweetened-condensed milk solution, sucrose solution). Using modified versions of the generalized matching law, preference was sensitive to changes in relative reinforcer rate and bias was systematically affected by changes in relative reinforcer type. Relative resistance to extinction was not consistently sensitive to changes in reinforcer rate and bias values varied across rats as a function of reinforcer type. Systematic deviations in sensitivity and bias for preference and resistance to change suggest that the different reinforcer types might have interacted with changes in relative reinforcer rate. These findings suggest that the overall context of

²Coauthored with Timothy A. Shahan

reinforcement that includes the interaction between different reinforcer types should be considered when assessing preference and relative resistance to change.

Introduction

Choice between two concurrently available sources of reinforcement often has been studied using concurrent variable-interval (VI) schedules of reinforcement (see Davison & McCarthy, 1988; Williams, 1988, for reviews). Changes in reinforcement variables have been shown to have reliable effects on choice behavior (e.g., Herrnstein, 1961). For instance, a number of studies have shown that choice is independently affected by changes in relative reinforcer rate and relative reinforcer type (Bron, Sumpter, Foster, & Temple, 2003; Cliffe & Parry, 1980; Foster, Matthews, Temple, & Poling, 1997; Foster, Temple, Robertson, Nair, & Poling, 1996; Hamblin & Miller, 1977; Hollard & Davison, 1971; Matthews & Temple, 1979; Miller, 1976). For instance, Miller manipulated qualitatively different grain reinforcers across conditions for pigeons responding in a concurrent-choice situation. These findings were well described by a version of the generalized matching law (Baum, 1974):

$$\log\left(\frac{B_1}{B_2}\right) = a_r \log\left(\frac{r_1}{r_2}\right) + a_q \log\left(\frac{q_1}{q_2}\right) + \log b. \quad (1)$$

With the subscripts indicating the two options, B is response rates, r is reinforcer rate, and q is reinforcer quality, or type. The a parameters show sensitivity of choice behavior to changes in reinforcement variables. $\log b$ is inherent bias for one response over another, independent of changes in reinforcement variables. Equation 1 suggests that relative

responding ($\log [B_1 / B_2]$) is a concatenated function of relative reinforcement variables, such as rate ($\log [r_1 / r_2]$) and type ($\log [q_1 / q_2]$) (see Baum & Rachlin, 1969; Killeen, 1972; Rachlin, 1971).

The allocation of responding across response options has been used to provide an index of the value (V) of the outcomes:

$$\frac{B_1}{B_2} = \frac{V_1}{V_2} . \quad (2)$$

Because inherent position bias was controlled in Miller (1976), changes in the bias parameter resulted primarily from the different reinforcer types. Given Equation 2, obtained biases indicated the relative value of the different reinforcer types. Using a standard reinforcer, the bias values obtained across conditions could be used to hedonically scale the qualitatively different reinforcer types. Buckwheat was used as a standard reinforcer in comparison to hemp in the first condition and wheat in the next condition. The mean bias value for buckwheat versus hemp was 0.043 and for wheat versus buckwheat was 0.145. Setting the log value of the standard buckwheat (b) reinforcer to 1, the log values of hemp (h) and wheat (w) relative to buckwheat could be determined:

$$1 - \log V_h = 0.043,$$

$$\log V_h = 0.957,$$

and

$$\log V_w - 1 = 0.145,$$

$$\log V_w = 1.145.$$

The scaled value of hemp and wheat relative to buckwheat was obtained by taking the antilogarithm of the log values ($V = 10^{\log V}$). Therefore, the value of Buckwheat (10) was greater than Hemp (9.1) but less than Wheat (13.9).

An additional implication of the capability to quantify the relative value of different reinforcer types using the bias parameter was that the log values from the first two conditions could be used to predict the bias value for the final condition when hemp and wheat were compared directly:

$$\begin{aligned}\log V_h - \log V_w &= 0.957 - 1.145, \\ 0.957 - 1.145 &= -0.188.\end{aligned}$$

The predicted bias value when wheat and hemp were compared was -0.188 and the obtained value was -0.15. Given the close correspondence between the predicted and obtained bias values, these findings suggest that the bias parameter from the generalized matching law could be used to hedonically scale different reinforcer types.

Like choice behavior, the effects of reinforcement variables on preference for one stimulus context over another and relative resistance to disruption within those stimulus contexts have been described quantitatively. According to behavioral momentum theory, preference and relative resistance to change provide converging quantitative expressions of how conditions of reinforcement impact relative response strength (Nevin & Grace, 2000a). Within concurrent-chains schedules of reinforcement, responding in two concurrently available initial links provides access to one of two mutually exclusive terminal links that are signaled by different stimuli. Using a modified version of the generalized matching law (Equation 1), the allocation of responses across the initial links

provides an index of preference between the terminal-link reinforcement contexts (Grace & Nevin, 1997):

$$\log\left(\frac{B_{i1}}{B_{i2}}\right) = a_r \log\left(\frac{r_{t1}}{r_{t2}}\right) + a_x \log\left(\frac{x_{t1}}{x_{t2}}\right) + \log b . \quad (2)$$

B_{i1} and B_{i2} are responding on the two initial links, r_{t1} and r_{t2} are the reinforcer rates produced in the corresponding terminal links, and x_{t1} and x_{t2} are any other reinforcer variables presented in the terminal links (e.g., different reinforcer types; cf. Baum & Rachlin, 1969; Killeen, 1972; Rachlin, 1971). The a_r and a_x parameters represent the sensitivity of relative initial-link responding to relative terminal-link reinforcement rates and any other reinforcement variables, respectively, and the parameter $\log b$ represents inherent bias for one option over another, independent of changes in relative reinforcement.

When responding is uniformly disrupted across the terminal-link contexts by, for example, extinguishing reinforcement, presenting food response independently during the initial links, or satiating subjects prior to experimental sessions, the response that decreases less relative to baseline rates is considered more resistant to change. Like choice in Equation 1 and preference in Equation 2, relative resistance to change in the terminal links is a function of the reinforcement variables in the terminal links (Grace & Nevin, 1997):

$$\log\left(\frac{B_{x1}}{B_{o1}}\right) - \log\left(\frac{B_{x2}}{B_{o2}}\right) = a_r \log\left(\frac{r_{t1}}{r_{t2}}\right) + a_x \log\left(\frac{x_{t1}}{x_{t2}}\right) + \log b . \quad (3)$$

Each subscript represents one of two mutually exclusive terminal-link stimulus contexts. B_x is response rates during disruption and B_o is response rates during stable baseline prior to disruption. The right side of the equation is the same as in Equation 2, except that the free parameters scale the relation between relative resistance to change and relative terminal-link reinforcement rate or other reinforcement variables. Consistent with the notion that preference and resistance to change are converging expressions of response strength, Grace and colleagues (2002) have shown that preference and relative resistance to change are correlated across a number of studies with pigeons responding for different rates of food reinforcement.

Grace and colleagues (2002) examined whether changes in relative rate and magnitude of food reinforcers have independent and additive effects on pigeons' preference and resistance to disruption, as predicted by Equations 2 and 3, respectively. Different ratios of reinforcer durations, or magnitudes (i.e., 2:1, 1:1, 1:2), were presented in terminal links of concurrent chains across three alternating components of a multiple schedule. Thus, the x reinforcement variables in Equations 1 and 2 represented different magnitude (m) ratios across components in the terminal links (i.e., $\log [m_{t1}/m_{t2}]$). When relative terminal-link reinforcement rate was parametrically manipulated from a 1:4 to 4:1 difference across conditions in the three components by changing variable-interval (VI) schedules, preference and resistance to disruption were sensitive to those changes in all three components. Moreover, sensitivity to changes in relative reinforcer rate (a_r) did not differ across components presenting different relative reinforcer magnitudes—preference and resistance to change only were biased by the different relative reinforcer

magnitudes. Therefore, the findings from Grace and colleagues suggest that the effects of relative reinforcer rate and magnitude are independent and combine additively to determine preference and resistance to change. These findings were consistent with findings from concurrent-choice situations (e.g., McLean & Blampied, 2001, but see Todorov, 1973). Importantly, like with the generalized matching law (Equation 1), these findings suggest that the sensitivity and bias parameters from Equations 2 and 3 are independent from one another when reinforcer rate is manipulated and magnitude is held constant.

Concurrent choice, preference, and relative resistance to change have been shown to be independently affected by relative reinforcement rate and magnitude. Concurrent-choice performance also has been shown to be independently affected by relative reinforcement rate and type (e.g., Miller, 1976). Therefore, preference and relative resistance to change might also be independently affected by relative reinforcement rate and type. If so, the methods established by Miller could be extended using measures of preference in concurrent chains and relative resistance to change (i.e., Equations 1 and 2, respectively) to predict and hedonically scale the relations between qualitatively different reinforcers. Such findings would suggest that preference and relative resistance to disruption between different reinforcer types could be predicted based on previously established relations between those and other reinforcer types.

To assess whether this was the case, rats responded for qualitatively different reinforcers presented in the terminal links of a concurrent-chains procedure. With food pellets serving as the standard reinforcer type, preference and resistance to extinction

were assessed when food and a sweetened-condensed milk solution were presented across terminal links of one condition, food pellets and a sucrose solution were presented in the next condition, and a sucrose and a sweetened-condensed milk solution were presented in the last condition. Therefore, we examined whether preference and relative resistance to change between the sucrose and sweetened-condensed milk solution could be accurately predicted based on the relation of those reinforcers to food in previous conditions.

Method

Subjects

Four Long Evans rats obtained from Charles River (Portage, MI, USA) were maintained at approximately 80% of their adult weights (± 10 g). Rats were approximately 120 days old and experimentally naïve at the start of the experiment. Running weights were 316 g, 304 g, 323 g, and 313 g for N97, N98, N99, and N100, respectively, and were maintained by postsession feeding of Harlan Teklad (Madison, WI, USA) 8604 Rat Diet as necessary. When not in experimental sessions, rats were housed individually in a temperature-controlled colony with a 12:12 hr light/dark cycle (lights on at 7 a.m.). All rats had free access to water in their home cages.

Apparatus

Two Med Associates® (St. Albans, VT, USA) operant conditioning chambers were used. Each chamber was approximately 30 cm long, 24 cm wide, 21 cm high, and housed in a sound-attenuating cubicle. The back panel of each chamber was equipped

with two response levers centered 13 cm apart and a horizontal array of red, yellow, and green LEDs above each lever. The front panel of each chamber was equipped with a 28-V DC houselight at the top center of the panel, a Sonalert (2900 ± 500 Hz, 75-85 dB), and three rectangular openings (3.2 cm wide by 4.1 cm high) centered with 5 cm between each opening, 2 cm from each side of the chamber, and the bottom edges 2 cm above a grid floor. The left and right openings provided access to solenoid-operated dippers that delivered 0.1 ml of either a sucrose solution or a sweetened-condensed milk solution. The center opening provided access to 45-mg Bio-Serv food pellets (Product# F0165). During dipper and food presentations, lever LEDs and the houselight were darkened while a light inside the activated opening was turned on for 3 s. Pellet deliveries included a single pellet and were accompanied by an audible brief “double click.” Timing of other events was suspended during reinforcement. A chamber ventilation fan masked extraneous noise. Control of experimental events and data recording was conducted with Med Associates® (St. Albans, VT, USA) interfacing and programming. The 10% sucrose solutions were prepared as percent weight per volume with distilled water and table sugar and stored at room temperature. The 50% sweetened-condensed milk solutions were prepared as percent volume per volume with distilled water and Meadow Gold® sweetened-condensed milk. Sweetened-condensed milk (hereafter milk) solutions were stored in a refrigerator between sessions.

Procedure

During training, food pellets or sucrose were made available across daily sessions response independently on a variable-time (VT) 60-s schedule. At the start of each

session, the LEDs over one lever also were turned on and pressing that lever produced food or sucrose on a fixed-ratio (FR) 1 schedule. The LEDs over the other lever were off for the duration of that session. The response-independent and response-dependent presentations were always the same reinforcer type within a training session. For rats N97 and N99, a steady tone and houselight with the lever LEDs flashing on and off every 0.1 s signaled that responding on the right lever would produce food pellets. A pulsing tone, flashing houselight, and flashing lever LEDs turning on and off every 0.5 s signaled that responding on the left lever would produce sucrose. The lever and stimulus assignments were reversed for rats N98 and N100. These training sessions ended after 60 min or when 200 reinforcer presentations occurred, whichever came first. Rats N97 and N99 were trained with food during the first and third training sessions and with sucrose on the second and fourth training sessions. The order of training sessions was reversed for rats N98 and N100. After the four training sessions, the VT schedule was turned off and a two-component multiple schedule was introduced.

Following training, responding in the initial links of concurrent-chains schedules provided access to two mutually exclusive terminal links. Reinforcer type was manipulated across conditions and relative reinforcer rate was manipulated within conditions as indicated in the Appendix. Rats responded for food pellets in both terminal links during Condition 1; food pellets and milk were presented for responding on the right and left levers, respectively, in Condition 2; food pellets and sucrose were presented for responding on the right and left levers, respectively, in Condition 3; and sucrose and milk solutions were presented for responding on the right and left levers, respectively, in

Condition 4. Terminal-link reinforcement ratios across the right and left levers in each condition were 1:1 (VI 20 s vs. VI 20 s), 4:1 (VI 8 s vs. VI 32 s), and 1:4 (VI 32 s vs. VI 8 s).

Rats N97 and N98 were run in the two chambers immediately before rats N99 and N100. Each session ended after 24 cycles of a concurrent-chains procedure or 60 min, whichever came first. A cycle began in the initial links of the concurrent chains with the houselight off and both lever lights illuminated. Responding in the initial links provided access to one of two mutually exclusive terminal links. On each cycle, terminal-link entries were randomly assigned to either the left or right lever, with the restriction that exactly 12 terminal-link entries occurred to each side per session. Terminal-link entries to the left and right terminal links were scheduled on separate arithmetic VI 25-s schedule (see Grace & Nevin, 2000, for interval construction). There were 12 intervals for each arithmetic VI schedule. Therefore, exactly 12 terminal-link entries occurred on the left and right levers. A terminal link entry occurred when that lever was selected, the VI schedule had elapsed, and a 1.5-s changeover delay had elapsed since the last response on the lever on which the terminal-link entry was not arranged. Timing of the initial-link VI schedules did not begin until one response occurred to either lever (cf. Grace & Nevin).

Entries into the terminal links were signaled by either: (a) a steady tone and houselight with one lever light flashing on and off every 0.1 s, or (b) a pulsing tone, flashing houselight, and flashing lever light turning on and off every 0.5 s. In the terminal links, responding on the left lever produced access to the liquid solution (sucrose or milk) and responding on the right lever produced access to food pellets on independent VI 20-s

schedules without replacement according to Fleshler and Hoffman (1962). Both terminal links were always a constant 60 s in duration, excluding reinforcer time. If a reinforcer was available but not obtained, it was presented after the first response the next time that terminal link was presented. After a terminal link ended, the initial links were immediately introduced again. For rats N98 and N100, the steady tone and houselight were paired with the terminal link on the left lever and the pulsing tone and flashing houselight were paired with the terminal link on the right lever. The assignments were reversed for rats N97 and N99.

Each reinforcer ratio included 20 baseline sessions followed by 6 sessions of disruption with extinction. After extinction, the baseline schedules in the initial and terminal links were reinstated and the reinforcer ratio/type was changed as indicated in the Appendix. Resistance to extinction of terminal-link responding was assessed by making transitions from the initial links to terminal links response independent on a VT 25-s schedule, and discontinuing reinforcement in both terminal links (see Grace & Nevin, 2000). Sessions occurred 7 days per week at approximately the same time.

Results

In the following sections, preference and relative resistance to extinction were assessed as a function of changes in relative reinforcer type across conditions and relative reinforcer rate within conditions. For each initial link, numbers of responses, responses per min, local time, and terminal-link entry rates are presented in Appendix 1 for each condition and reinforcer ratio in the order they occurred. The numbers of responses are

summed across the final six sessions prior to extinction and responses per min, local time, and terminal-link entry rates are the mean of the final six sessions prior to extinction.

Terminal-link entry rates were the same across the right and left levers because the initial links were scheduled interdependently. Therefore, a single value for terminal-link entry rate is provided for both right and left levers. Terminal-link entry rates were lower than programmed in all cases, but they did not differ systematically within or between conditions. Appendix 2 presents terminal-link reinforcement rates and responses per min during baseline and extinction as the mean of the six sessions prior to baseline. Terminal link reinforcer rates changed with changes in programmed rate but also were consistently lower than the programmed rates. Obtained relative reinforcement rates, however, were similar across conditions in which programmed relative reinforcement rates were equal.

Stimulus control in the terminal links was very good for all rats, as indicated by the mean discrimination indices (Rat N97: $M = 0.98$, $SD = 0.04$; Rat N98: $M = 0.96$, $SD = 0.05$; Rat N99: $M = 0.97$, $SD = 0.05$; Rat N100: $M = 0.97$, $SD = 0.04$). Discrimination indices are calculated as the proportion of responses on one lever when a terminal link was active in the numerator and responses on that lever when the terminal link was active and inactive in the denominator.

Preference and Resistance to Change

The left panel of Figure 3-1 shows preference as the log ratio of mean initial-link response rates from 6 consecutive baseline sessions across conditions as a function of changes in relative terminal-link reinforcement rate. The right panel shows relative resistance to extinction across conditions as a function of changes in relative terminal-

link reinforcement rate. Each data point is the ratio of means of the log proportion of baseline response rates from six sessions of extinction. The numerator of each ratio is the measure from the right lever in each condition (e.g., Sucrose in the Sucrose vs. Milk condition). The data points from each condition are fit using linear regression. Sensitivity (a) values are indicated in Table 2 and presented in the left panel of Figure 3-2. Bias ($\log b$) values are indicated in Table 2 and presented in the left panel of Figure 3-3.

In the left panel of Figure 3-1, preference was sensitive to changes in relative reinforcement rates in all conditions but tended to differ across conditions. Sensitivity tended to be highest in the Food versus Food condition, with the exception of N97, and was lowest for all rats in the Food versus Sucrose condition. There were systematic shifts in the y-intercept, or bias ($\log b$), values across conditions for all rats. Absolute bias values were smallest during the Food versus Food condition and were not systematically different across rats. Bias values during the Food versus Food condition originally were intended to be used to provide a control for inherent position bias across levers (see Matthews & Temple, 1979) by subtracting the bias obtained during the Food versus Food condition from the bias obtained during each of the other conditions. This would provide a direct measure of the biasing role of differences in reinforcer type (i.e., $\log [q_1 / q_2]$) independent of inherent bias (i.e., $\log b$). Given the tendency for steeper slopes and the relatively small and inconsistent biases across rats during the Food versus Food condition, the bias values from the Food versus Food condition will not be used to control for inherent biases. Hereafter, $\log b$ will refer to biases that both are inherent and produced by differences in relative reinforcer type.

For relative resistance to extinction shown in the right column of Figure 3-1, there were no obvious patterns of sensitivity (see also Figure 3-2) and bias (see also Figure 3-3) within or between conditions when comparing across all rats. There were a number of instances in which sensitivity values were very small and/or negative. However, sensitivity tended to be positive in the Food versus Food condition (except for Rat N98). Note that this is the only condition in which the reinforcer types were identical, suggesting that differences in reinforcer type might have influenced sensitivity. There was a tendency for sensitivity to be lowest or more negative in the Sucrose versus Milk condition.

To assess whether the unsystematic relative resistance to change findings were a result of decreases in sensitivity to different reinforcer types across sessions of extinction, Figure 3-4 shows mean relative resistance to extinction when assessed after one, three, and all six sessions as a function of relative reinforcer rate. The general pattern of disruption across comparisons does not change. The only clear exception is that the function from the Sucrose versus Milk condition becomes more negative when assessed with 3 and 6 sessions of extinction. Relative resistance to extinction sensitivity and bias parameters following one, three, and six sessions from individual subjects is located in Table 3-3. The sensitivity and bias values from one and six sessions of extinction do not become any more systematic than when assessed from six sessions. Given that the general pattern of disruption did not change as a function of the number of extinction sessions included, the remainder of the analyses will include only data from all six sessions.

Prediction and Scaling

Using methods developed by Miller (1976), predictions of preference between sucrose and milk in the final condition and scaling of food, milk, and sucrose were based on the $\log b$ values from the four rats. Following the Food versus Food condition, all rats showed a bias for food over milk in the Food versus Milk condition (i.e., Food > Milk). Next, bias values increased in the Food versus Sucrose condition, indicating a larger preference for food over sucrose than the preference for food over milk (i.e., Food|Sucrose > Food|Milk). Finally, consistent with the previous relation, all rats had a bias for milk over sucrose in the Sucrose versus Milk condition (i.e., Milk > Sucrose). Table 2 includes the obtained $\log b$ values across all conditions and the predicted $\log b$ values for the Sucrose versus Milk condition for individual rats. Given that food pellets functioned as the standard reinforcer, the \log value of a food pellet ($\log V_f$) was set to 1. The $\log b$ value from the Food versus Milk condition (e.g., 0.68 for Rat N97) was used to obtain the \log value of milk ($\log V_m$) relative to food pellets ($1 - \log V_m$). Thus, for Rat N97, $\log V_m$ was 0.32 (i.e., $1 - \log V_m = 0.68$). Similarly, the $\log b$ value from the Food versus Sucrose condition was used to obtain the \log value of sucrose ($\log V_s$) relative to food pellets ($1 - \log V_s$). Finally, given $\log V_s$ and $\log V_m$, the predicted bias during the Sucrose versus Milk condition was determined ($\log V_s - \log V_m$). As shown in Table 2, the predicted $\log b$ value for the Sucrose versus Milk condition was in the same direction as the obtained $\log b$ value across all rats. Therefore, the present procedures were sufficient to predict the direction of preference between sucrose and milk based on the

preference relations between food and milk and between food and sucrose. In all cases, however, obtained $\log b$ values were more extreme than predicted $\log b$ values.

Miller (1976) constructed a hedonic scale of reinforcer types by taking the antilogarithm of the log values ($\text{antilog} = 10^{\log V}$) of wheat and hemp relative to the standard buckwheat reinforcer. From the present experiment, the antilog of the log values from the Food versus Milk condition and Food versus Sucrose condition were used to obtain values for food (V_f), milk (V_m), and sucrose (V_s). These values are indicated in Table 2. Because one food pellet functioned as the standard ($\log V_f = 1$), V_f was 10 for all rats. Both V_m and V_s were less than V_f and V_m always was greater than V_s . The correspondence in direction between the predicted and obtained $\log b$ values therefore indicates that V_m and V_s are ordinally correct. However, the obtained $\log b$ values from the Sucrose versus Milk condition consistently were more negative than the predicted values. Thus, there was a larger preference for milk over sucrose when those reinforcers were compared *directly* in the Sucrose versus Milk condition than what was predicted when milk and sucrose were compared *indirectly* through their relation to food (in the Food versus Milk and Food versus Sucrose conditions).

For relative resistance to change, Table 2 shows obtained and predicted $\log b$ values for each rat. The log value of the standard food pellet reinforcer ($\log V_f$) was set to 1 and the log values of milk ($\log V_m$) and sucrose ($\log V_s$) were determined from the Food versus Milk and Food versus Sucrose conditions, respectively. Finally, the predicted bias during the Sucrose versus Milk condition was determined ($\log V_s - \log V_m$) for each rat. With the exception of Rat N98, obtained $\log b$ values showed some systematic patterns.

Unlike with preference, however, predicted and obtained $\log b$ values did not always correspond. For Rat N97, $\log b$ values increased across conditions and were negative (as predicted) during the Sucrose versus Milk condition and, as with preference, obtained $\log b$ values were more extreme than predicted. Thus, predicted and obtained bias values indicated a bias toward milk over sucrose. For Rat N98, there was a bias for milk over food in the Food versus Milk condition and no bias in the Food versus Sucrose condition. Thus, it was predicted that there would be a bias for milk over sucrose in the Sucrose versus Milk condition. Paradoxically, there was a bias for sucrose over milk. For Rat N99, no difference in $\log b$ was predicted, but the obtained $\log b$ during the Sucrose versus Milk condition was positive. For Rat N100, $\log b$ from the Food versus Milk condition was larger than $\log b$ from the Food versus Sucrose condition. As predicted, there was a bias for sucrose in the Sucrose versus Milk condition. Overall, there were varying levels of correspondence between predicted and obtained $\log b$ values for the Sucrose versus Milk condition.

Given the lack of systematic effects of changing relative reinforcer rate and type across individual rats, it is difficult to make general conclusions about scaling the different reinforcer types based on obtained $\log b$ values. Nonetheless, Table 2 shows the reinforcers scaled by taking the antilog of the $\log b$ values obtained during the Food versus Milk and the Food versus Sucrose conditions. As previously described, the value of the standard food pellet (V_f) was 10 for all rats. For all rats, the values of Milk (V_m) and Sucrose (V_s) were closer to V_f than with preference. For Rats N97, N99, and N100, V_m and V_s both were lower than V_f . For Rat N97, V_m was larger than V_s . For Rat N99,

V_m was equal to V_s . For Rat N100, V_m was smaller than V_s . For Rat N98, V_m was larger than V_f and V_s was equal to V_f . Thus, the values of food, milk, and sucrose corresponded with those from preference only for Rat N97.

Relation Between Preference and Resistance to Change

Figure 3-5 shows the relation between relative resistance to extinction and preference. Relative resistance to extinction is plotted on the y -axis as in the left side of Equation 3 (i.e., $\log [B_{x1} / B_{o1}] - \log [B_{x2} / B_{o2}]$) against preference on the x -axis as in the left side of Equation 1 (i.e., $\log [B_{i1} / B_{i2}]$). Lines were fitted to the functions using linear regression¹ and the slopes are indicated in Table 2. Relative resistance to extinction and preference in the Food versus Food condition were positively related for 3 of 4 rats, with the exception being Rat N98. There were no consistent relations between relative resistance to extinction and preference in the other conditions, with the exception of somewhat of a negative relation in the Sucrose versus Milk condition. The different ranges between data points for a given condition along the x -axis or y -axis indicate differences in sensitivity across conditions for preference and resistance to change, respectively (see Figure 3-2). Shifts in the functions along the x -axis or y -axis indicate changes in bias across conditions for preference and resistance to change, respectively (see Figure 3-3).

When considering the relation between relative resistance to extinction and preference across all conditions in Figure 3-5, there appears to be a general tendency for relative resistance to extinction to increase along the y -axis with increases in preference along the x -axis. This relation was assessed directly in Figure 3-6 with the mean relative

resistance to extinction and preference data across all rats. This is how Grace and colleagues (2002) summarized previous studies examining the relation between preference and resistance to change. The linear regression line¹ is shown in Figure 3-6. The slope of this function was 0.10 and r^2 was 0.51 and was significantly different from zero. Both the slope and r^2 were lower than the slope of 0.36 and r^2 of 0.80 found by Grace and colleagues when they summarized the relation between resistance and preference from their and other relevant studies. The lower sensitivity might have been a result of the use of extinction as a disrupter rather than response-independent food presentations between the stimulus contexts, using rats as experimental subjects rather than pigeons, or the use of qualitatively different reinforcers. It is unlikely that the qualitatively different reinforcers could account for the weaker relation between resistance to change and preference in the present experiment because the mean slope still was only 0.15 in the Food versus Food condition. Nonetheless, these findings are suggestive of a general relation between relative resistance to change and preference, even though this relation was not always consistent across conditions or rats.

Bias values indicate shifts in preference and relative resistance to extinction as a function of changes in relative reinforcer type. Figure 3-7 shows the relation between log b values for preference and relative resistance to extinction across conditions for all rats in the top panel and the mean function in the bottom panel. Lines were fitted to the functions using linear regression¹ and the slopes are shown in the legend in the top panel and the linear-regression equation is shown in the bottom panel. The relation between bias parameters for preference and relative resistance to extinction were positive for 3 out

of 4 rats, with a range across all four rats from 0.17 (Rat N97) to -.03 (Rat N98). The slope of the mean relation was 0.09 with an r^2 of 0.74. This function, however, was not significantly different from zero. Nonetheless, the slope of 0.09 from the mean function is similar to the slope from Figure 3-6 (0.10) that shows the overall relation between preference and relative resistance to change. Therefore, the relations in Figures 3-6 and 3-7 are at least suggestive of a general relation between resistance to change and preference with rats responding for reinforcers that vary in type.

Discussion

The present experiment examined the effects of changing relative reinforcer rate and type on preference and relative resistance to change with rats responding on a concurrent-chains procedure. Preference was sensitive to changes in relative reinforcement rate and was systematically biased by changes in relative reinforcer type. Conversely, with the exception of when food pellets maintained responding in both contexts, relative resistance to extinction across terminal links was not consistently affected by changes in relative reinforcer rate. In addition, changes in relative reinforcer type biased relative resistance to extinction less systematically than preference.

According to behavioral momentum theory, measures of preference and resistance to change are both quantitative expressions of how conditions of reinforcement in a stimulus context come to strengthen behavior and determine the value of that context. Therefore, a prediction of behavioral momentum theory is that preference and relative resistance to change should be correlated (see Nevin & Grace, 2000a). Preference and

relative resistance to extinction tended to be related to the greatest extent when food was presented in both terminal links, but tended to be less systematically related in the other conditions in which reinforcer types differed (see Figure 3-5). However, when the mean relation between resistance to extinction and preference was examined across rats similar to the analyses of Grace and colleagues (2002; see Figure 3-6), and when only the biasing effects of differences in relative reinforcer type were examined (see Figure 3-7), there was some tendency for a correlation between preference and relative resistance to extinction. Therefore, support for a relation between preference and relative resistance to change as a function of relative reinforcer rate and type was suggestive, but not entirely conclusive. Given the systematic findings of relative reinforcer type on preference, the lack of a consistently systematic relation between these measures clearly was a result of the inconsistent relative resistance to extinction findings.

Why were there systematic effects of changing relative reinforcer rate and type on preference but to a lesser extent on relative resistance to extinction? Previous research consistently has shown that preference is more sensitive to changes in relative reinforcer rate than relative resistance to disruption (see Grace et al., 2002, for a summary of these results). Moreover, resistance to extinction in particular has been shown to be less sensitive than other types of disrupters (see Nevin & Grace, 2000b; Nevin, Grace, et al., 2001). A common explanation for relative resistance to extinction being less sensitive to changes in relative reinforcer rate than other disrupters is that there is a greater change in conditions when transitioning to extinction in contexts signaling higher reinforcer rates (i.e., generalization decrement; see Nevin, McLean, et al., 2001; Shull & Grimes, 2006).

With higher reinforcement rates, responding is disrupted both by the discontinuation of reinforcement and the more easily discriminated change in reinforcement rate. The generalization decrement hypothesis might be sufficient to explain why relative resistance to extinction was not always sensitive to changes in relative reinforcement rate. It does not provide a good explanation for why changes in relative reinforcer type did not always systematically bias relative resistance to extinction.

One explanation that has received some recent support with concurrent-chains procedures is that rats might be differentially sensitive to certain procedural manipulations than are pigeons. For instance, Mazur (2005, 2007) found that rats' preference was more sensitive to changes in the delay to reinforcement in one terminal link than were pigeons. In addition, preference of pigeons was sensitive to the presence or absence of omitting stimuli on trials in which food reinforcement did not occur but rats were not. As mentioned by Mazur, it is difficult to make firm conclusions about the generality of such results because it is difficult to control confounding variables across studies with different species (e.g., different reinforcer magnitudes, responses, salience of discriminative stimuli). Nevertheless, differences across rats and pigeons are a potential explanation for why clear biases in resistance to change were obtained with pigeons and differences in reinforcer magnitude in Grace and colleagues (2002), but not in the present experiment with differences in reinforcer type.

Bias parameters for relative resistance to extinction might not have been systematically affected in all cases because differences in relative reinforcer type were not large enough to produce consistent biases. Findings from Grace and colleagues

(2002) suggest otherwise. Changes in bias for preference in the present study when relative reinforcer type was manipulated were comparable to those from Grace and colleagues, in which the relative duration of pigeons' access to food was manipulated. Log b values from the present study had a range of 0.74 to 1.36 log units across rats and the range from Grace and colleagues was from 0.74 to 1.46 log units across pigeons. Although Grace and colleagues did not assess relative resistance to extinction, they did find that resistance to disruption by free food during the initial links was systematically affected by those differences in relative reinforcer magnitude. Thus, if the changes in relative reinforcer type were large enough to bias preference to a similar extent as in Grace and colleagues, the qualitative differences in reinforcer type should have been large enough to systematically bias relative resistance to extinction. Relative resistance to extinction tended to be systematically related to differences in relative reinforcement rate in the Food versus Food condition, suggesting that relative resistance to extinction was sensitive to changes in terminal-link manipulations in general.

Another explanation for the unsystematic relative resistance to extinction findings is that they were specifically a result of arranging different reinforcer types in the terminal links. Different reinforcer types could interact in a different way than when two identical reinforcers are arranged. Therefore, increasing the qualitative difference between different reinforcer types could impact processes other than relative response strength. If this were the case, then increasing qualitative differences between reinforcer types would not necessarily make the biases in relative resistance to extinction more systematic. With food pellets and a sucrose solution, for example, qualitative difference

could be increased by decreasing the concentration of sucrose in the sucrose solution. As the sucrose concentration decreased, the solution would eventually be composed of water alone. Because food and water fulfill different biological needs, a thirsty organism is not completely satisfied by access to food and vice versa. Moreover, unlike with two sources of food pellets, increasing the availability of one option (water) has been shown to *increase* the consumption or value of the other (food pellets) and vice versa (Green & Rachlin, 1991; Hursh, 1978).

In behavioral economic terms, the interaction between qualitatively different reinforcers is determined by the degree to which different reinforcer types are *substitutable* (see Green & Freed, 1993). If increasing the availability of food *decreases* the value of another option, like with two identical food sources, these options are substitutes. If increasing the availability of food *increases* the value of another option, like with food and water, these options are complements. In the context of the present discussion, larger decreases in sucrose concentration likely would decrease substitutability by making the sucrose solution more similar to water, which has been shown to be a complement for food (see Green & Rachlin, 1991; Hursh, 1978). When changes in the availability of one option have little effect on the value of another option, like perhaps with food and toys, these options are independent. Therefore, substitutability is a continuum on which different reinforcer types interact in different ways.

As previously mentioned, Miller (1976) manipulated the relative rate of different types of grain in a concurrent-choice situation with pigeons. The different grains were highly substitutable because changes in grain type only biased responding and sensitivity

to changes in relative rate did not differ with changes in type. In this case, manipulations of relative reinforcer type were akin to quantitatively manipulating relative reinforcer magnitude (see McLean & Blampied, 2001). Hursh (1978), on the other hand, arranged for different rates of food and water, two known compliments (see Green & Rachlin, 1991), to be presented in a concurrent-choice situation with monkeys. Unlike Miller's findings, sensitivity was impacted by the different reinforcer types when relative rates of food and water were manipulated. Specifically, relative response rates were inversely related to relative reinforcer rate, which produced a negatively sloped function (i.e., "anti-matching"). Conversely, when Hursh examined the effects of manipulating relative rates of two sources of food, typical matching functions were obtained. These studies suggest that relative reinforcer rate and type interact in different ways depending on the substitutability of the reinforcer types involved. Therefore, if increasing the qualitative difference between reinforcers types in the present experiment likely also would decrease substitutability, it is unlikely that increasing qualitative differences necessarily would have resulted in more systematic sensitivity and bias values for relative resistance to extinction.

In the present experiment, there tended to be changes in sensitivity and bias across conditions for preference and to some extent for relative resistance to extinction (see Figures 3-2 & 3-3). Although these changes were not always systematic and there are confounds with the order in which the conditions were presented, there was a general trend for sensitivity to be highest and bias to be lowest in the Food versus Food condition. Different sensitivity values across conditions suggest that changing relative

reinforcer rates might have affected both preference and relative resistance to extinction differently depending on what types of reinforcers currently were available. It probably can be assumed that food pellets, milk, and sucrose were less substitutable for each other than were food pellets for food pellets in the Food versus Food condition. In other words, like with Hursh (1978), differences in sensitivity to changes in relative reinforcer rate suggest there might have been different degrees of substitutability between reinforcer types. To conclusively determine to what extent reinforcer substitutability impacts preference and relative resistance to change, the substitutability between these reinforcer types first would have to be assessed and quantified using methods pioneered by Green and Rachlin (1991; see also Belke et al., 2006).

The different degrees to which changes in relative reinforcer rate and type interact calls into question the validity of using $\log b$ bias values from versions of the matching law for the prediction and scaling of reinforcer types (Equations 1, 2, & 3). Interactions between reinforcer variables like rate and type across two or more options (e.g., Hursh, 1978) violate a major assumption of the concatenated generalized matching law—that variables have independent and additive effects on behavior (see Baum & Rachlin, 1969). The assumption that the value of a reinforcer or stimulus context is based solely on the reinforcement variables (e.g., schedule, rate, type) for that option is referred to as *simple scalability* (see Grace, 1993). Interactions between reinforcer rate and type across two or more response options due to degree of substitutability violate the assumption of simple scalability. If sensitivity changes depending on whether Reinforcer A is compared to Reinforcer B versus Reinforcer C, then it is impossible to conclude that Reinforcer A, B,

and C differ only in how they are valued on an interval scale. Instead, their value depends on the context of what other reinforcers are available.

Even if sensitivity values for preference had been constant across conditions, the systematic deviation between predicted and obtained bias values pose difficulties for hedonically scaling different reinforcer types using bias values. Bias values tended to be small and unsystematic in the Food versus Food condition. They increased in the Food versus Milk condition and increased further during the Food versus Sucrose condition. Based on the bias values from the previous two conditions, the prediction that milk should be preferred to sucrose in the last conditions was confirmed. Thus, $\log b$ values were sufficient for scaling the reinforcer types on an ordinal scale. The simple directional correspondence between the predicted and obtained bias values in the Sucrose versus Milk condition satisfied the condition for weak stochastic transitivity (see Navarick & Fantino, 1974). Navarick and Fantino have stated that "...we believe [tests of weak stochastic transitivity] to be decisive tests of any theory of choice" (p. 427). However, the obtained bias values from the Sucrose versus Milk condition consistently were larger than predicted. That is, the predicted preference of milk over sucrose based on their relations to food was smaller than the preference obtained when both were compared directly.

Unlike in the present experiment, Miller (1976) obtained a close correspondence between predicted and obtained $\log b$ values. The close correspondence in his study might have been due to the relatively small obtained $\log b$ values across all conditions. When buckwheat and hemp were compared, $\log b$ was 0.043. Next, when wheat and buckwheat were compared, $\log b$ was 0.145. Finally, the obtained $\log b$ value when hemp

and wheat were compared was -0.15 , close to the predicted -0.188 . Thus, the largest $\log b$ value did not exceed 0.2 log units, whereas $\log b$ values often exceeded one log unit in the present experiment (see Table 3-2). Such constrained $\log b$ values in Miller's study make it more likely that obtained $\log b$ values will fall close to predicted values. Miller might have obtained less correspondence between predicted and obtained $\log b$ values had he used a wider range of qualitative differences of his reinforcers. As already suggested, however, increasing qualitative differences might only have resulted in decreases in substitutability and systematic deviations in bias and sensitivity. Therefore, the systematic sensitivity values, relatively small $\log b$ values, and close correspondence between predicted and obtained $\log b$ values from Miller's experiment likely were a result of arranging highly substitutable reinforcers.

Given the smaller predicted bias for milk over sucrose than was obtained, it is unclear whether the scaled value of sucrose should decrease, the scaled value of milk should increase, or the scaled values of milk and sucrose both should change. Such systematic deviations between predicted and obtained $\log b$ values call into question the validity of scaling reinforcers simply based on their relation to a standard. These deviations between predicted and obtained $\log b$ values are another instance in which preference likely was dependent on the context of the other reinforcers available. These deviations suggest that the bias values do not lie along an interval scale that is invariant with respect to context. That is, simple scalability again was violated.

The present findings argue for developing a better understanding of how contextual effects of different reinforcer types interact to affect preference and relative

resistance to change. There has been no theoretical development regarding interactions between qualitatively different reinforcers in behavioral momentum theory (but see Nevin, 1995, 1999; Nevin & Grace, 2000a, for related discussions). Grace (1994) developed a quantitative model of concurrent-chains performance to account for contextual reinforcement effects other than interactions between different reinforcer types. These contextual effects include violations of weak stochastic transitivity with different schedules of reinforcement and changes in preference as a result of changes in the relative duration of initial and terminal links (see Grace, 1993, for a review of these effects). Given that behavior in natural contexts often is maintained by different reinforcer types, it is important to understand how different reinforcers interact to affect preference and the persistence of behavior. A goal of future research within the framework of behavioral momentum theory should be directed toward incorporating interactions between different reinforcer types.

Authors' Notes

This experiment was part of the first author's doctoral dissertation in Psychology at Utah State University and he thanks the committee members Scott Bates, Clint Field, Amy Odum, and Tim Slocum. The authors would like to thank Corina Jimenez-Gomez for her thoughtful comments during the preparation of this manuscript. Portions of these data were presented in a symposium at the 2008 annual meeting of the Association for Behavior Analysis in Chicago, IL.

Footnote

¹Given that two dependent variables are compared in Figures 3-6 and 3-7, structural relations are a more appropriate measure to examine the relation between preference and relative resistance to extinction (see Isaac, 1970). Linear regression was used for convenience and because the slopes of the structural relations were within ± 0.03 of the linear-regression slopes in Figure 3-6 and within rounding error of the linear-regression slopes in Figures 3-7.

Table 3-1. *Conditions. Order of conditions and changes in relative rate of reinforcement within conditions across the four rats. Conditions include the Food versus Food condition (F vs. F), Food versus Milk condition (F vs. M), Food versus Sucrose condition (F vs. S), and the Sucrose versus Milk condition (S vs. M).*

Conditions	N97	N98	N99	N100
F vs. F	1:1	1:1	1:1	1:1
	4:1	4:1	1:4	1:4
	1:4	1:4	4:1	4:1
F vs. M	1:1	1:1	1:1	1:1
	4:1	4:1	1:4	1:4
	1:4	1:4	4:1	4:1
F vs. S	1:1	1:1	1:1	1:1
	1:4	1:4	4:1	4:1
	4:1	4:1	1:4	1:4
S vs. M	1:1	1:1	1:1	1:1
	1:4	1:4	4:1	4:1
	4:1	4:1	1:4	1:4

Table 3-2. *Sensitivity and Bias. Sensitivity (a), bias (log b), predicted log b, and values of food, milk, and sucrose determined by taking the antilogarithm of the log values (see text for more explanation) for preference and resistance to change. Structural relation values are the slope of linear-regression functions relating log b values between relative resistance to extinction and preference (see text for more explanation).*

Rat	Condition	Preference				Resistance to change				structural relation
		a	log b	Predicted log b	$V_{f/m/s}$	a	log b	Predicted log b	$V_{f/m/s}$	
N97	F vs. F	1.53	0.24		10.00	0.29	0.03		10.00	0.16
	F vs. M	1.63	0.68		2.09	0.41	0.11		7.76	0.26
	F vs. S	1.10	0.98		1.05	0.45	0.17		6.76	0.41
	S vs. M	1.64	-0.66	-0.30		0.04	-0.12	-0.06		0.00
N98	F vs. F	2.52	0.04		10.00	-0.16	-0.08		10.00	-0.06
	F vs. M	0.87	1.08		0.83	-0.04	-0.16		14.45	-0.04
	F vs. S	0.46	1.40		0.40	-0.04	0.00		10.00	0.18
	S vs. M	0.63	-0.67	-0.32		-0.16	0.01	-0.16		-0.26
N99	F vs. F	1.63	0.22		10.00	0.58	0.21		10.00	0.35
	F vs. M	0.64	0.75		1.78	0.20	0.23		5.89	0.25
	F vs. S	0.47	1.05		0.89	0.25	0.23		5.89	0.52
	S vs. M	0.79	-0.61	-0.30		-0.24	0.16	0.00		-0.23
N100	F vs. F	1.81	-0.04		10.00	0.43	-0.01		10.00	0.24
	F vs. M	1.19	0.80		1.58	-0.05	0.31		4.90	-0.04
	F vs. S	0.79	0.98		1.05	0.11	0.25		5.62	0.15
	S vs. M	0.83	-0.61	-0.18		-0.13	0.09	0.06		-0.24

Table 3-3. *Sensitivity and Bias Following One, Three, and Six Sessions. Sensitivity (a) and bias ($\log b$) for relative resistance to change when examined following one sessions of extinction or as a mean of the first three sessions of extinction. Sensitivity and bias from all six sessions of extinction also are shown.*

Rat	Condition	1 session		3 sessions		6 sessions	
		a	$\log b$	a	$\log b$	a	$\log b$
N97	F vs. F	-0.03	0.01	0.1	0.01	0.29	0.03
	F vs. M	0.01	-0.12	0.42	0.13	0.41	0.11
	F vs. S	0.23	-0.27	0.36	-0.14	0.45	0.17
	S vs. M	0.43	-0.28	0.36	-0.24	0.04	-0.12
N98	F vs. F	-0.01	-0.02	-0.11	-0.05	-0.16	-0.08
	F vs. M	0.30	0.24	0.06	0.20	-0.04	-0.16
	F vs. S	-0.04	0.03	0.05	0.08	-0.04	0.00
	S vs. M	-0.14	-0.08	-0.17	-0.06	-0.16	0.01
N99	F vs. F	0.50	0.15	0.51	0.15	0.58	0.21
	F vs. M	0.38	0.15	0.28	0.24	0.20	0.23
	F vs. S	0.41	0.08	0.31	0.19	0.25	0.23
	S vs. M	-0.21	-0.01	-0.21	-0.01	-0.24	0.16
N100	F vs. F	0.54	-0.08	0.59	0.00	0.43	-0.01
	F vs. M	-0.26	0.29	-0.13	0.37	-0.05	0.31
	F vs. S	0.32	0.30	0.33	0.27	0.11	0.25
	S vs. M	-0.02	-0.09	-0.09	0.01	-0.13	0.09

Appendix A. *Responses and Local Time. These are for the left and right levers during the initial links and are summed across the last six sessions prior to extinction. Response rates on the left and right levers during the initial links and the terminal-link (TL) entry rate are shown as means across the last six sessions prior to extinction.*

Rat	Condition		Responses		Response rate		Local time		TL entry rate
			Right	Left	Right	Left	Right	Left	
N97	F vs. F	1:1	2183	2472	31.73	35.96	2572.76	1557.18	1.05
		4:1	5352	281	54.75	3.03	5618.48	241.27	0.75
		1:4	1185	3629	17.01	51.65	1330.79	2880.68	1.03
	F vs. M	1:1	3510	421	40.04	4.87	4502.07	746.98	0.83
		4:1	5789	181	49.60	1.59	6783.44	225.35	0.62
		1:4	1063	2487	13.75	31.60	1459.97	3268.84	0.92
	F vs. S	1:1	4296	449	43.73	4.72	5469.07	501.04	0.75
		1:4	2810	1238	40.91	17.92	2800.57	1383.24	1.04
		4:1	6628	191	67.04	1.98	5770.68	153.19	0.74
	S vs. M	1:1	658	4887	7.94	58.50	1015.94	3971.90	0.87
		1:4	241	7981	2.38	76.96	256.78	5972.15	0.70
		4:1	2519	951	33.78	12.70	3358.59	1131.86	0.96
N98	F vs. F	1:1	1085	959	11.22	9.86	3503.44	2518.18	0.74
		4:1	10026	272	94.62	2.59	6028.02	282.42	0.69
		1:4	439	11773	4.65	124.74	449.37	5216.16	0.76
	F vs. M	1:1	5838	515	62.69	5.59	5106.61	468.56	0.78
		4:1	8323	200	65.96	1.59	7434.92	229.12	0.57
		1:4	3541	986	46.05	12.75	3697.18	954.02	0.93
	F vs. S	1:1	6616	156	54.02	1.28	7232.32	110.72	0.59
		1:4	4611	442	55.29	5.36	4575.15	500.07	0.86
		4:1	5860	163	42.64	1.18	8088.50	222.61	0.52
	S vs. M	1:1	527	2411	5.18	23.75	1657.49	4443.41	0.71
		1:4	390	5034	3.85	49.33	588.99	5528.49	0.71
		4:1	978	2091	11.81	25.45	1978.98	3059.55	0.86
N99	F vs. F	1:1	2104	1108	22.40	12.16	4271.02	1381.24	0.78
		1:4	511	2503	5.84	28.69	1075.36	4193.74	0.83
		4:1	3222	210	33.70	2.20	5359.55	416.81	0.78
	F vs. M	1:1	4018	186	33.70	1.57	6888.26	268.83	0.61
		1:4	1318	1002	17.73	13.53	2700.94	1753.05	0.97
		4:1	2430	567	27.46	7.31	3525.24	1427.67	0.77
	F vs. S	1:1	4164	393	35.39	3.42	6490.98	706.13	0.61
		4:1	4710	202	42.61	1.83	6486.88	138.66	0.65
		1:4	3051	500	35.36	5.71	4625.88	574.89	0.83
	S vs. M	1:1	329	3393	2.61	26.44	554.64	7688.52	0.57
		4:1	1258	1432	12.96	14.28	1994.98	4197.80	0.73
		1:4	359	3396	3.70	34.99	604.97	5250.27	0.74
N100	F vs. F	1:1	3657	4554	52.66	65.63	1709.23	2462.45	1.04
		1:4	832	11116	10.02	133.05	392.55	4619.00	0.86
		4:1	11977	1098	143.64	13.31	4327.81	668.95	0.87
	F vs. M	1:1	8592	1093	102.94	13.48	3970.21	999.35	0.88
		1:4	3592	3287	48.91	44.54	2024.19	2443.11	0.97
		4:1	10714	382	107.87	3.95	5666.40	295.98	0.75
	F vs. S	1:1	6325	599	83.28	8.19	3912.09	612.82	0.96
		4:1	8706	342	91.78	3.60	5343.69	348.37	0.76
		1:4	4520	1521	64.74	21.79	2880.91	1304.19	1.03
	S vs. M	1:1	577	5843	6.36	64.49	743.06	4711.01	0.79
		4:1	2134	1719	27.47	22.10	2018.05	2664.85	0.93
		1:4	541	5412	6.28	62.38	524.42	4665.61	0.84

Appendix B. *Reinforcer Rates and Baseline Response Rates. These are shown as means across the last six sessions prior to extinction. Response rates during extinction are shown as means across the six extinction session.*

Rat	Condition		Reinforcer rate		Baseline		Extinction	
			Right	Left	Right	Left	Right	Left
N97	F vs. F	1:1	2.86	2.76	96.07	83.09	18.16	12.71
		4:1	6.36	1.65	64.79	47.63	15.78	7.85
		1:4	1.71	6.44	65.51	64.04	5.51	7.95
	F vs. M	1:1	2.80	2.71	86.67	50.64	5.57	2.01
		4:1	6.63	1.75	80.08	49.09	5.82	1.82
		1:4	1.72	6.62	74.12	62.87	3.60	4.61
	F vs. S	1:1	2.80	2.57	87.04	63.37	1.42	1.10
		1:4	1.74	6.56	81.91	68.60	5.25	4.33
		4:1	5.65	1.72	60.36	53.37	12.42	3.31
	S vs. M	1:1	2.72	2.80	50.93	89.70	5.24	8.50
		1:4	1.68	6.67	26.18	77.82	1.57	7.68
		4:1	7.05	1.78	112.89	67.81	6.72	5.96
N98	F vs. F	1:1	2.63	2.72	30.76	31.34	15.41	15.34
		4:1	6.45	1.56	97.11	20.46	19.20	6.68
		1:4	1.75	6.60	67.07	117.90	12.46	23.88
	F vs. M	1:1	2.82	2.60	137.65	48.61	18.91	5.82
		4:1	6.42	1.62	118.05	37.98	19.31	4.07
		1:4	1.71	6.76	112.97	90.01	8.85	4.15
	F vs. S	1:1	2.80	2.69	101.75	47.40	11.42	3.65
		1:4	1.71	6.59	104.27	88.92	4.92	4.63
		4:1	6.48	1.68	86.71	27.89	9.33	3.72
	S vs. M	1:1	2.39	2.76	19.95	78.55	3.10	13.64
		1:4	1.40	6.55	16.65	96.36	1.25	5.01
		4:1	6.15	1.68	68.61	100.59	3.15	5.06
N99	F vs. F	1:1	2.85	2.68	87.56	47.78	23.81	10.17
		1:4	1.78	6.37	75.13	41.50	10.29	6.42
		4:1	6.81	1.75	80.13	51.97	3.05	0.48
	F vs. M	1:1	2.82	2.60	104.02	32.77	11.18	1.54
		1:4	1.78	6.51	105.58	48.71	5.40	2.18
		4:1	6.38	1.76	76.43	52.40	8.39	3.08
	F vs. S	1:1	2.82	2.64	99.71	44.82	8.70	2.10
		4:1	6.77	1.51	80.06	25.65	11.15	1.51
		1:4	1.78	6.58	82.48	72.92	3.10	2.36
	S vs. M	1:1	2.21	2.72	26.30	79.89	2.89	5.47
		4:1	4.83	1.56	48.90	58.16	5.70	6.26
		1:4	1.39	6.77	14.90	52.24	2.18	3.64
N100	F vs. F	1:1	2.85	2.86	147.57	164.82	31.30	42.42
		1:4	1.65	6.81	119.95	145.69	12.57	26.45
		4:1	6.79	1.76	138.85	167.12	14.11	8.85
	F vs. M	1:1	2.83	2.75	166.96	115.33	16.74	5.81
		1:4	1.78	7.13	193.18	208.50	14.77	7.22
		4:1	6.74	1.75	111.96	95.46	18.38	8.10
	F vs. S	1:1	2.87	2.82	134.06	105.51	4.95	1.97
		4:1	6.63	1.72	87.25	67.91	12.24	4.90
		1:4	1.76	7.08	135.21	141.33	6.58	4.78
	S vs. M	1:1	2.76	2.89	84.28	140.90	3.42	3.06
		4:1	7.02	1.67	133.50	96.79	8.75	7.58
		1:4	1.46	7.10	20.08	173.43	1.71	11.78

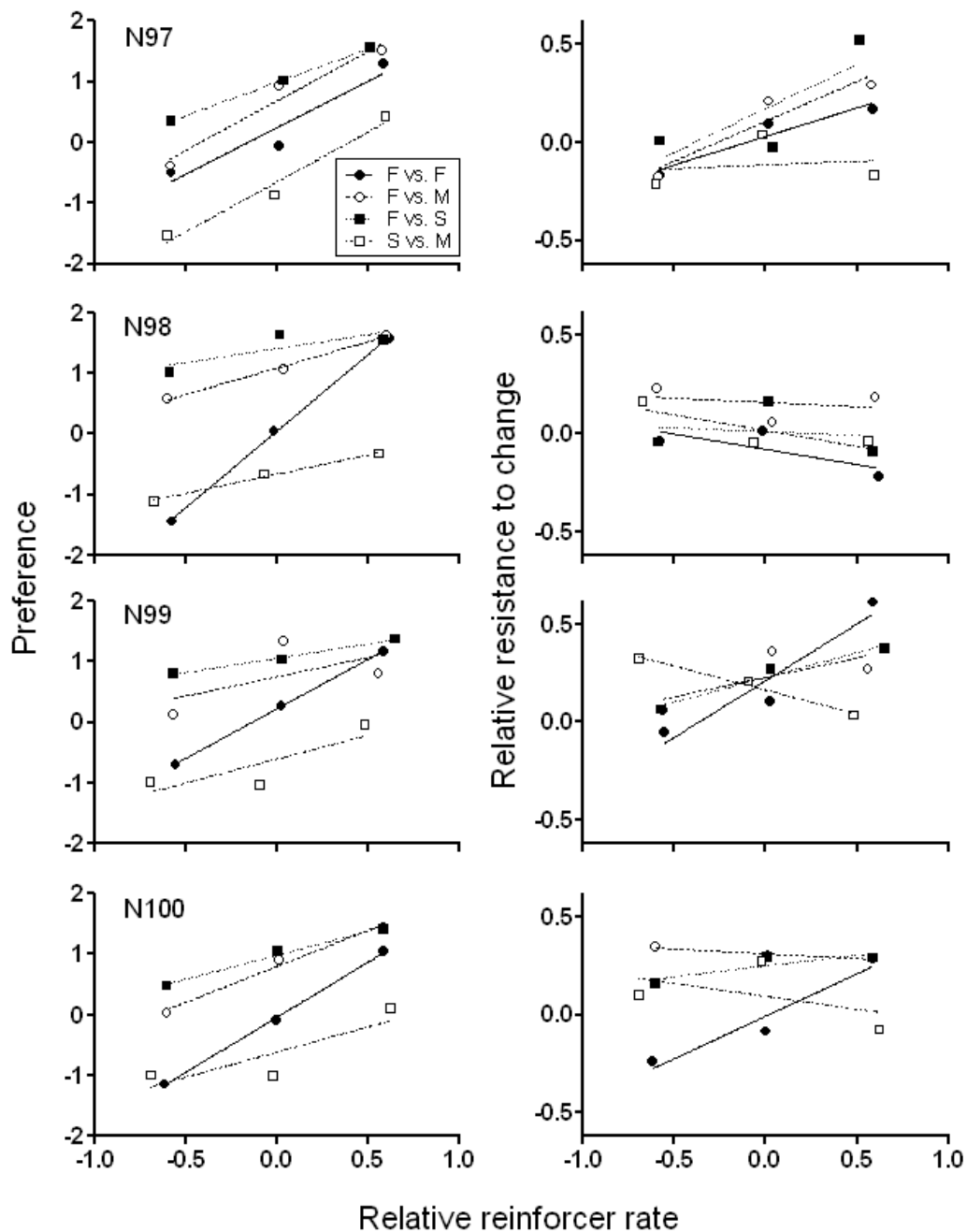


Figure 3-1. Preference and relative resistance to change. Preference and relative resistance to change are shown as a function of relative terminal-link reinforcer rates across all conditions and rats. Preference was calculated as the log ratio of right-to-left initial link response rates averaged across the last six sessions of baseline prior to extinction. Relative resistance to change was calculated as the difference of right-to-left log mean proportion of baseline response rates in the terminal links. Slopes and y-intercepts of the functions are shown in Table 2.

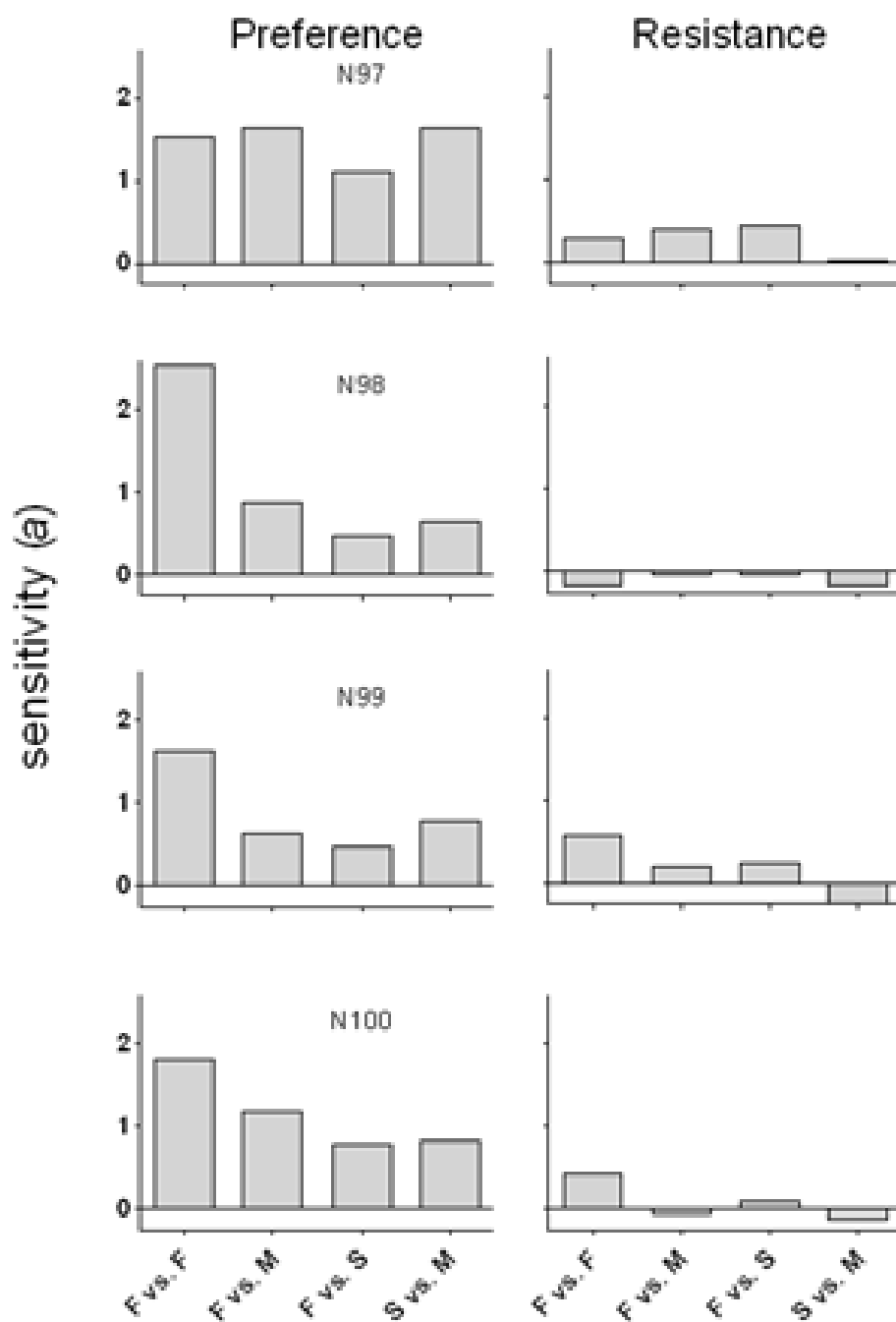


Figure 3-2. Sensitivity for preference and relative resistance to change. Sensitivity (a) values for preference and relative resistance to extinction across conditions.

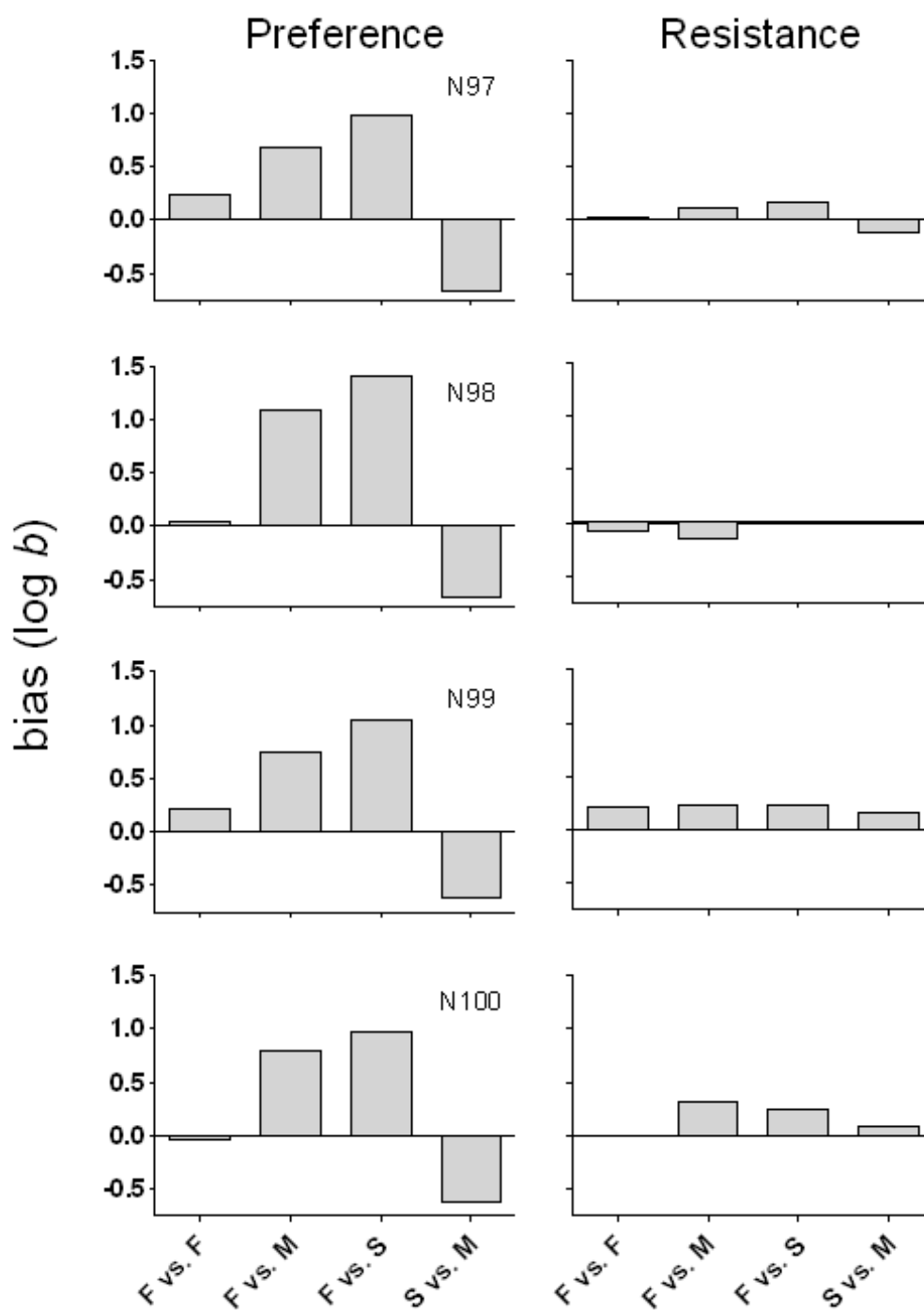


Figure 3-3. Bias for preference and relative resistance to change. Bias ($\log b$) values for preference and relative resistance to extinction across conditions.

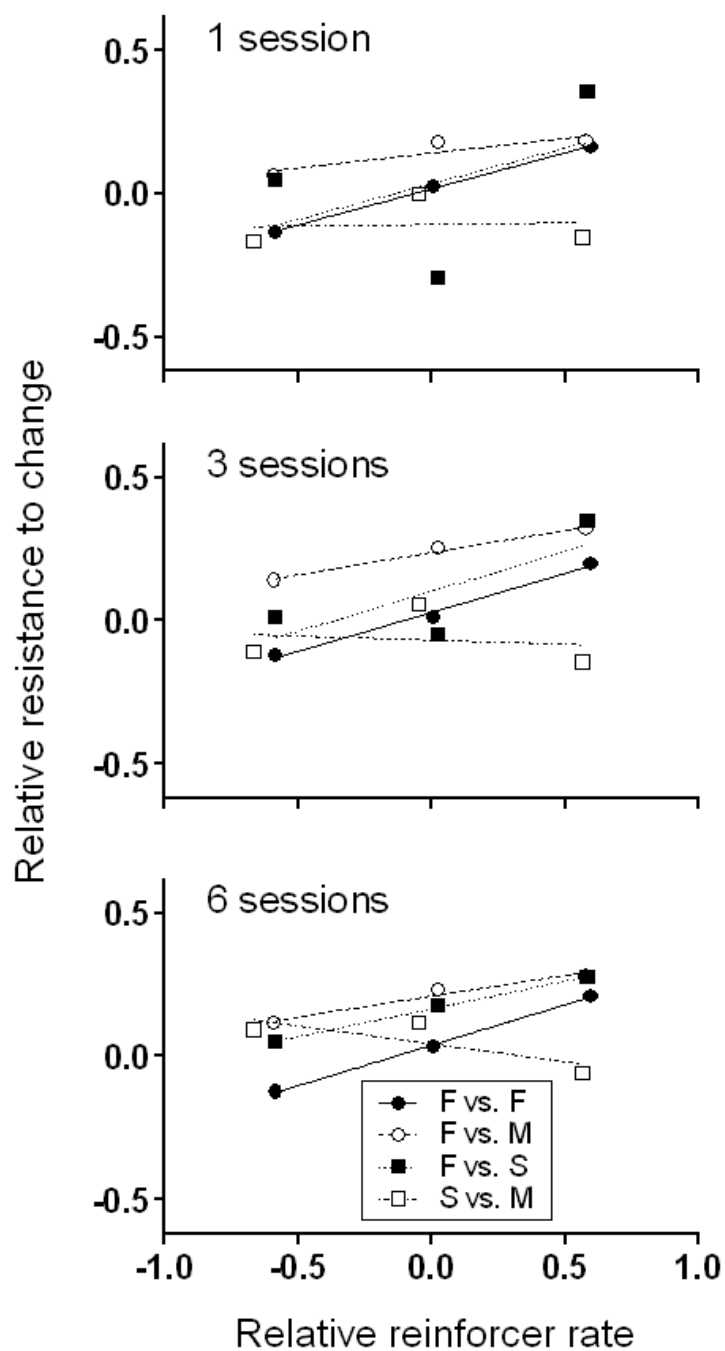


Figure 3-4. Mean relative resistance to change. Mean relative resistance to change across rats is shown as a function of relative terminal-link reinforcer rates across all conditions. The top panel shows relative resistance to change after one session, the middle panel shows the mean across three sessions, and the bottom panel shows the mean of six sessions. Sensitivity and bias estimates are shown in Table 3-3.

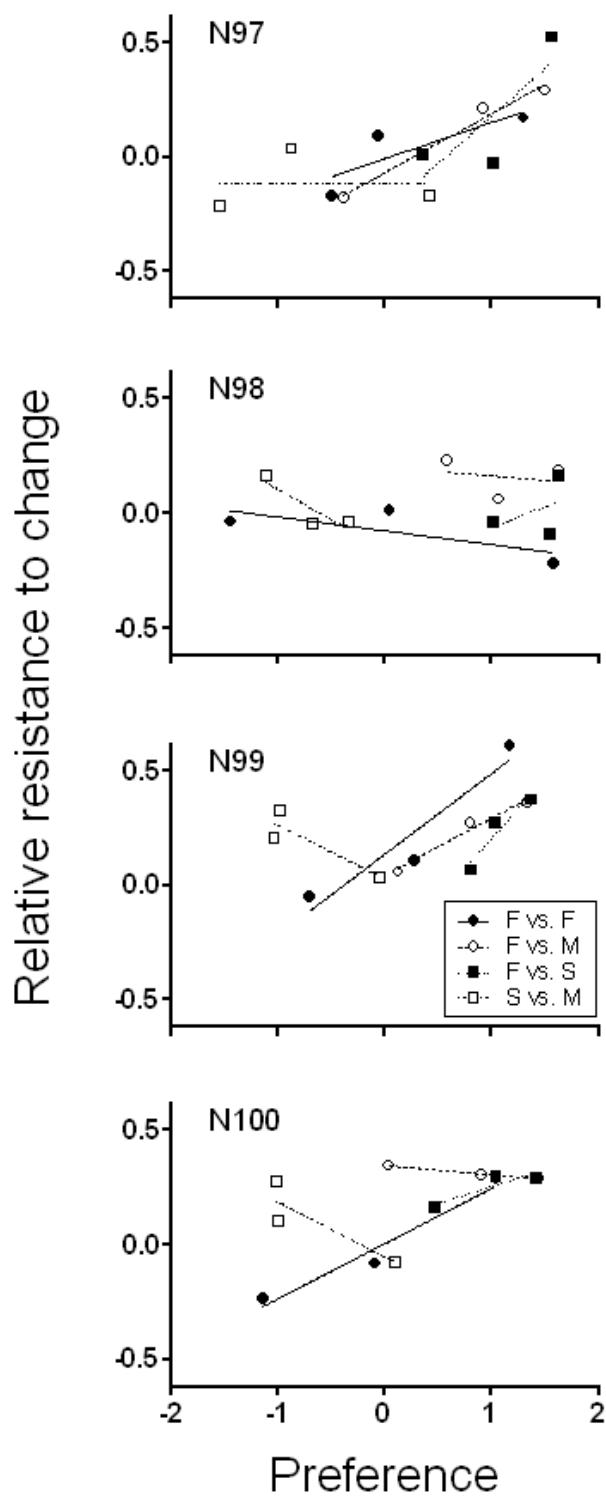


Figure 3-5. Structural relation. Relative resistance to change is plotted as a function of preference across all conditions and rats. Linear-regression slopes are shown in Table 2.

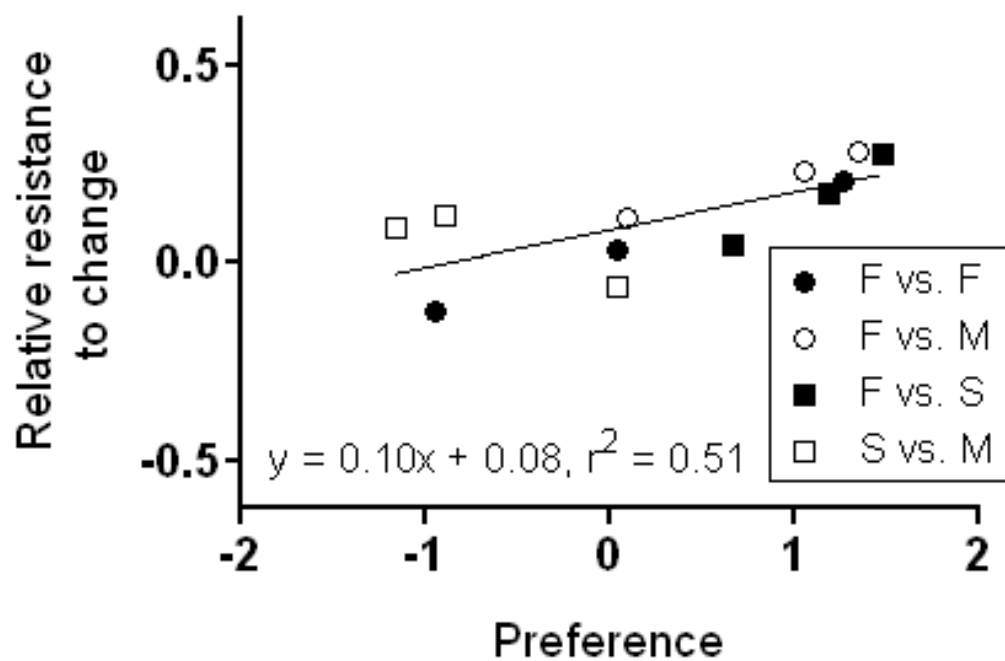


Figure 3-6. Mean structural relation. Mean relative resistance to change is plotted as a function of mean preference across rats. Linear-regression equations and r^2 are shown in the figure.

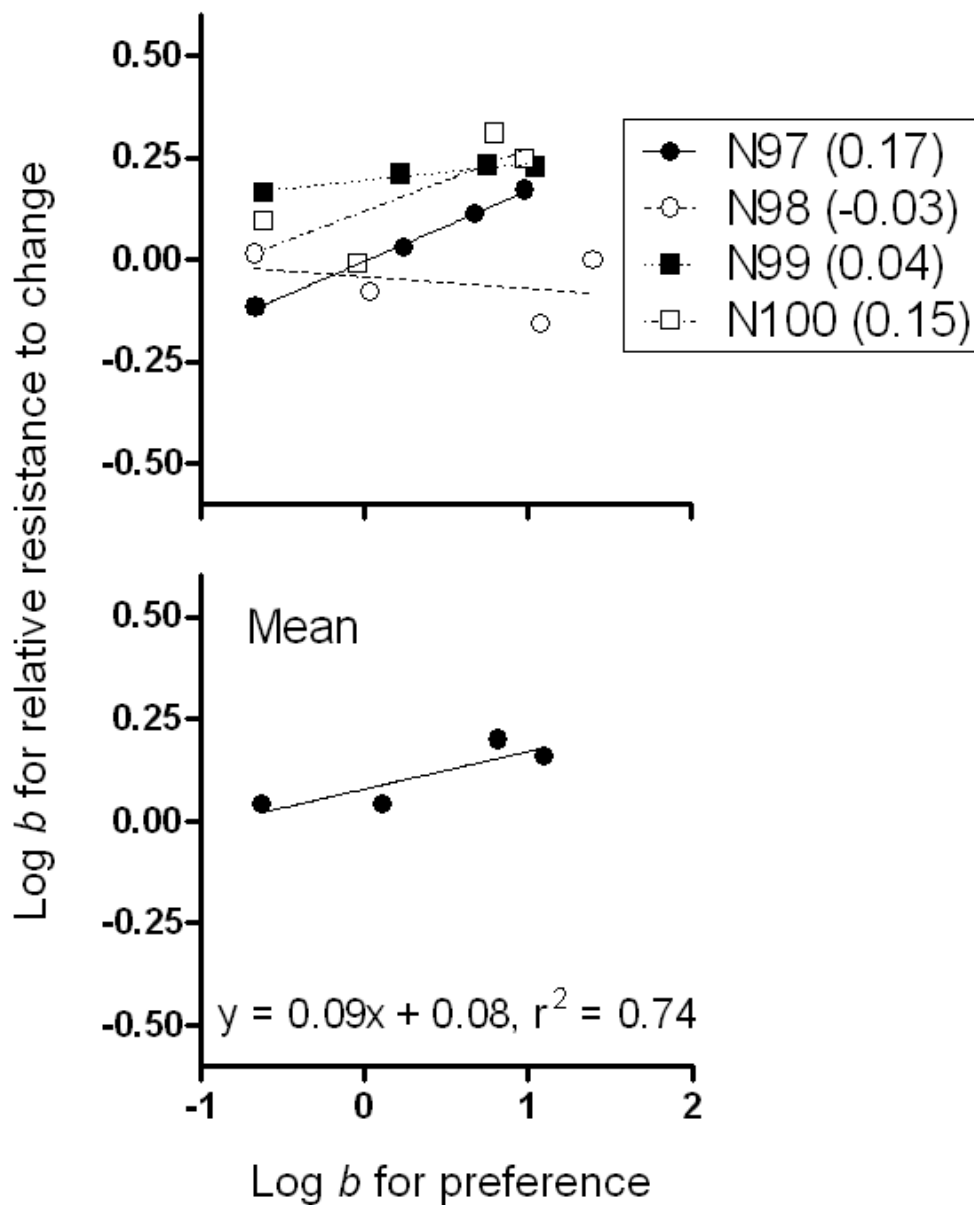


Figure 3-7. Structural relation using $\log b$. $\log b$ values for relative resistance to change are plotted as a function of $\log b$ values for preference for individual rats (top panel) and for the mean function (bottom panel). The slopes of the linear-regression lines are shown in the legend for the top panel and the linear-regression equation is shown in the figure in the bottom panel.

CHAPTER 4

SUMMARY AND CONCLUSIONS

The goal of the present series of experiments was to provide additional insight into the understanding of how qualitatively different reinforcers affect response strength. Using a behavioral momentum framework, preference and relative resistance to change were assessed when relative reinforcer type differed across two stimulus contexts. In Experiment 1 of Chapter 2, it was found that resistance to disruption was differentially impacted across contexts by whether the disrupter type was the same or different than the reinforcer maintaining responding. These findings replicated a number of previous findings (e.g., Colwill & Rescorla, 1986) and showed that most traditional uniform disrupters are not appropriate for examining the strengthening effects of different reinforcers types. Therefore, the remainder of the experiments in Chapters 2 and 3 used extinction to more uniformly disrupt responding when stimulus contexts presented different reinforcer types. In Experiments 2 and 3 of Chapter 2, variations in relative reinforcer type systematically affected response rates (Experiments 2 & 3) and preference (Experiment 3). Resistance to extinction, however, was not systematically affected by changes in relative reinforcer type. In Chapter 3, preference and relative resistance to extinction were assessed when relative reinforcer rate was manipulated within conditions and relative reinforcer type was manipulated between conditions. Preference was consistently affected by changes in reinforcer rate and type. Resistance to extinction, however, tended to be sensitive to changes in relative reinforcer rate only when reinforcer types were identical across contexts and not when reinforcer types differed. Moreover,

changes in relative reinforcer type produced varying degrees of bias on relative resistance to extinction.

Several possible explanations for the different effects of changing relative reinforcer type on preference and resistance to change were provided. Resistance to change has reliably been shown to be a less sensitive measure for assessing changes in relative reinforcer rate than preference in concurrent chains (see Nevin & Grace, 2000b; Nevin, Grace, et al., 2001). In addition, resistance to extinction consistently has been shown to be less sensitive than other traditional disrupter types. One implication of these findings is to examine whether other disrupters could be introduced uniformly to contexts presenting qualitatively different reinforcers (e.g., response effort, punishment).

A different explanation for the unsystematic resistance-to-extinction findings is that previous studies assessing preference and resistance to extinction have used pigeons as experimental subjects. These studies have obtained greater sensitivity to changes in relative reinforcer rate with extinction than in the experiment in Chapter 3. Given that some differences in sensitivity to procedural manipulations in concurrent-chains procedures have revealed potential species differences between rats and pigeons (Mazur, 2005, 2007), the low sensitivities in the present experiment relative to those with pigeons might reflect such a difference. Thus, one potential avenue is to examine how qualitatively different reinforcers affect resistance to extinction in species other than rats.

The most straightforward way to overcome a lack of sensitivity of a dependent measure is to increase the difference between levels of the independent variable. Within the framework of behavioral momentum theory, increasing the difference between levels

of an independent variable should affect relative response strength. When changing relative reinforcer rate or magnitude, such changes tend to have fairly straightforward effects on response strength. When reinforcer types are identical, increasing the value of one source of reinforcement should produce a complimentary decrease in the value of the other source. When changing relative reinforcer type, however, increasing the qualitative difference between reinforcer types likely affects more than the response-strengthening effects of reinforcement. Increasing the difference between reinforcer types might also change the way those reinforcers interact. In the extreme case, increasing the value of one reinforcer type (e.g., food) might also increase the value of another reinforcer type (e.g., water). Thus, increases in the qualitative difference between reinforcer types would not necessarily have produced more systematic resistance-to-extinction findings.

Even preference, which was consistently affected by changes in relative reinforcer rate and type, revealed some potential difficulties with examining the effects of qualitatively different reinforcers. First, sensitivity to variations in relative reinforcer rate tended to change when relative reinforcer type was manipulated. These changes in sensitivity also suggest different levels of interaction between the different reinforcer types that depended on their relative rate of presentation (see Hursh, 1978). Interactions between reinforcer variables violate primary assumptions of the generalized matching law. The assumptions are that effects of different reinforcer variables should be additive within the framework of the concatenated version of the generalized matching law and that the sensitivity and bias parameters should be independent (Baum & Rachlin, 1969; Killeen, 1972). Behavioral momentum theory has borrowed these same assumptions for

describing the effects of reinforcement variables on preference and relative resistance to change. If changing relative reinforcer type violates these most basic assumptions of behavioral momentum theory, then behavioral momentum theory, in its current form, might not be the best framework from which to understand the effects of qualitatively different reinforcers.

It is difficult to reconcile the general notion that different reinforcer types can interact to produce qualitatively different patterns of behavior with a response-strengthening framework for understanding behavior. The generalized matching law and behavioral momentum theory conceptualize the different effects of reinforcement variables as quantitatively different strengthening effects of those variables (see Herrnstein, 1970; Nevin & Grace, 2000a). Perhaps even more fundamentally, the matching law and behavioral momentum theory conceptualize the response-strengthening effects of reinforcement through a reinforcer-efficacy framework. The concept of reinforcer efficacy implies that particular behavioral measures (e.g., response rates, choice) indicate the extent to which events contingent on behavior are effective reinforcers (Bickel, Marsch, & Carroll, 2000; Griffiths, Brady, & Bradford, 1979; Katz, 1990). Within behavioral momentum theory, differences in reinforcer efficacy are conceptualized by quantitative effects on relative response strength, as measured by relative resistance to disruption and preference. However, there is a long line of previous research and theorizing that suggest that reinforcers may not enhance responding through a strengthening process (e.g., Davison & Baum, 2006; Rachlin, 1992; Shettleworth, 1975; Timberlake, 2004; Timberlake & Allison, 1974; see also Bickel et al.; Katz).

Several theoretical frameworks completely eschew the strengthening concept of reinforcers and assume these events serve a range of alternative functions. For example, Davison and Baum (2006) suggest that both primary reinforcers (e.g., food) and stimuli correlated with primary reinforcers (i.e., conditioned reinforcers) function in a discriminative role. These events signal to an organism the likelihood whether “phylogenetically important events” like food will be forthcoming for emitting the same or different responses (see also Krageloh, Davison, & Elliffe, 2005). Conversely, Timberlake’s (1993) behavior-systems approach suggests that the strengthening concept is limited and that the effect of any event on behavior needs to be considered within the broader context of cognitive, regulatory, and ecological variables within a causal system. For instance, food and food-related stimuli are part of a system of interrelated stimuli and behavior that are involved in finding, obtaining, and consuming food. Finally, behavioral-economic and related approaches (see Allison, 1993; Premack, 1965; Rachlin, Battalio, Kagel, & Green, 1981) suggest that responses function as currency and reinforcers function as goods. Organisms respond to maximize the utility of goods by obtaining those goods in some proportion. For instance, a combination of food and water likely would maximize the utility of those goods to a greater extent than would all food or all water. One commonality of these approaches is that the role of behavior and consequences must be conceptualized within the broader context of the organism. The context includes, but is not limited to, genetic history, learning history, current motivation, and the availability of alternative sources and types of reinforcers.

According to at least one behavioral-economic approach, measures of relative reinforcer efficacy such as response rates, progressive-ratio break points, and choice correspond to and can be predicted with different aspects of economic demand curves (see Madden, Smethells, Ewan, & Hursh, 2007, for a discussion). One implication of this is that it might be worthwhile to determine whether relative resistance to change and preference correspond with the quantitative values of reinforcer efficacy derived from demand curves (see Nevin, 1995, for a discussion and limitations of such analyses). More generally, behavioral momentum theory might fit within, or at least be informed by, other theoretical frameworks that have established theory and methods for understanding the effects of qualitatively different reinforcers.

The findings from the present series of experiments have implications for using preference assessments in applied settings. With preference assessments, individuals are provided with discrete choices between different items. Items that are chosen most frequently typically are used later as reinforcers for a behavior that is being trained (see Canella, O'Reilly, & Lancioni, 2005, for a review). Using behavioral momentum theory as a framework, those items that are preferred should engender stronger behavior than less preferred items and therefore produce behavior that is more resistant to disruption. The present findings in which relative resistance to change did not always correspond with the preferred reinforcer type suggest that this relation might not always hold. The actual patterns of preference and resistance to change might be influenced to varying extents by the degree to which items used as reinforcers interact with other aspects of the individual's environment. For instance, a particular food item that is preferred might not

function as an effective reinforcer if behavioral training occurs following a meal in which that item or a strong substitute has been consumed (e.g., Wilder, Carr, & Gaunt, 2000).

Therefore, potential interactions between reinforcers and the context in which an individual behaves should be accounted for to maximize the effectiveness of behavioral interventions.

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CURRICULUM VITAE

Christopher A. Podlesnik

462 N 200 E Apt. 2
 Logan, UT 84321
 Birthdate: November 15, 1979
 Birthplace: Latrobe, PA

E-mail: capodlesnik@cc.usu.edu
 Phone: (435) 797-5553
 Fax: (435) 797-1448

EDUCATIONAL HISTORY

- *Utah State University, Logan, Utah*
 Ph.D. Candidate present
 M.S. in Psychology 2005
 - *West Virginia University, Morgantown, West Virginia*
 B.A. in Psychology, Summa Cum Laude, 2002
 Minor in Philosophy
- Honors: College of Education and Human Services:
- 2nd Place Presentation in Graduate Research Symposium 2007
 - 1st Place Presentation in Graduate Research Symposium 2006
 - Graduate Research Assistant of the Year 2006
 - Walter R. Borg Scholarship (\$7,000) 2005
 - SABA Experimental Analysis of Behavior Fellowship (\$2,000) 2005
 - West Virginia University Presidential Award 2000-2002
 - Eberly College of Arts and Sciences Certificate of Achievement 2000-2002
 - West Virginia University Honors Program 1999-2002

POSITIONS HELD

- *Graduate Instructor, Utah State University,* 2007-present
Advanced Undergraduate Learning Course
- *Graduate Research Assistant, Utah State University,* 2004-2006
Supervisor: Timothy A. Shahan, Ph.D.
- *Graduate Teaching Assistant, Utah State University,* 2003-2004
Supervisor: Amy L. Odum, Ph.D.
- *Graduate Research Assistant, Utah State University,* Fall 2003
Supervisor: Timothy A. Shahan, Ph.D.
- *Undergraduate Research Assistant, West Virginia University,* 2000-2001
Supervisor: Kennon A. Lattal, Ph.D.

- *Undergraduate Research Assistant, West Virginia University, Fall 2000*
Supervisor: Cynthia Anderson, Ph.D.
- *Undergraduate Research Assistant, West Virginia University, Spring 2000*
Supervisor: Phillip N. Chase, Ph.D.

PUBLICATIONS

Refereed Articles in Print

- Podlesnik, C. A., & Shahan, T. A. (2008). Response-reinforcer relations and resistance to change. *Behavioural Processes*, 77, 109-125.
- Shahan, T. A., & Podlesnik, C. A. (2007). Divided attention and the matching law: Sample duration affects sensitivity to reinforcement allocation. *Learning and Behavior*, 35, 141-148.
- Podlesnik, C. A., Jimenez-Gomez, C., & Shahan, T. A. (2006). Resurgence of alcohol seeking produced by discontinuing non-drug reinforcement as an animal model of drug relapse. *Behavioural Pharmacology*, 17, 369-374.
- Podlesnik, C. A., & Chase, P. N. (2006). Sensitivity and strength: Effects of instructions on resistance to change. *The Psychological Record*, 56, 303-320.
- 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.
- Shahan, T. A., & Podlesnik, C. A. (2006). Divided attention performance and the matching law. *Learning and Behavior*, 34, 255-261.
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- Shahan, T. A., & Podlesnik, C. A. (2005). Rate of conditioned reinforcement affects observing rate but not resistance to change. *Journal of the Experimental Analysis of Behavior*, 84, 1-17.

Refereed Articles in Press

- Shahan, T. A., & Podlesnik, C. A. (in press). Quantitative analyses of observing and attending. *Behavioural Processes*.
- Shahan, T. A., & Podlesnik, C. A. (in press). Conditioned reinforcement value and resistance to change. *Journal of the Experimental Analysis of Behavior*.

RESEARCH INTERESTS

Experimental analysis of behavior, response persistence and recovery, qualitatively different reinforcers, attending, conditioned reinforcement, drug self-administration, choice

PRESENTATIONS

- Podlesnik, C. A., & Shahan, T. A. (2008). *Resistance to change and response recovery*. Symposium conducted at the 34th Annual Association for Behavior Analysis Convention, Chicago, IL.
- Podlesnik, C. A., & Shahan, T. A. (2008). *The effects of reinforcer rate and type on preference and resistance to change*. Symposium conducted at the 34th Annual Association for Behavior Analysis Convention, Chicago, IL.
- Shahan, T. A., & Podlesnik, C. A. (2007). *Quantitative analyses of observing and attending*. Invited Address given at the conducted at the annual meeting of the Society for the Quantitative Analyses of Behavior, San Diego, CA.
- Podlesnik, C. A. (2007). *Reinforcement rate, resistance to disruption, and response recovery*. Paper presented at the 10th Annual Intermountain Paper and Poster Symposium, Logan, UT.
- Podlesnik, C. A., & Shahan, T. A. (2007). *Stimulus-reinforcer relations and recovery of instrumental responding after extinction*. Symposium conducted at the Winter Conference on Animal Learning and Behavior, Winter Park, CO.
- Shahan, T. A., & Podlesnik, C. A. (2007). *Conditioned reinforcement and quantitative models of behavior allocation and persistence*. Symposium conducted at the Winter Conference on Animal Learning and Behavior, Winter Park, CO.
- Podlesnik, C. A., Jimenez-Gomez, C., & Shahan, T. A. (2006). *Resurgence as a novel animal model of drug relapse*. Poster presented at the 32nd Annual Association for Behavior Analysis Convention, Atlanta, GA.
- Shahan, T. A., & Podlesnik, C. A. (2006). *Effects of added free-food presentations uncorrelated with S+ on observing rate and resistance to change*. Symposium conducted at the 32nd Annual Association for Behavior Analysis Convention, Atlanta, GA.
- Podlesnik, C. A., & Shahan, T. A. (2006). *Reinforcer quality and resistance to change*. Poster presented at the annual meeting of the Society for the Quantitative Analyses of Behavior, Atlanta, GA.
- Podlesnik, C. A. (2006). *A novel animal model of alcohol relapse*. Paper presented at the 9th Annual Intermountain Paper and Poster Symposium, Logan, UT.
- Shahan, T. A., & Podlesnik, C. A. (2006). *Divided attention and the matching law*. Invited address at the annual meeting of the Winter Conference on Animal Learning and Behavior, Winter Park, CO.
- Podlesnik, C. A., & Shahan, T. A. (2005). *An examination of the role of the response-reinforcer relation in resistance to change*. Symposium conducted at the 31st Annual Association for Behavior Analysis Convention, Chicago, IL.

- Podlesnik, C. A., Jimenez-Gomez, C., Ward, R. D., & Shahan, T. A. (2005). *The role of the response-reinforcer relation in resistance to change: The role of immediate, briefly-delayed, and longer-delayed reinforcement*. Poster presented at the 31st Annual Association for Behavior Analysis Convention, Chicago, IL.
- Podlesnik, C. A., & Shahan, T. A. (2005). *Resurgence as a function of the stimulus-reinforcer relation: An alternative measure of response strength?* Poster presented at the annual meeting of the Society for the Quantitative Analyses of Behavior, Chicago, IL.
- Jimenez-Gomez, C., Podlesnik, C. A., & Shahan, T. A. (2005). *Sensitivity to relative conditioned-reinforcement rate without changes in primary-reinforcement rate*. Poster presented at the annual meeting of the Society for the Quantitative Analyses of Behavior, Chicago, IL.
- Podlesnik, C. A., & Chase, P. N. (2004). *Rule-governed behavior and insensitivity to contingencies: The role of behavioral momentum*. Symposium conducted at the 30th Annual Association for Behavior Analysis Convention, Boston, MA.
- Shahan, T. A., Podlesnik, C. A., & Jimenez-Gomez, C. (2004). Observing, attending, behavioral momentum, and the matching law. In R. Pitts (Chair), *Celebrating B. F. Skinner's 100th Birthday: Conditioned Reinforcement*. Symposium conducted at the 112th annual meeting of the American Psychological Association, Honolulu, HI.
- Shahan, T. A., & Podlesnik, C. A. (2004). Observing, Rate of Conditioned Reinforcement, and Resistance to Change. Delivered at a Festschrift for John A. Nevin conducted at the University of New Hampshire.
- Podlesnik, C. A. (2002). *Sensitivity and strength: Effects of instructions on the momentum of behavior*. Poster presented at the 1st Annual West Virginia University Psychology Capstone Poster Session, Morgantown, WV.
- Podlesnik, C. A., & Doughty, A. H. (2001). *A novel method for examining superstition in the pigeon*. Poster presented at the Eberly College of Arts and Sciences Research Conference, Morgantown, WV.

SYMPOSIA CHAIRED

- Podlesnik, C. A. (2008). *Behavioral Momentum Theory: 25 Years*. Symposium conducted at the 34th Annual Association for Behavior Analysis Convention, Chicago, IL.
- Podlesnik, C. A. (2008). *Topics on the Persistence of Behavior*. Symposium conducted at the 34th Annual Association for Behavior Analysis Convention, Chicago, IL.

REVIEWER EXPERIENCE

Ad Hoc Reviewer, *Journal of the Experimental Analysis of Behavior*
 Ad Hoc Reviewer, *Behavioural Processes, 2008 SQAB Special Issue*

SUPERVISION EXPERIENCE

Supervised 4 undergraduates earning credits in an independent research course

GRANTS

- Sigma Xi Grant-in-Aid of Research, \$400, 2006.
- Eberly College of Arts and Sciences Undergraduate Academic Enrichment Fund, \$500, 2002.

PROFESSIONAL POSITIONS

- *Mental Health Specialist, Chestnut Ridge Hospital, Morgantown, WV* 2001-2003
- *Neuropsychological Field Experience, Psychometrist, Chestnut Ridge Hospital, Morgantown, WV* Summer 2000

MEMBERSHIP IN PROFESSIONAL ORGANIZATIONS

- The Association for Behavior Analysis
- Southeastern Association for Behavior Analysis
- Society for the Quantitative Analyses of Behavior (Student Council)
- Psi Chi

REFERENCES

- Timothy A. Shahan, Associate Professor
Department of Psychology
Utah State University
(435) 797-5558
Tim.Shahan@usu.edu
- Amy L. Odum, Associate Professor
Department of Psychology
Utah State University
(435) 797-5578
Amy.Odum@usu.edu
- Timothy A. Slocum, Associate Professor
Department of Special Education & Rehabilitation
Utah State University
(435) 797-3212
TSlocum@cc.usu.edu

- John A. Nevin, Ph.D., Professor Emeritus
Rural Route 2, Box 162, Vineyard Haven, MA 02568
JNevin@cisunix.unh.edu