JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1992, 57, 317-337 NUMBER 3 (MAY)

RESISTANCE TO CHANGE AND THE LAW OF EFFECT

DAVID N. HARPER AND ANTHONY P. MCLEAN

UNIVERSITY OF CANTERBURY, CHRISTCHURCH, NEW ZEALAND

Three experiments using multiple schedules of reinforcement explored the implications of resistance-to-change findings for the response–reinforcer relation described by the law of effect, using both steady-state responding and responding recorded in the first few sessions of conditions. In Experiment 1, when response-independent reinforcement was increased during a third component, response rate in Components 1 and 2 decreased. This response-rate reduction was proportionately greater in a component in which reinforcer magnitude was small (2-s access to wheat) than in the component in which it was large (6-s access to wheat). However, when reinforcer rates in the two components were varied together in Experiments 2 and 3, response-rate change was the same regardless of the magnitude of reinforcers used in the two components, so that sensitivity of response rates to reinforcer rates (Experiment 2) and of response-rate ratios to reinforcer-rate ratios (Experiment 3) was unaffected by the magnitude of the reinforcers. Therefore, the principles determining resistance to change, described by behavioral momentum theory, seem not to apply when the source of behavior change is the variation of reinforcement contingencies that maintain the behavior. The use of extinction as a manipulation to study resistance to change is questioned.

Key words: resistance to change, quantitative law of effect, generalized matching law, sensitivity to reinforcement, behavioral momentum, multiple schedules, key peck, pigeons

There are two main conceptions of response strength in schedule-control research, each deriving from a different style of experimental behavior analysis. One identifies response strength with the rate or probability of a response, and derives from research conducted in a tradition dominated by the law of effect. This type of work is characterized by studies in which the schedules maintaining responding are varied over conditions, and resulting changes in response rate are related to changes in the rate of the "strengthening" variable, reinforcement. Quantitative analysis indicates a hyperbolic relation between response rate and reinforcer rate, which is thought to depend on the availability of extraneous reinforcers obtained for behavior other than the target response (see e.g., de Villiers & Herrnstein, 1976; Herrnstein, 1970, 1974). Thus, "strong" behavior is identified with a high response rate and is observed when high frequencies of reinforcement maintain the response. A feature of this research is that it analyzes steady-state behavior—that is, the level at which the response occurs after prolonged exposure to each schedule.

A second area of study, and one enjoying a resurgence of interest, is research dealing with behavioral resistance to change. Resistance is measured using changes in the rate of a response following an alteration of the environmental context for that response; here, strong behavior is identified with high resistance. Early studies considered resistance to extinction. For example, Hearst (1961) compared resistances of several responses to extinction following training in which different reinforcement schedules were in effect, each with a distinctive stimulus, in a multiple schedule of reinforcement. Infrequently reinforced responding showed greater resistance to extinction, in that more responses were made before an extinction criterion was met where previous reinforcement had been infrequent than where it was frequent. This difference was called the partial reinforcement effect. More recently, resistance to change has been measured by the proportional change in rate of a response. For example, response-rate change may be brought about by changes to an additional reinforcement schedule arranged either concurrently or successively with the first. The extent to which the target response changes with variation of the additional schedule, relative to its rate in prior baseline conditions, provides the measure of resistance to change. Typically, high resistance to change is found for behavior that is

---

The data reported here formed a part of a Master's thesis submitted by David Harper to the University of Canterbury in March 1990, and were reported to a meeting of the New Zealand Psychological Society in August 1990. Reprints may be obtained from either author, Department of Psychology, University of Canterbury, Private Bag, Christchurch, New Zealand.

maintained by a high rate of reinforcement, and low resistance is found for that maintained by infrequent reinforcement (e.g., Nevin, 1974; Nevin, Mandell, & Atak, 1983). Thus, whereas early studies of resistance to extinction indicated that infrequent reinforcement produced greater resistance (i.e., greater strength), more recent work using a number of preparations and a different measure of resistance suggests the opposite, namely, that strength of behavior is greater following higher levels of reinforcement (see Nevin, 1988, for a reconsideration of the partial reinforcement effect, and Nevin, 1992, for a review).

Nevin et al. (1983) developed behavioral momentum theory to describe the typical resistance-to-change results. In this theory, behavior possesses two independent properties analogous to those of bodies in motion: velocity and mass. Behavioral velocity is measured by response rate, and mass is measured by the proportional change in rate of a response when reinforcer conditions are altered. Hence, behavioral mass captures that aspect of behavior referred to as resistance to change. Determinants of behavioral mass include reinforcers obtained in the presence of the same discriminative stimulus as the target response, whether contingent on that response (e.g., Nevin et al., 1983) or contingent on other responses (e.g., Nevin, Tota, Torquato, & Shull, 1990). In behavioral momentum theory, a change in reinforcer conditions or in some other contextual variable is called a *force* applied to behavior and is used to assess the behavioral mass established by constant features of the setting. Forces used have included deprivation changes through prefeeding of subjects, introduction of extinction, and response-independent food presented during an alternated variable-time (VT) schedule.

Behavioral resistance to change is of considerable interest in its own right, and behavioral momentum theory has been successful in accounting for data from a variety of procedures. Moreover, the experimental analysis of behavioral resistance may also have implications for quantitative analysis in regular schedule-control research. Traditional schedule research differs from that on behavioral resistance in terms both of the assessment procedures and the measure of behavioral strength used. However, both are concerned with the extent to which behavior changes when prevailing reinforcer conditions are altered and, consequently, it would be surprising if variables determining behavioral mass did not affect the relation observed between the response and the reinforcer rate maintaining it. That is, the notion of behavioral mass ought to have some implications for the quantitative law of effect. There are two major difficulties in relating the two, however, involving differences in the data studied and the types of manipulations used to bring about behavior change.

One difference is that unlike research on the law of effect, behavioral resistance studies have not usually made use of steady-state behavior, although such data have sometimes been cited in support of behavioral momentum theory. For example, Nevin (1974) arranged multiple schedules in which a rich and a lean variable-interval (VI) schedule were presented successively, each with a distinctive stimulus, throughout experimental sessions. Between presentations of these multiple schedule components, 30-s periods occurred in which discriminative stimuli were absent (no keylight) and no reinforcement contingencies were in effect. After extensive training, responding in components was disrupted during occasional sessions in which response-independent food was presented during the dark-key periods. Resistance of responding to change brought about by food when the key was dark was then assessed using these single sessions and was found to be greater for the component with the richer reinforcement schedule. Thus, such research examines the short-term effects of disruptors. In regular schedule research, on the other hand, the presentation of reinforcement in a third component continues over many sessions until behavior is stable, and response reduction in the target components is called negative behavioral contrast.

The different changes in response rate revealed using this short-term analysis raise a question that is potentially important to schedule research. Does the difference in resistance indicate that, if a disruptor remained in effect until behavior was stable, the change in responding would be greater for the low-mass component than for the high-mass one (relative to their respective baselines)? The short-term analysis does not allow us to discriminate between greater eventual change in response rate for the low-mass component versus changes that are eventually equal for the two components but take fewer sessions for the low-mass component. However, it seems clear from the recent literature on resistance to change that what is expected is greater changes in response rate. Nevin (1988, 1992) cited steady-state responding in multiple schedules with versus without alternative reinforcement (Pliskoff, Shull, & Gollub, 1968) and superimposed punishment (Bouzas, 1978) in support of the general conclusion that frequently reinforced responding is more resistant to such disruptors. The differences in steady-state response rate between components in these studies presumably would be irrelevant to momentum theory if behavioral mass affected the speed of behavior change, but not the extent of it. The difference between extent and speed of change is important to regular schedule research because if greater changes occur for low-mass responding, then behavioral mass must affect characteristics of the hyperbolic relation specified in the quantitative law of effect.

A second matter complicating any attempts to relate resistance-to-change findings with the law of effect has to do with the different experimental manipulations used to bring about behavior change. The major manipulation in studies on the law of effect is variation of the schedules of reinforcement maintaining a response, although interactions among schedules in complex schedule arrangements are also studied (Catania, 1963; Reynolds, 1961; see Williams, 1983, for a review relating to behavioral contrast in multiple schedules). In behavioral resistance studies on the other hand, common manipulations used to apply force have been to alter the rate of response-independent food in a blackout period between components of multiple schedules (e.g., Fath, Fields, Malott, & Grossett, 1983; Nevin, 1974; Nevin et al., 1983) or to prefeed subjects before sessions. Thus, research in the two traditions differs with respect to the common manipulations used as well as the stability of the behavior under study. In behavioral-resistance research, behavior change is normally brought about by changes in conditions that are remote from the maintaining schedule of reinforcement, whereas work on the law of effect frequently involves changes to the maintaining schedule itself.

One procedure employed in behavior-resistance research that does involve variation of the maintaining schedule is to place the behavior under study into extinction. For example, Nevin et al. (1983) arranged two multiple-schedule components that differed only in their reinforcer rates. After training, both components were changed to extinction and responding in the two components decreased, with greater proportional change for the component previously correlated with less frequent reinforcement. However, steady-state responding is likely to be zero when extinction is used, so this procedure is not suited to an exploration of mass determinants in regular schedule research. Moreover, there may be problems with using extinction to assess resistance to change even in the short term, and indeed, in Nevin et al.'s direct comparison the difference in response-rate change between the two components was far less extreme than that observed in another condition in which responding was disrupted with response-independent food presented between the two components, rather than by extinction (but see Nevin, 1992, for a broader discussion). It may be that this difference arose because reducing the reinforcement schedules to extinction not only applies a force but also removes the conditions maintaining the mass differential between responses. Furthermore, when a mass differential is established via a difference in the reinforcer rate, then reduction of the reinforcer rates to zero may be more discriminable in the component with the higher reinforcer rate, where it involves a greater change in absolute reinforcer rate, and might be expected to produce a larger change in behavior, thereby reducing differences between components. Thus, using extinction may complicate analyses in terms of the law of effect or, indeed, in terms of resistance to change (see also Nevin, 1979).

To make resistance-to-change data more amenable to analysis in terms of the law of effect, some procedural alterations are required. A procedure is needed that allows the mass differential between the two target components to remain, while the frequency of reinforcement is varied. Usually, reinforcer rate is used to establish a mass differential. However, if alterations in the reinforcer rate are to be the source of experimental manipulation (as tends to be the case in research on the law of effect), then some other aspect of reinforcement must be used to establish a mass differential. Several possibilities include delay of reinforcement, alternative reinforcers delivered within a component, and the duration or magnitude of the reinforcers. For example, Nevin (1974, Experiment 3) established a reinforcer differential across two equal-valued VI components of a multiple schedule by presenting reinforcers of either 7.5-s or 2.5-s duration in the two components. Components were separated by a 30-s period in which response keys were unlit and responding was unreinforced. During occasional sessions, response-independent food was delivered during the dark-key periods, and responding during components decreased more in the component with short reinforcers. Nevin concluded that reinforcer duration affected resistance to change in a manner similar to reinforcer rate. However, because response-independent food was only delivered for single sessions, Nevin's results do not answer the question of whether differences in response-rate change are transitory and, therefore, absent in steady-state behavior.

Here, we present two experiments in which a mass differential was established between two multiple-schedule components with reinforcers of different duration. Forces were applied in two ways: in Experiment 1 response-independent food was delivered during dark-key presentations between the two target components (cf. Nevin, 1974; Experiment 3), and in Experiment 2 force was applied to the two responses by simultaneously varying the frequencies of reinforcement in the two target components, with no dark-key period between them. This second procedure allows the maintenance of conditions that establish the mass differential (i.e., different reinforcer durations in components) over conditions in which the force (reinforcer-rate change) is applied to both responses equally. In a third experiment, the implications of differential resistance to change for discriminative responding (undermatching) in multiple schedules was studied. In each experiment, conditions were maintained until responding had stabilized, so that the differential resistance to change could be studied using steady-state behavior.

EXPERIMENT 1

Studying differential resistance to change between two multiple-schedule responses requires establishing some between-component difference in reinforcement that remains constant when responding is disrupted, in order to generate different behavioral masses. Usually, different reinforcer rates in the two multiple-schedule components are arranged. However, this method is not appropriate when reinforcer-rate manipulations produce the behavioral disruption needed to reveal different resistances to change. That is, variables that are used to apply a force to behavior should not also be used to establish different behavioral masses.

One possible alternative method for establishing a mass difference between two multiple-schedule responses is to use different magnitudes of reinforcement in the two components. Before proceeding to vary schedules that maintain responding, however, the effect of different reinforcer magnitudes on resistance to change requires replication with steady-state responding. Assuming the effect is robust, these different magnitudes, and hence behavioral masses, can then be kept constant over conditions in which rates of reinforcement are varied. Accordingly, Experiment 1 attempted to replicate Nevin's (1974) finding of greater resistance to change in a component with larger magnitudes of reinforcement when equal VI schedules are used in two components of a multiple schedule. Over conditions, response-independent food was presented at different rates during a dark-key period between components. Proportional change in response rate in the two components was compared using data from the first few sessions (cf. Nevin, 1974) and steady-state data obtained when responding in the two components was stable.

METHOD

Subjects

Four adult homing pigeons, with limited prior experience in multiple schedules, were maintained at 80 to 85% of their free-feeding weights. Water and grit were continuously available in the living cage. Supplementary feed of mixed grain was normally given roughly an hour after the end of the session when necessary to maintain prescribed body weights.

Apparatus

Four similar experimental chambers, measuring approximately 34 cm by 34 cm by 32 cm, each contained an interface panel. A hopper was mounted in the center of the panel 6

Table 1

Component schedules used in each condition, with reinforcer durations in parentheses, and orders of exposure for each subject with number of training sessions (in parentheses) required to meet the stability criterion for Experiment 1. The asterisk identifies the case where the stability criterion was not met after 30 sessions (see procedure).

	Reinforcement schedule and duration for each component							
Condition	Red (2 s)	Green (6 s)	Dark key (3 s)	Subject	Condition numbers and sessions to stability			
1	VI 120 s	VI 120 s	EXT	C5	1 (47)	2 (22)	3 (18)	4 (30)*
2	VI 120 s	VI 120 s	VT 120 s	C6	1 (37)	2 (22)	3 (18)	4 (15)
3	VI 120 s	VI 120 s	EXT	C7	3 (42)	4 (26)	1 (17)	2 (15)
4	VI 120 s	VI 120 s	VT 30 s	C8	3 (37)	4 (26)	1 (15)	2 (17)

cm from the floor, and three response keys were mounted 21 cm from the floor and 9 cm apart. Only the center key was used; it was lit from behind with red or green light in two multiple-schedule components or darkened for 30 s between each presentation of a component. Pecks to the key exceeding approximately 0.15 N turned off the key illumination for 0.05 s and occasionally produced reinforcers (grain presentation) arranged by VI schedules (Fleshler & Hoffman, 1962). During reinforcement, the key was darkened and the hopper containing wheat was illuminated white. A ventilation fan in the rear of the chamber helped mask extraneous sounds, and the chambers were all in a darkened room remote from the experimental control system. All experimental events were scheduled and recorded by an IBM® AT-compatible computer running MED-PC® software.

Procedure

Experimental sessions were conducted 7 days per week at approximately the same time of day, and comprised 26 multiple-schedule components during which the center key was illuminated red or green for 1 min, equally often and in an irregular order. Each presentation was preceded by a 30-s dark-key period during which a VT schedule was operative. During red-key components, a VI 120-s schedule arranged 2-s reinforcer, and during green-key components, an identical VI 120-s schedule arranged 6-s reinforcers. Component and VI timing was suspended during reinforcement.

In successive conditions of the experiment, the VT schedule that operated during dark-key periods arranged response-independent presentations of the hopper lasting 3 s. Subjects were trained in a condition for at least 15 sessions and until absolute response rate was stable in both components simultaneously according to a stability criterion. The procedure for assessing stability was to calculate the moving average of five sessions of responding in a component over nine successive sessions. The five averages obtained in this way each had to lie within ±7.5% of the overall mean, calculated over the nine sessions, in order for performance in that component to be judged stable. For each subject's first condition, training was disrupted in two sessions after Session 20 by equipment failure. When the fault had been rectified, training continued in that condition for at least 15 sessions and until the criterion had been satisfied again. Bird C5's responding failed to stabilize according to the criterion in Condition 4, and data from the last five of 30 sessions were adopted. In the first condition (baseline), the VT schedule arranged no food during the dark-key periods; in subsequent conditions, dark-key schedules of VT 30 s and VT 120 s were used. Each of these VT schedule conditions was preceded by a return to baseline conditions, to provide data against which to measure behavior change. The schedules used in red-, green-, and dark-key periods are given in Table 1, along with the order of exposure and number of sessions to stability for each subject.

RESULTS AND DISCUSSION

Response and reinforcer rates were measured in terms of number of responses per minute and number of reinforcers per hour in each component. The time base for these calculations excluded the time occupied by reinforcement during each component. (Absolute rates for this and all experiments reported here are given in the appendix.) Response rate change was measured using the ratio *Bx/Bo,* where *Bo* is the response rate in the red or green components averaged over the last five sessions of the preceding baseline condition (in which response-independent food was not available) and *Bx* is the response rate in the same component during conditions in which response-independent food was presented during the dark-key component. Two values of *Bx* were obtained from conditions in which response-independent food was delivered: one from the initial five sessions and a second from the final five sessions of an experimental condition.

Figure 1 shows response rate (relative to baseline) in each component plotted as a function of the response-independent reinforcer rate arranged during the dark-key component. Graphs on the left show the response-rate change in each component from the initial five sessions in each experimental condition (VT 30 s and VT 120 s). These graphs are comparable to those of Nevin (1974, Experiment 3), who calculated response-rate change after just one session of response-independent food delivery and, therefore, examined the initial effects of a disruptor. The graph on the right shows, for the same subject, response-rate change in each component using the last five sessions of a condition and therefore represents steady-state responding.

Presenting response-independent food in the dark-key component produced a negative contrast effect in that responding in the red and green components decreased as a function of dark-key food rate. The greater force of VT 30 s decreased response rates to a greater degree than did VT 120 s in both components. All birds displayed greater reductions in response rate relative to baseline in the short-reinforcer component than in the long-reinforcer component. This was the case for seven of eight cases during the initial five sessions and in all cases during the final five sessions of a condition.

The results from the initial sessions are similar to those of Nevin (1974, Experiment 3). Nevin demonstrated that the greater the rate of response-independent food, the greater the suppression of behavior in both components. Furthermore, Nevin also found a greater proportional behavior change in a component arranging short reinforcers as opposed to long ones. The present results also expand upon those of Nevin's study. If the conditions that bring about a change in behavior are maintained along with a constant mass difference between components, the differential in resistance to change between the components observed at the start is maintained throughout a condition. That is, the effect of applying a force to behavior was still present and consistent with the differences in the mass-establishing conditions after an extended number of sessions. Therefore, when reinforcer duration establishes a mass difference and response-independent food is used as a force, behavioral momentum theory can be extended to include steady-state responding.

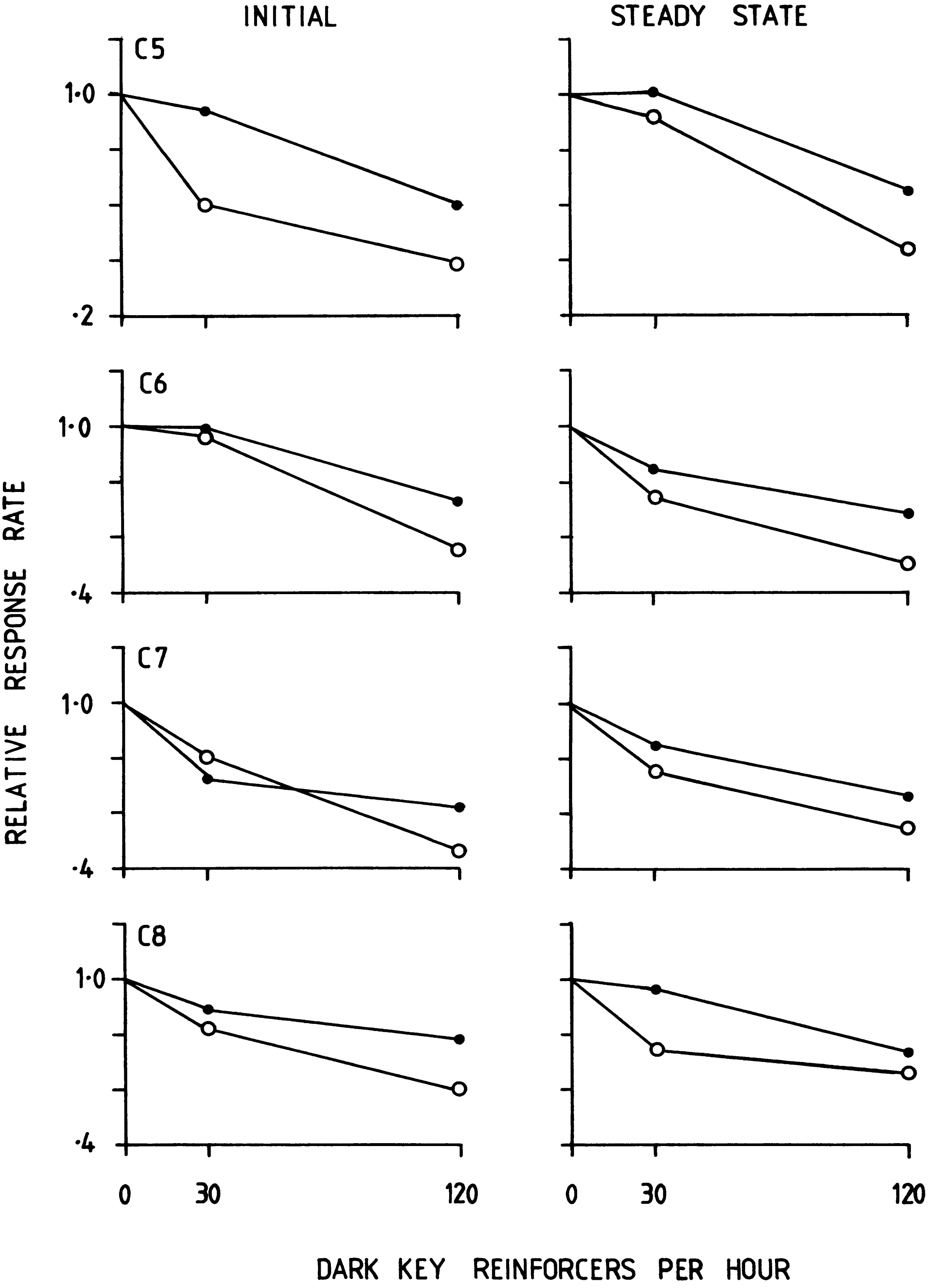
Reinforcer duration is thus confirmed as a determinant of resistance to change in a multiple-schedule component when reinforcer rate is varied in a third component (i.e., the dark-key period). We can now turn to the question of whether variation of the schedules maintaining responding in the two multiple-schedule components will also bring about different changes in response rate over conditions when the two components arrange reinforcers of different duration. Experiment 2 addressed this question.

EXPERIMENT 2

Experiment 1 showed that responding maintained by reinforcers of longer duration was more resistant to change brought about by variation of reinforcer rate in a temporally distant component (i.e., the dark-key period)

⟶

Fig. 1. Response rate in short-reinforcer (unfilled circles) and long-reinforcer (filled circles) components with different rates of response-independent food delivered during the dark-key component. Response rate is presented as a proportion of the rate observed in the same component during baseline conditions in which no food was presented during dark-key components. Left panels give data from the first five sessions in a condition, right panels give data from the last five sessions (Experiment 1).


INITIAL
STEADY STATE
C5
C6
C7
C8
1·0
·2
1·0
·4
1·0
·4
1·0
·4
RELATIVE RESPONSE RATE
0
30
120
0
30
120
DARK KEY REINFORCERS PER HOUR

than was responding maintained by shorter ones. The effect of reinforcers in the dark-key period is predicted by quantitative statements of the law of effect, such as that by Herrnstein (1970). According to these, behavior bears two relationships with the reinforcers obtained in its context. First, response rate varies directly with the frequency of reinforcers that maintain the response and, second, it varies inversely with the frequency of other reinforcers. For the arrangement used in Experiment 1, this statement accurately predicts the response-rate reductions in a component with increases in dark-key food rate.

We are unaware of any attempt to write a statement of the absolute-rate law of effect for situations in which alternative reinforcers differ in terms of magnitude as well as rate. However, the following can easily be derived from the concatenated matching law (Baum & Rachlin, 1969) in the same manner as Herrnstein's law of effect was derived from the regular matching law:

$$P_1 = \frac{kR_1A_1}{\Sigma R_iA_i}, \tag{1}$$

where k is the asymptotic level of the response P_1 and is the rate observed when no alternative reinforcement is available, R and A refer to reinforcer rates and amounts, respectively, and subscripts identify response alternatives. In Equation 1, which is consistent with Herrnstein's (1970) general approach, variation of alternative reinforcement produces changes in P_1 that are relatively large if A_1 is small, and are smaller if A_1 is large. That is, analysis based on the law of effect predicts the greater behavior changes observed for the short-reinforcer component in Experiment 1.

The law of effect also predicts that changes to the schedules of reinforcement that maintain responding in the two components will bring about changes in response rate. That is, P_1 in Equation 1 varies directly as a function of R_1. It remains to be seen whether the extent of changes in response rate brought about in this way will depend on the magnitudes of the reinforcers used in the two components. According to momentum theory, variation of the reinforcer rates in multiple-schedule components should produce changes in responding in the two components, and these will differ depending on whether mass is high or low in a component. In a component in which behavioral mass is low, response-rate change should be large when reinforcer rate is varied; where mass is high, behavior change should be small. The extension of behavioral momentum theory to steady-state responding would gain considerable generality if the mass differential between two components could be demonstrated using (as a force) variation in the schedules maintaining responding.

Until now, the only manipulation of the maintaining reinforcer rate has involved reduction to zero, when extinction is introduced in both components. However, there is some uncertainty about how the effects of extinction should be interpreted, because the conditions that establish different behavioral masses are eliminated when extinction is introduced. Moreover, the differential effects of extinction cannot be studied in steady-state responding. There seems to be no reason why a variety of reinforcer-rate changes other than reduction to zero should not serve equally well to assess relative resistance to change.

In Experiment 2, as in Experiment 1, responding was maintained with 6-s reinforcers in one component and 2-s reinforcers in the other. Instead of varying the rate of response-independent reinforcement in a dark-key period between components, the rates of reinforcers in the two components were varied simultaneously over conditions. In each condition, the scheduled rates of reinforcement were equal in the two components, so the only difference between components was in the duration of reinforcers. Although absolute behavioral mass might vary from condition to condition, the *ratio* of the behavioral masses in the two components ought to remain constant. Therefore, responding should resist change more in the component with long reinforcers when reinforcer frequency is varied.

The procedure we employed here has at least two advantages over previous procedures. First, reinforcer rates were varied in the two components simultaneously, without reducing the frequency to zero. Variations that maintain nonzero reinforcer rates have the advantage that they allow steady-state responding to be examined. Second, changes in reinforcers per hour in the two components were always equal; this was not the case in studies in which extinction was used with components that differed in terms of reinforcer rate. Consequently,

Table 2

Component schedule combinations and reinforcer durations used in each condition, with orders of exposure and number of training sessions required to meet the stability criterion.

Condition	Reinforcement schedule (and duration) for each component		Subject	Condition numbers and sessions to stability						
	Red (2 s)	Green (6 s)								
1	VI 90 s	VI 90 s	C5	2 (23)	3 (20)	2 (20)	4 (20)	2 (20)	5 (20)	
2	VI 120 s	VI 120 s	C6	1 (20)	2 (21)	5 (22)	2 (20)	3 (20)	2 (20)	6 (20)
3	VI 60 s	VI 60 s	C7	2 (24)	4 (24)	2 (20)	5 (20)	2 (20)	3 (21)	
4	VI 240 s	VI 240 s	C8	1 (20)	2 (20)	4 (20)	2 (20)	3 (20)	2 (20)	5 (21)
5	VI 480 s	VI 480 s								
6	VI 40 s	VI 40 s								

reinforcer-rate change cannot reasonably be assumed to be more discriminable in the higher mass component with our procedure, but may be in the more usual procedure.

METHOD

Subjects and Apparatus

The subjects and apparatus used in Experiment 2 were the same as those in Experiment 1.

Procedure

Sessions were conducted 7 days per week at approximately the same time of day, and comprised 28 multiple-schedule components during which the center key was illuminated either red or green for 90 s at a time, equally often and in irregular order. No dark-key period occurred between the two components. Responses on the center key were reinforced according to VI schedules (Fleshler & Hoffman, 1962). When a reinforcer was delivered in the red component, wheat was presented for 2 s; in the green component, reinforcers lasted 6 s. The discriminative stimuli were turned off during reinforcement.

The scheduled reinforcer rates in the two components were varied over conditions but remained equal in the two components throughout the experiment. Every second change in the experimental conditions was a return to multiple VI 120 s VI 120 s, which served as a baseline against which to measure behavior change. Subjects were trained in conditions for at least 20 sessions and until the absolute response rates in both components were stable according to the criterion used in Experiment 1. The schedules used in red and green components are given in Table 2, along with the order of exposure and number of sessions to stability for each subject.

RESULTS AND DISCUSSION

For all analyses, response rates were averaged over the last five sessions, and reinforcer rates were averaged over the last 10 sessions. Ten sessions were used for reinforcers because, with lean VI schedules, estimates with five sessions were unstable. Both response rates and reinforcer rates were calculated taking account of the time occupied by reinforcement in each component.

Figure 2 gives a plot of response rates in each component as a function of reinforcer rate in that component. The smooth curves in Figure 2 are nonlinear regression fits of Herrnstein's (1970) equation to group average response and reinforcer rates and to individual response and reinforcer rates. In Equation 2,

$$P_i = \frac{kR_i}{R_i + R_0}. \qquad (2)$$

The terms are the same as for Equation 1, and R_0 refers to extraneous reinforcers that maintain responding other than key pecking. Equation 2 is identical to Equation 1 except for the units of measurement for R_0. These hyperbolas were fitted using the procedure of Wetherington and Lucas (1980). Different panels show the group average response rates and performances for individual subjects. In all cases, response rate in a component increased as the absolute reinforcer rate increased. In most cases, the function relating absolute reinforcer and response rates was well fitted by the hyperbolic function suggested by Herrn-

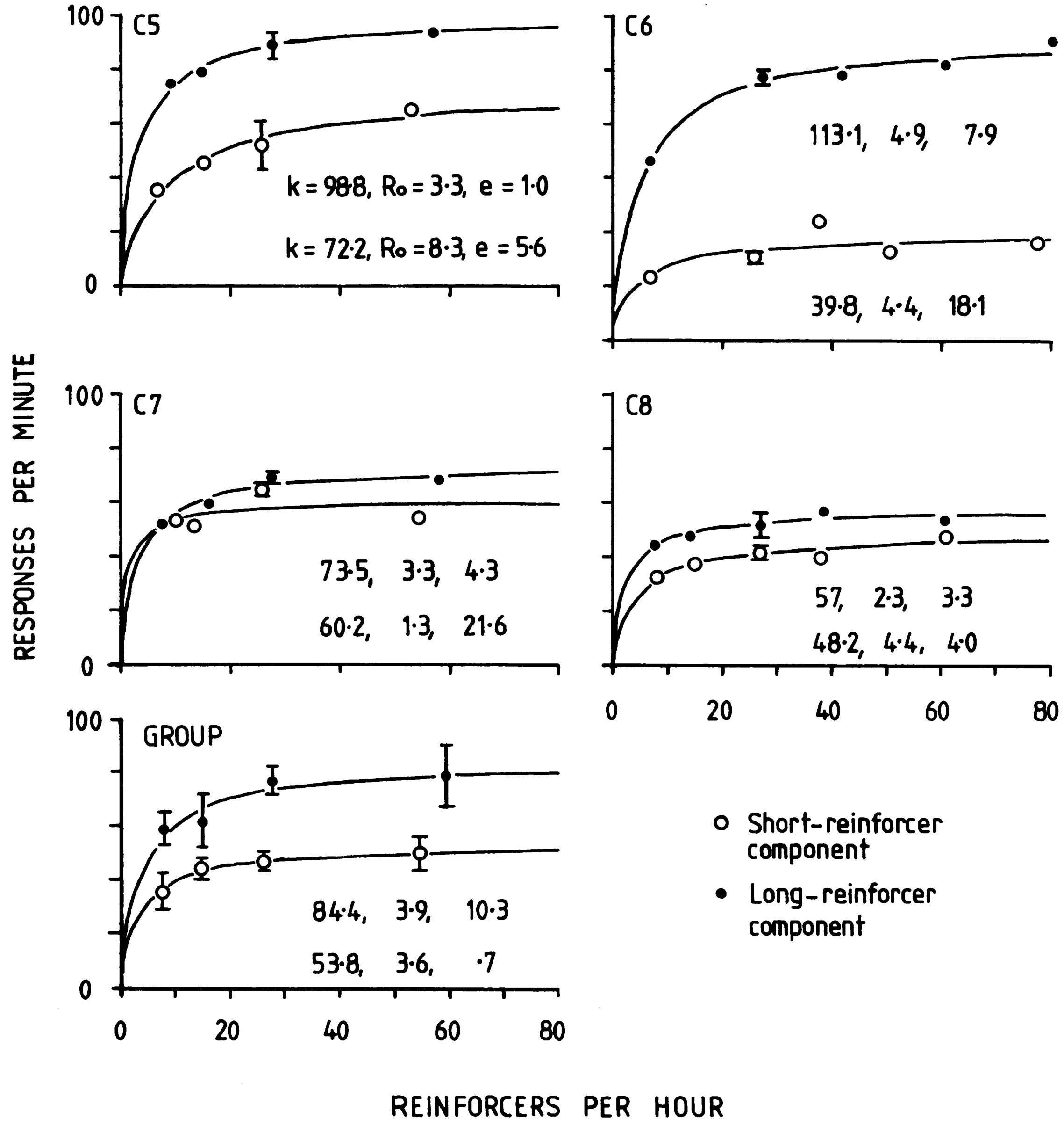


Fig. 2. Responses per minute in short-reinforcer (unfilled circles) and long-reinforcer (filled circles) components plotted as a function of reinforcers per hour in the same components. The smooth curves are plots of Equation 2, fitted by the method of least squares. In each panel, parameter estimates are given for k and R_0, followed by the mean squared error (e). The uppermost series of estimates in each panel applies to the long-reinforcer component, and the lower series applies to the short-reinforcer component. Error bars mark one standard error in either direction from the mean in cases in which several determinations were conducted (Experiment 2).

stein (1970, 1974) for single-schedule performance. Fitting this equation to the present data yields estimates of two free parameters: k and R_0. The obtained values of k and R_0 and the mean squared errors (e) for the best fitting hyperbolas are given in each panel of Figure 2.

The results indicated that response rates in both components were, for most subjects, well related to reinforcer rates by the hyperbolic function reported in other studies using a variety of schedules (e.g., Bradshaw, Szabadi, & Bevan, 1978; Catania & Reynolds, 1968; McDowell & Wood, 1984). The fitted parameter

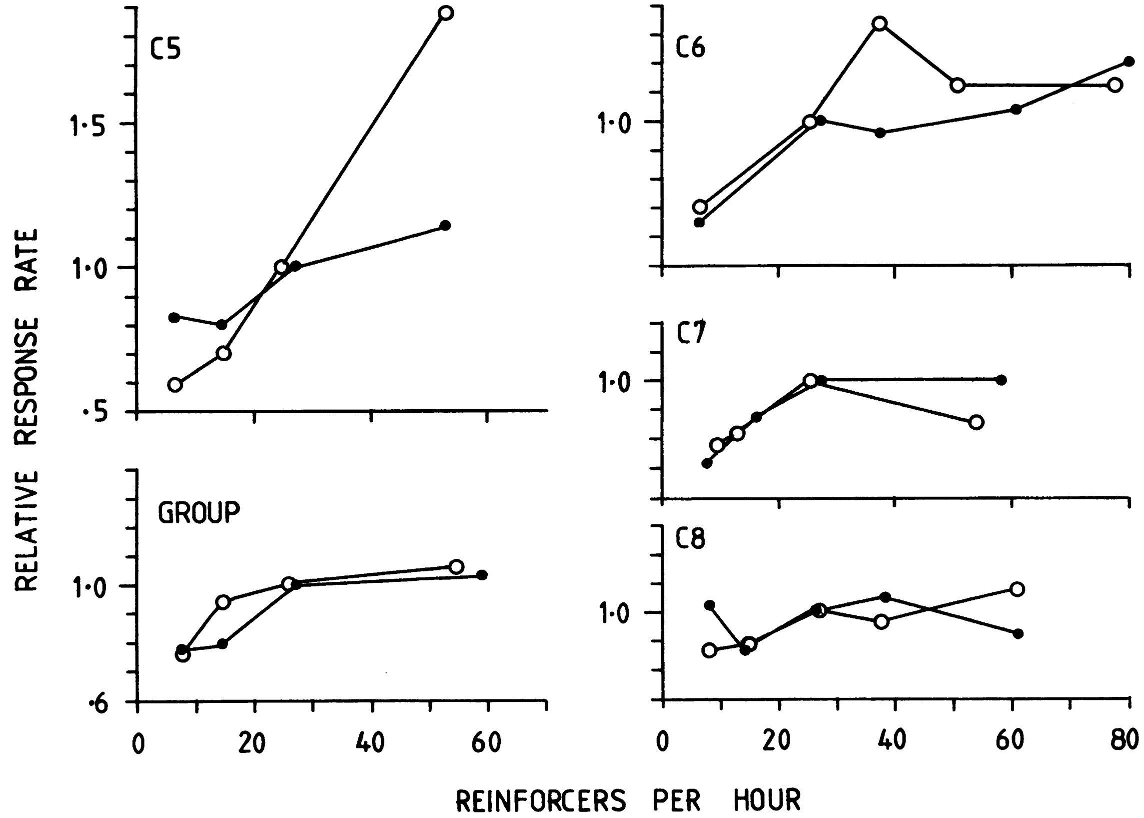


Fig. 3. Response rate in short-reinforcer (unfilled circles) and long-reinforcer (filled circles) components plotted as a function of reinforcers per hour in the same component. Response rates are presented as proportions of the rates observed in the same component during baseline conditions (Experiment 2).

estimates revealed that the asymptotic level of responding (*k*) was always greater with 6-s reinforcers than with 2-s reinforcers. This finding is similar to that reported by McDowell and Wood (1984) and Bradshaw et al. (1978), who also varied reinforcer rates with different reinforcer magnitudes, although they used single rather than multiple schedules. In both of these studies, higher reinforcer magnitude (in cents or sucrose concentration, respectively) resulted in higher estimates of *k* when reinforcer frequency was varied. Like our results, these changes in *k* are not consistent with Herrnstein's (1970) statement of the law of effect (Equations 1 and 2).

Figure 2 makes it clear that the different reinforcer durations used in the two components did affect behavior, because overall levels of responding were consistently higher for the component with long reinforcers. However, Figure 2 does not allow assessment of whether relative resistance to change differed in the two components. Figure 3 gives component response rates in each condition relative to the rate found in the same component during a baseline (i.e., multiple VI 120 s VI 120 s) condition. For C6 and C8 the following condition's data were used as a baseline for Condition 1, because there was no preceding baseline condition conducted in these cases. In all other cases, data from the immediately preceding multiple VI 120-s VI 120-s condition were used as the baseline. These proportions are plotted as a function of absolute reinforcer rate in a component. Data are presented separately for each bird, and the group average is also plotted. For the group, response rate (relative to baseline rate) increased as absolute reinforcer rate increased. For reinforcer rates below baseline level (30 per hour), responding decreased and the proportion was below 1.0. For those reinforcer rates above baseline, the proportion was above 1.0 (i.e., responding increased). If responding in the short-reinforcer component was less resistant to change than that in the long-reinforcer component, then the

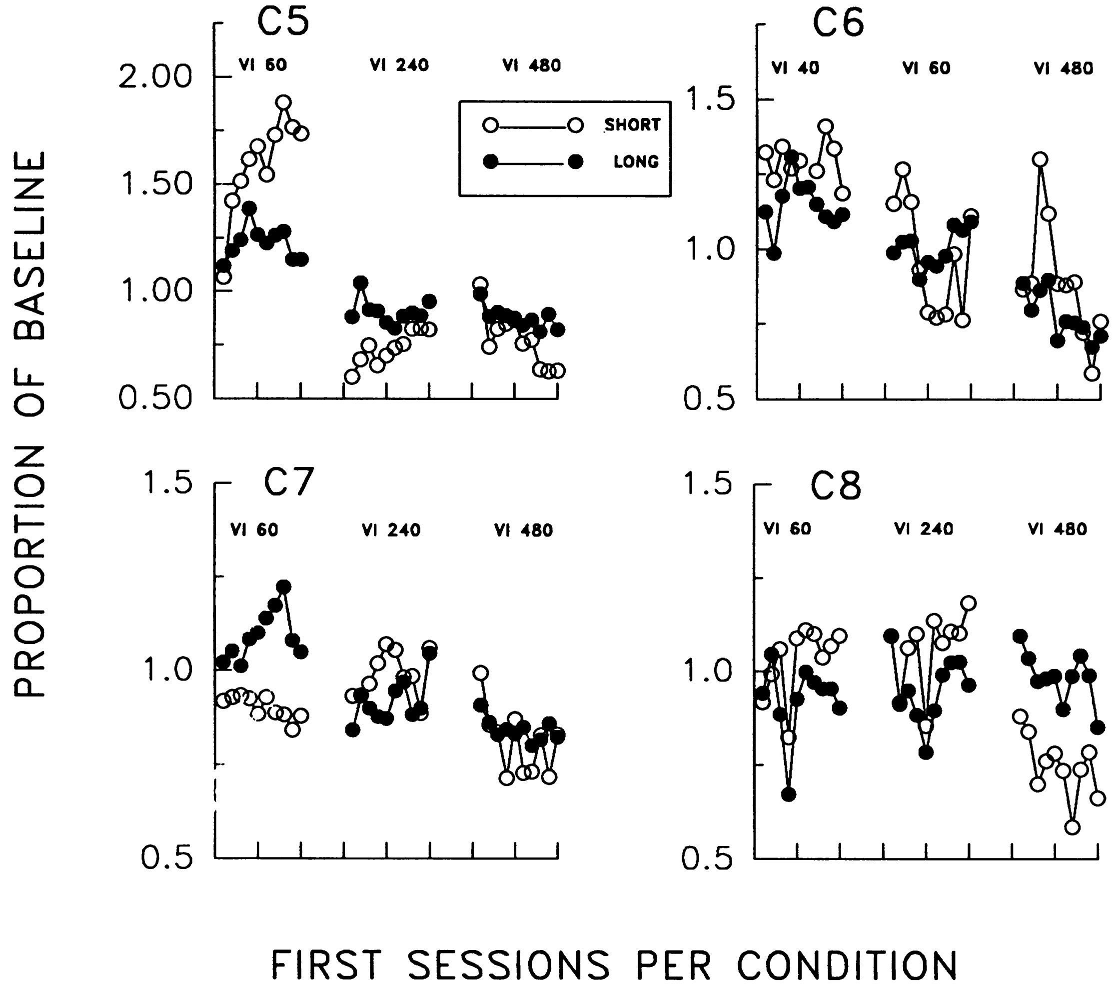


Fig. 4. Response rates in short- and long-reinforcer components over the first 10 sessions in nonbaseline conditions. Response rates are presented as proportions of the rates observed during the preceding baseline condition. One day's data from one component are missing for Bird C6 in the VI 40-s condition owing to equipment failure.

functions relating relative response rate to absolute reinforcer rate would have been steeper for that component. However, for most subjects there was rather little systematic change in relative response rate with changes in the absolute level of reinforcement. Birds C5 and C8 showed greater response-rate change in the short-reinforcer component, but the remaining 2 subjects did not; group average response rates changed equally in the two components. This analysis was repeated using predicted response rates generated from the descriptive hyperbolas shown in Figure 2, in case the analysis had been overly sensitive to variability in individual data points and thus obscured proportionately greater changes in one or the other component. Such predictions were based on the whole data set and have the advantage that they take care of small differences in obtained reinforcer rate between components, but yet again showed essentially the same effects regardless of the reinforcer duration.

Figure 4 shows responding in each of the first 10 sessions of the nonbaseline conditions, which used VI 60, VI 240, and VI 480-s schedules. Bird C6 was not exposed to VI 240 s but was trained with VI 40 s; data from that condition are shown. Response rates in each component are presented as proportions of rates in the immediately preceding baseline condition. There is a tendency for these proportions to be more extreme for the short-reinforcer component than for the long-reinforcer one, suggesting that response rates during the first few sessions in a condition may have been more responsive to changes in reinforcer rate, but there are also some clear exceptions and counterexamples (C6 in VI 480 s, C7 in VI 60 s, C7 and C8 in VI 240 s). Thus, unlike the similar analysis by Shettleworth and Nevin (1965) using extinction, these data do not support the generalization that responding maintained by long reinforcers shows greater resistance to changes in the rate of reinforcement.

A possible reason for the lack of difference between long- and short-reinforcer responding is that insufficient force was applied for differences in mass between components to become apparent. This is unlikely because the hyperbolic relationship between absolute response and reinforcer rates indicates that response rates did not change a great deal relative to baseline with the higher reinforcer rates. For both components, an asymptotic level of responding was apparently reached by all subjects, indicating that any greater changes in reinforcer rate would have had very little effect on response rates. Similarly, it is unlikely that the similarity between component performances arose from similar behavioral mass in the two components, because Experiment 1 established that 2-s and 6-s reinforcer durations were sufficient to produce differences in resistance to change that were revealed when response-independent food was used as a force.

To conclude, it appears that reinforcer-rate changes in the maintaining schedule were sufficient to change response rates in components. The reinforcer durations used were clearly sufficient to affect overall rates of responding and, according to the results of Experiment 1, should have been sufficient to create a difference in resistance to change. However, no such difference in resistance was revealed when rates of the reinforcers maintaining responding were varied. Thus, Experiment 2 raises doubts that altering the maintaining schedule changes responding differentially according to the behavioral mass of a component. This lack of differential behavior change is in contrast to the results obtained when resistance is assessed by varying the rate of response-independent food (Experiment 1).

EXPERIMENT 3

Experiment 2 was concerned with the sensitivity of absolute response rate to changes in absolute reinforcer rate and its possible dependence on the determiners of behavioral mass. Experiment 3 was concerned with sensitivity of relative response rates. Relative response rates in multiple schedules tend to undermatch (i.e., are less extreme than) relative reinforcer rates (e.g., Lander & Irwin, 1968; Lobb & Davison, 1977; McLean & White, 1981, 1983; Pliskoff et al., 1968). This feature of multiple-schedule performance is reflected by values of a (sensitivity to reinforcer ratios) between 0.3 and 0.6 in the generalized matching equation:

$$\log\left[\frac{P_1}{P_2}\right] = a \log\left[\frac{R_1}{R_2}\right] + \log[c]. \quad (3)$$

Equation 3 describes a straight line function with slope a relating response and reinforcer ratios on log–log coordinates (for a review, see McSweeney, Farmer, Dougan, & Whipple, 1986).

A prediction of lower sensitivity with longer reinforcer duration can be derived from behavioral momentum theory. In a two-component multiple schedule, if behavior in both components possesses high mass then the response rate in each component will change less when reinforcer rates in the two components are varied than if both possess low mass. Because the behavior in both components changes less with high mass, the ratio of P_1/P_2 will be less sensitive to the changes in the ratio R_1/R_2. Establishing high mass with a longer duration of reinforcement in both components should, therefore, result in lower sensitivity to changes in the reinforcer ratio. Changes in the ratio R_1/R_2 would act as a force to change behavior in the two components and should do so in two ways: first, by varying the maintaining schedule in a component (although Experiment 2 raises some doubt that this variation will reveal a mass differential) and, second, by varying the successive reinforcement context for responding in each component (i.e., through component interaction as in Experiment 1).

Studies that have varied the ratios of component reinforcer rates in a multiple schedule have not compared a series of conditions with one common reinforcer duration against the same series of conditions with a different common reinforcer duration, although some studies have used variations of relative reinforcer duration (e.g., Merigan, Miller, & Gollub, 1975; Shettleworth & Nevin, 1965). Conse-

Table 3

Schedule combinations and reinforcer durations (in seconds) for components in each condition, with orders of exposure and number of training sessions given for each bird. Repetitions of conditions for a subject are indicated by an R next to condition numbers, and asterisks indicate conditions where data were taken after 35 sessions of training without the stability criterion having been met.

		VI schedule (in seconds)													
Condition	Reinforcer duration	Red component	Green component	Subject	Condition numbers and sessions to stability										
1	2	360	60	C1	1 (30)	3 (26)	2 (26)	4 (20)	5 (20)	7 (20)	6 (22)	8 (21)	5R (20)	6R (25)	2R(35)*
2	2	60	360	C2	4 (26)	2 (27)	3 (34)	1 (30)	8 (22)	6 (25)	7 (23)	5 (20)	2R (25)	1R (26)	
3	2	160	75	C3	5 (27)	7 (27)	6 (29)	8 (21)	1 (35)*	3 (35)*	2 (28)	4 (24)	1R (23)		
4	2	75	160	C4	8 (27)	6 (21)	7 (20)	5 (25)	4 (26)	2 (35)*	3 (20)	1 (35)*	2R (30)	4R (21)	
5	6	360	60												
6	6	60	360												
7	6	160	75												
8	6	75	160												

quently, the effect of reinforcer duration on sensitivity to variation in relative reinforcer rate in multiple schedules is not known. Experiment 3 used two series of conditions; within each the reinforcer rate ratio was varied. Between series, the magnitude of the reinforcers was varied.

METHOD

Subjects and Apparatus

Four new homing pigeons were kept under conditions identical to those in Experiments 1 and 2. Also used were four new experimental chambers that were similar in design to those in Experiments 1 and 2.

Procedure

The center key was illuminated red or green for 90-s periods in an alternating order. Responses on the center key were reinforced according to VI schedules (Fleshler & Hoffman, 1962). Experimental conditions were presented in two series, and each pigeon was exposed to both. Each arranged the same series of reinforcer rates in components but differed in the duration of reinforcement. In Series 1, reinforcement was wheat presented for 2 s, whereas in Series 2 it was wheat presented for 6 s. The stimuli (red or green) were turned off during reinforcement. Sessions consisted of 14 presentations of each component. The conditions for each pigeon are shown in Table 3.

The procedure was conducted 7 days a week at approximately the same time every day. For each bird, daily sessions were continued within a condition for at least 20 sessions and until a stability criterion had been met. The proportion of responses that occurred in the red component was calculated for each of the last five sessions in a condition; these were then averaged to give one overall value. The stability criterion was that each proportion over the last five sessions was within ±.025 of the overall proportion. This criterion ensured that the relative response rates were stable and not fluctuating extremely from session to session. If a subject failed to meet the criterion after 35 sessions in any condition, it was automatically moved on to the next; the last five sessions' data were adopted in any case.

RESULTS AND DISCUSSION

Summary response rates used in the present analysis were calculated by taking the response

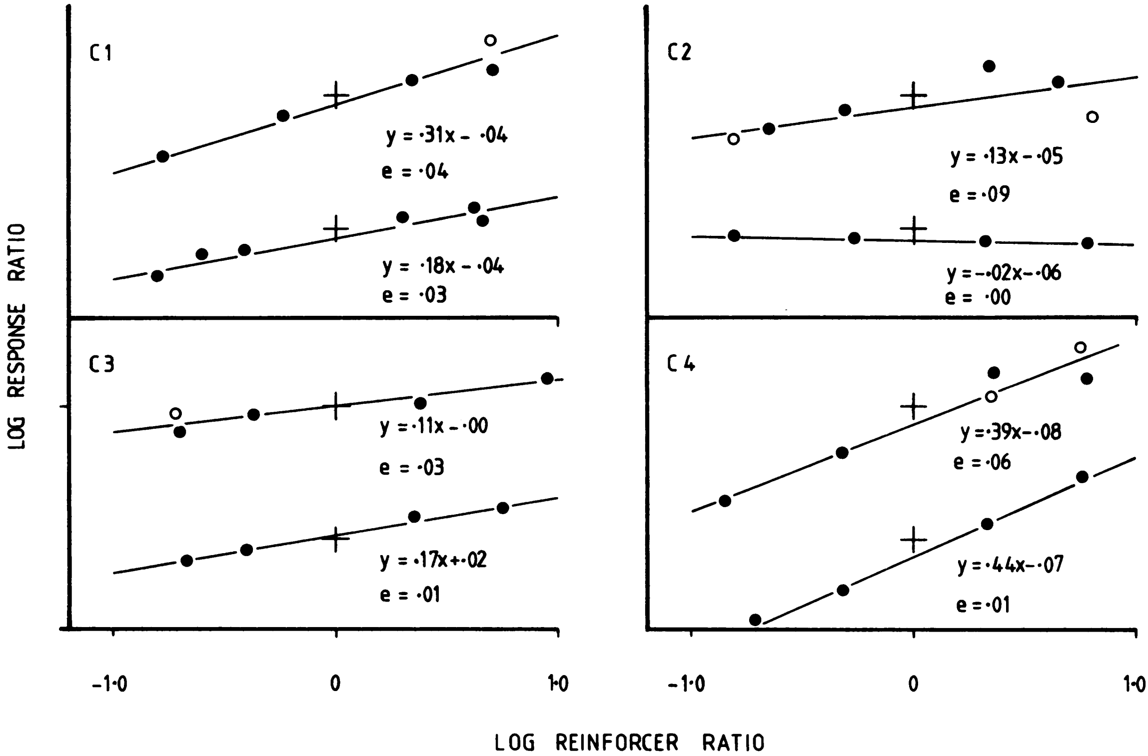


Fig. 5. Base 10 logarithms of response-rate ratios plotted as a function of base 10 logarithms of reinforcer-rate ratios. Two data sets are plotted for each subject, each with a separate origin indicated by a cross. For each subject, the uppermost data set comes from conditions with short reinforcers, and the lower set from conditions with long reinforcers. Equations of least squares regression lines and standard errors of estimate (*e*) are given for each data set (Experiment 3).

rates over the final five sessions in a condition and reinforcer rates over the final 10 sessions in a condition. Figure 5 shows logarithms of response-rate ratios plotted as a function of logarithms of reinforcer-rate ratios. Ratios in this figure are rates in the red component divided by rates in the green component. The upper function in each panel shows data from Series 1 (Conditions 1 through 4) in which the reinforcer duration was 2 s. The lower one shows data from Series 2 in which the duration was 6 s. The origins of the functions have been displaced by 0.6 log unit to avoid overlap, and are indicated by a cross.

Least squares regression lines were fitted to the data obtained for each pigeon. Equations of the fitted regression lines are shown in Figure 5, and correspond to the function given by the generalized matching relation (Equation 3). The slopes of these lines provided a measure of sensitivity (*a*) to reinforcer-rate ratios, and in Series 1 (responding for short reinforcers) ranged from 0.11 to 0.39. The values obtained in Series 2 (responding for long reinforcers) ranged from 0.020 to 0.44. Sensitivity values were low in the range of what is normally obtained in multiple schedules. The generalized matching equation fitted the present data well, with low standard errors of estimate for all regression lines.

A comparison of the matching line slopes obtained with 2-s or 6-s reinforcer durations indicated that for Birds C1 and C2 there was a greater sensitivity with 2-s reinforcers than with 6-s reinforcers. However, Birds C3 and C4 displayed slightly greater sensitivity with 6-s reinforcers, and, overall, the data indicate inconsistent differences in reinforcer-rate sensitivity as a function of reinforcer duration.

The independence of multiple-schedule sensitivity (to reinforcer-rate ratios) from reinforcer magnitude is contrary to what is predicted by behavioral momentum theory, if resistance to change is interpreted in terms of extent rather than speed of behavior change. It is possible that the change in reinforcer rates was insufficient to cause differential effects on the response ratio, but this seems unlikely because several other studies that have varied the component reinforcer rates across components have provided data consistent with predictions from behavioral momentum theory. For example, Charman and Davison (1983) varied deprivation to observe the effect on sensitivity when scheduled reinforcer-rate ratios were varied over a range comparable with that used here. At low levels of deprivation (presumably decreasing the value of reinforcers and thereby reducing behavioral mass), variation of the ratio of reinforcers produced more extreme changes in response ratios than were observed with higher deprivation, and these ratios tended to match the reinforcer ratio. Therefore, in their study reinforcer-rate change as a force had effects on behavior that were consistent with the mass that momentum theory predicts to be established in both components over two series in which reinforcer value was varied.

Another possible explanation for the lack of a sensitivity difference due to reinforcer duration in the present experiment is that behavioral mass reached such a high level over conditions in the two series that behavior became insensitive to any changes in the reinforcer conditions. It is possible that mass established by reinforcer duration accumulates over sessions and eventually reaches a point at which it changes only very slowly when contextual reinforcement conditions are altered. If so, the accumulation of mass would likely have continued over the two series in the present study, because the same discriminative stimuli were used in each series; Nevin (1988) noted that it was the stimulus–reinforcer contingency, sometimes based on reinforcement history over many sessions, that is important in determining behavioral mass. Therefore, mass built up in one series of conditions may have affected resistance to change in the next series.

One indication that this might have occurred is that the 2 birds that began training on the short-reinforcer series (C1 and C2) were the only 2 birds to show a flatter function when changed to the high-mass series. Because C3 and C4 began under high-mass conditions, their responding may have accumulated sufficient behavioral mass that reducing reinforcer duration did not immediately decrease mass to any great extent; indeed, these 2 birds displayed very little difference in response-ratio sensitivity between series. However, this between-subjects comparison does not provide strong evidence and is not confirmed by comparisons involving conditions that were repeated for some subjects. In Figure 5, data from short-reinforcer conditions that were run soon after the long-reinforcer series (unfilled circles) can be compared with data from the same conditions run either before the long-reinforcer series or after prolonged exposure to short reinforcers and should, according to this explanation, undermatch more strongly than the remaining response ratios. Except for Bird C2, these log response ratios do not appear to be less extreme than corresponding points from the other determinations. Moreover, this process does not explain the results of Experiment 2, despite the fact that subjects in that experiment had previously served in Experiment 1. In Experiments 1 and 2, the red stimulus always signaled short reinforcers and the green one signaled long reinforcers. Even if behavioral mass accumulated over these two experiments, it should still have been higher in the green component than in the red one. For these reasons, the order in which subjects were exposed to conditions seems unlikely to obscure differential effects of reinforcer magnitude on the extent to which behavior may change.

GENERAL DISCUSSION

To demonstrate the implications of behavioral resistance principles for regular schedule research, changes to the maintaining reinforcer schedule need to be shown to have different effects on responding dependent upon different behavioral masses. Mass differences established by different reinforcer frequencies are not appropriate for this demonstration, because these would be confounded when the maintaining reinforcer schedules were varied as a means to apply force. The results of Nevin (1974, Experiment 3) indicated that reinforcer duration may establish a mass differential across components, and this difference should not be altered by making equal changes to the reinforcer rates for the two responses. For this reason, Experiment 1 examined reinforcer duration as a means to establish a mass differential in responding. In keeping with Nevin's findings, Experiment 1 demonstrated that longer reinforcer durations resulted in smaller response-rate change (measured as a proportion of baseline) when the dark-component food rate was varied. This difference was still clearly present in steady-state responding, achieved after at least 15 sessions with a given rate of dark-component food. Reinforcer duration is, therefore, a means to establish persistent differences in resistance to change. However, when a different force was applied through alterations in the reinforcer rate (Experiment 2) or reinforcer-rate ratio (Experiment 3), no consistent difference in resistance to change was observed between behavior maintained using short versus long durations of reinforcement.

The present procedure has important advantages over using extinction as a force to study differential resistance to change. When two components arrange different reinforcer rates during a baseline condition, and both are subsequently reduced to extinction, the results are difficult to interpret in terms of resistance to change for two reasons. First, extinction represents a larger change in terms of reinforcers per hour for the formerly rich component, and this may produce greater or faster behavior changes than in the formerly lean component. The unequal salience of this manipulation across components may then mean that relative change in behavior is not a good indication of relative behavioral resistance. Second, with extinction the conditions maintaining the mass differential being measured are disrupted in the course of the measurement procedure. Both problems tend to reduce the measured difference in resistance to change between the two components, and indeed when Nevin et al. (1983) compared estimates of relative resistance to change assessed using extinction versus variation of dark-component food rate, the results from the extinction method showed much smaller differences. The method used here (Experiment 2) avoids both problems, because reinforcers per hour in the two components were reduced equally; hence, the change should not be more discriminable in one component than in the other. Moreover, because reinforcer rates were varied without using extinction, the mass differential brought about by different reinforcer magnitudes ought to have remained present when forces were applied to responding. For these reasons, *stronger* differences were expected in relative resistance to change between components than Nevin et al. (1983) obtained using extinction. Instead, no differences were found at all, and Experiment 3 confirmed this result with a slightly different procedure.

Why might it be that the procedures used in Experiments 2 and 3 failed to reveal the differences in resistance to change due to reinforcer magnitude that were seen in Experiment 1? One possibility is that the confounding effect between the variables that establish behavioral mass and those that exert force may have remained, despite efforts to separate them. We have assumed that, provided the same operation is performed in the two components, the forces applied will be equal, and differences in resistance to change will emerge reflecting any differences between components in conditions that determine behavioral mass. This assumption about the nature of forces is entirely consistent with the view implicit in published work on behavioral momentum theory, but may have been naive. Perhaps the effect of varying reinforcer rate combines with the duration of reinforcers in some way that is unspecified by behavioral momentum theory in determining the extent of the force applied to responding. For example, the force exerted by changing the reinforcer rate in components may be a function of the reinforcer-rate change in combination with the reinforcer duration used in that component. If so, then a large force would be applied to high-mass responding in one component and a smaller force applied to low-mass responding in the other, with the result that behavior change was similar in the two components.

If the assertion that forces applied to responding depend both on those parameters of reinforcement that are varied over conditions (rate in Experiment 2) and also on other, constant parameters of reinforcement (such as magnitude) is correct, then the implications of behavioral mass for the quantitative law of effect will be limited. When forces are applied from outside the components in which resistance to change is measured, such as in a third component, then no confounding effect between variables determining mass and those determining force will exist, and behavior change in the two target components should indeed reflect relative behavioral masses.

However, when forces are applied to responding from within the same components as the target responses, behavior change may be independent of behavioral mass. Implications of mass for the quantitative law of effect would then exist for only one of the relations described in the law of effect, namely the contrast effects observed in a component when reinforcers are varied in another component. It is interesting to note that data comparing contrast in rich versus lean target components (Spealman & Gollub, 1974) are consistent with predictions from momentum theory. Similarly, in the present work only Experiment 1, in which the force was applied during the dark component (producing behavioral contrast in the VI components), replicated the effects of reinforcer magnitude on resistance to change in two target components.

Although this explanation seems appealing, it does not accommodate Charman and Davison's (1983) results with various deprivation levels in multiple schedules. In their experiment, high sensitivity was found when component reinforcer rates were varied over conditions with low deprivation. Decreasing the level of deprivation might be expected to reduce behavioral mass in both components by reducing the value of the food reinforcers, making responding more susceptible to variations in reinforcer rate; the data are consistent with this expectation. However, if the force applied by varying reinforcer rate is also some function of the value of reinforcement, then it too must have been reduced by decreasing deprivation. It is unclear why the combination of reduced mass and force might have resulted in higher sensitivity in their procedure but not in ours.

Whatever the explanation for the different results in our Experiments 1 and 2, the failure to find different resistances to change when maintaining reinforcement schedules are varied is not confined to conditions in which reinforcer duration is used to manipulate behavioral mass. Steady-state results in multiple concurrent schedules of reinforcement have been interpreted in terms of behavioral momentum theory (e.g., Nevin, 1988), but are less consistent with predictions than at first seems to be the case. Nevin argued for consistency with the theory by examining relative response rate in a multiple schedule over changes to the frequency of concurrently available reinforcement. When responding on, say, a left key is maintained by a high rate of reinforcement during one component and by a lower rate in the alternated component, variation of the rate of reinforcement for right-key responding produces greater change in left-key responding in the component with the lower left-key reinforcer rate. That is, the ratio of left-key responses for the two components has been shown to increase with simultaneous increases of right-key reinforcement in the two components (McLean & White, 1983; Pliskoff et al., 1968). Here, right-key reinforcement serves as a force applied to left-key responding, and extreme ratios of left-key responses reflect the fact that behavior changes more for the infrequently reinforced left-key response than it does for the frequently reinforced one. As Nevin argues, the results seem compatible with behavioral momentum theory.

The difficulty arises when the force is applied to left-key responding by varying left-key reinforcement. It has been shown that reinforcers obtained in a multiple-schedule component add to the mass of responding in that component whether contingent upon that response or not; therefore, reinforcers from the right key in the multiple concurrent schedule arrangement described above can also be viewed as contributors to behavioral mass for responding in their respective components. For example, Nevin et al. (1990) found that reinforcers obtained from a concurrently available response in a multiple-schedule component increased resistance to change when satiation was used to disrupt responding, even though they were not contingent on the target response. Similarly, Nevin, Smith, and Roberts (1987) found that noncontingent transitions to a subsequent reinforcement schedule increased resistance as much as contingent transitions when subjects were prefed prior to experimental sessions (see also Nevin, 1984). Thus alternative, competing reinforcement (i.e., in multiple concurrent schedules) should increase the behavioral mass of multiple-schedule responses, despite not being contingent on the response under study.

When the multiple concurrent schedule results from Pliskoff et al. (1968) and McLean and White (1983) are reconsidered from the point of view that concurrently available reinforcers add to the mass of both responses in a component, they are no longer consistent with predictions of momentum theory—at least when variation of the maintaining schedules is used as a force to change behavior. If concurrently available reinforcers add to a component's mass, then variation of the left-key schedules should have less effect on left-key responding when right-key reinforcement is high than in conditions in which right-key reinforcement is low. When Pliskoff et al. (1968) and McLean and White (1983) compared multiple-schedule performance using high or low alternative reinforcement, they found the opposite: Relative response rate changed more with changes in relative reinforcer rate in those conditions with greater concurrently available reinforcement, and analysis of these data using Equation 3 confirms greater sensitivity to reinforcement with high alternative reinforcement. Thus, in momentum theory terms, arrangements that apply a force within the response system under study (such as varying the schedules that maintain the response) do not find the differences in resistance to change that are found when other, external manipulations (successively presented reinforcers or prefeeding) are used.

In view of our conclusion that variation of the schedules maintaining responding does not reveal differences in resistance to change, the interpretation of resistance to change in studies in which extinction is used as a force seems to require clarification. Extinction is an extreme variation of the maintaining schedules, and has often been used to demonstrate differences in resistance to change between components. It seems that extinction (but not the lesser variations in the maintaining schedule used here; see Figure 4) does show these differences when studied over only a few sessions. However, after prolonged exposure to extinction, response rates (relative to their baselines) would surely be equal in the two components at zero, which would be consistent with our steady-state results. That is, any difference in resistance to change observed with extinction as a force is apparently one of latency to change rather than one of extent of change measured using steady-state responding in successive conditions. In the case of prefeeding as a force, the interpretation is less clear. Prefeeding may be viewed as a large amount of the contingent reinforcer at a time remote from the experimental contingencies (an external force) but may also be viewed as a manipulation that reduces the value of the contingent reinforcers (an internal force).

This work attempted to discover the implications of resistance-to-change findings for the response–reinforcer relation described by the quantitative law of effect. Implications were expected because the literature on behavioral resistance makes use of steady-state differences in response rate to support behavioral momentum theory; therefore, it seemed likely that known determinants of behavioral mass could be used to modulate the hyperbolic relation between responding and reinforcement, making steady-state behavior more sensitive to changes in its determinants when low-mass conditions were used than when high-mass conditions were used. This attempt was successful in Experiment 1, in which a mass differential was demonstrated between steady-state multiple-schedule responses maintained by different reinforcer durations. In that experiment, variation of successively presented reinforcers reduced both responses, as predicted by the law of effect, and reduced the one maintained by short reinforcers more, as predicted by both the law of effect (Equation 1) and behavioral momentum theory. However, when multiple-schedule responding was changed using the relation between responding and its consequences (Experiment 2), the same difference in reinforcer duration between components did not produce different resistances to change. This is not consistent with either the quantitative law of effect or with the proposed extension of momentum theory to steady-state data. In Experiment 3, which used opposite changes in reinforcement in two multiple-schedule components, responding in each component was determined both by variation of the maintaining schedule and by variation of the temporally distant component. Again, however, no difference in resistance to change was observed. Reexamination of previous studies using concurrently available reinforcers in multiple-schedule components, as well as the present findings, support the interpretation that the steady-state relation between behavior and its consequences is not reliably modulated by the conditions that determine mass in behavioral momentum theory, although the relation between responding and alternative reinforcement may be.

REFERENCES

Baum, W. M., & Rachlin, H. C. (1969). Choice as time allocation. *Journal of the Experimental Analysis of Behavior,* **12,** 861–874.

Bouzas, A. (1978). The relative law of effect: Effects of shock intensity on response strength in multiple schedules. *Journal of the Experimental Analysis of Behavior,* **30,** 307–314.

Bradshaw, C. M., Szabadi, E., & Bevan, P. (1978). Relationship between response rate and reinforcement frequency in variable-interval schedules: The effect of the concentration of sucrose reinforcement. *Journal of the Experimental Analysis of Behavior,* **29,** 447–452.

Catania, A. C. (1963). Concurrent performances: Reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior,* **6,** 253–263.

Catania, A. C., & Reynolds, G. S. (1968). A quantitative analysis of the responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* **11,** 327–383.

Charman, L., & Davison, M. (1983). On the effects of food deprivation and component reinforcer rates on multiple-schedule performance. *Journal of the Experimental Analysis of Behavior,* **40,** 239–251.

de Villiers, P. A., & Herrnstein, R. J. (1976). Toward a law of response strength. *Psychological Bulletin,* **83,** 1131–1153.

Fath, S. J., Fields, L., Malott, M. K., & Grossett, D. (1983). Response rate, latency, and resistance to change. *Journal of the Experimental Analysis of Behavior,* **39,** 267–274.

Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior,* **5,** 529–530.

Hearst, E. (1961). Resistance-to-extinction functions in the single organism. *Journal of the Experimental Analysis of Behavior,* **4,** 133–144.

Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior,* **13,** 243–266.

Herrnstein, R. J. (1974). Formal properties of the matching law. *Journal of the Experimental Analysis of Behavior,* **21,** 159–164.

Lander, D. G., & Irwin, R. J. (1968). Multiple schedules: Effects of the distribution of reinforcements between components on the distribution of responses between components. *Journal of the Experimental Analysis of Behavior,* **11,** 517–524.

Lobb, B., & Davison, M. C. (1977). Multiple and concurrent schedule performance: Independence from concurrent and successive schedule contexts. *Journal of the Experimental Analysis of Behavior,* **28,** 27–39.

McDowell, J. J, & Wood, H. M. (1984). Confirmation of linear system theory prediction: Changes to Herrnstein's k as a function of changes in reinforcer magnitude. *Journal of the Experimental Analysis of Behavior,* **41,** 183–192.

McLean, A. P., & White, K. G. (1981). Undermatching and contrast within components of multiple schedules. *Journal of the Experimental Analysis of Behavior,* **35,** 283–291.

McLean, A. P., & White, K. G. (1983). Temporal constraint on choice: Sensitivity and bias in multiple schedules. *Journal of the Experimental Analysis of Behavior,* **39,** 405–426.

McSweeney, F. K., Farmer, V. A., Dougan, J. D., & Whipple, J. E. (1986). The generalized matching law as a description of multiple-schedule responding. *Journal of the Experimental Analysis of Behavior,* **45,** 83–101.

Merigan, W. H., Miller, J. S., & Gollub, L. R. (1975). Short-component multiple schedules: Effects of relative reinforcer duration. *Journal of the Experimental Analysis of Behavior,* **24,** 183–189.

Nevin, J. A. (1974). On the form of the relation between response rates in a multiple schedule. *Journal of the Experimental Analysis of Behavior,* **21,** 237–248.

Nevin, J. A. (1979). Reinforcement schedules and response strength. In M. D. Zeiler & P. Harzem (Eds.), *Advances in analysis of behavior: Vol. 1. Reinforcement and the organization of behavior* (pp. 117–158). Chichester and New York: Wiley.

Nevin, J. A. (1984). Pavlovian determiners of behavioral momentum. *Animal Learning & Behavior,* **12,** 363–370.

Nevin, J. A. (1988). Behavioral momentum and the partial reinforcement effect. *Psychological Bulletin,* **103,** 44–56.

Nevin, J. A. (1992). An integrative model for the study of behavioral momentum. *Journal of the Experimental Analysis of Behavior,* **57,** 301–316.

Nevin, J. A., Mandell, C., & Atak, J. R. (1983). The analysis of behavioral momentum. *Journal of the Experimental Analysis of Behavior,* **39,** 49–59.

Nevin, J. A., Smith, L. D., & Roberts, J. (1987). Does contingent reinforcement strengthen operant behavior? *Journal of the Experimental Analysis of Behavior,* **48,** 17–33.

Nevin, J. A., Tota, M. E., Torquato, R. D., & Shull, R. L. (1990). Alternative reinforcement increases resistance to change: Pavlovian or operant contingencies? *Journal of the Experimental Analysis of Behavior,* **53,** 359–379.

Pliskoff, S. S., Shull, R. L., & Gollub, L. R. (1968). The relation between response rates and reinforcement rates in a multiple schedule. *Journal of the Experimental Analysis of Behavior,* **11,** 271–284.

Reynolds, G. S. (1961). Behavioral contrast. *Journal of the Experimental Analysis of Behavior,* **4,** 57–71.

Shettleworth, S., & Nevin, J. A. (1965). Relative rate of response and relative magnitude of reinforcement in multiple schedules. *Journal of the Experimental Analysis of Behavior,* **8,** 199–202.

Spealman, R. D., & Gollub, L. R. (1974). Behavioral interactions in multiple variable-interval schedules. *Journal of the Experimental Analysis of Behavior,* **22,** 471–481.

Wetherington, C. L., & Lucas, T. R. (1980). A note on fitting Herrnstein's equation. *Journal of the Experimental Analysis of Behavior,* **34,** 199–206.

Williams, B. A. (1983). Another look at contrast in multiple schedules. *Journal of the Experimental Analysis of Behavior,* **39,** 345–384.

Received May 28, 1991
Final acceptance December 5, 1991

APPENDIX

Responses per minute and reinforcers per hour for each subject in each condition, listed in the order subjects were exposed to them. Repetitions of conditions are indicated by an R next to condition numbers. Different sections give data from different experiments. Response rates were calculated over five sessions by dividing response totals in a component by a time base, and reinforcer rates were calculated by dividing 10-day reinforcer totals by a time base. the time base was time spent in a component minus the time occupied by reinforcement in that component.

Subject	Condition	Responses per minute		Reinforcers per hour		
		Red	Green	Red	Green	Dark
Experiment 1						
C5	1	72.57	89.54	28.62	27.23	0
	2	66.86	90.09	25.85	20.31	30.92
	3	68.08	88.77	25.85	24.00	0
	4	30.62	58.26	27.23	24.00	123.23
C6	1	69.17	91.78	28.62	23.54	0
	2	51.92	77.55	24.92	20.77	27.23
	3	79.68	111.12	28.15	30.92	0
	4	40.98	77.02	28.15	22.62	123.69
C7	3	81.14	73.42	25.85	28.62	0
	4	45.05	48.85	25.85	25.38	124.62
	1	73.62	64.66	27.23	28.62	0
	2	63.78	56.80	24.46	27.23	26.77
C8	3	42.66	55.71	22.15	24.46	0
	4	27.88	40.58	27.69	24.92	123.69
	1	52.92	58.80	28.15	27.69	0
	2	39.20	56.18	25.85	26.77	26.77
Experiment 2						
C5	2	34.69	81.59	25.5	26.5	—
	3	64.72	93.27	53.0	57.3	—
	2	63.22	97.77	24.0	28.1	—
	4	44.80	78.96	15.3	14.6	—
	2	57.86	88.12	26.7	28.1	—
	5	34.58	73.59	6.6	9.3	—
C6	1	43.74	97.52	37.6	41.6	—
	2	32.51	100.84	25.8	28.4	—
	5	23.15	65.51	6.3	6.6	—
	2	29.01	98.50	24.3	25.9	—
	3	32.62	102.34	50.5	60.7	—
	2	32.48	92.53	26.4	27.2	—
	6	36.34	110.84	77.5	80.0	—
C7	2	62.84	66.64	25.8	28.1	—
	4	51.28	58.84	12.9	15.8	—
	2	68.00	72.34	26.4	29.4	—
	5	53.18	51.70	9.8	7.5	—
	2	63.07	67.86	24.6	24.6	—
	3	54.21	68.27	54.2	58.3	—

APPENDIX (*Continued*)

Subject	Condition	Responses per minute		Reinforcers per hour		
		Red	Green	Red	Green	Dark
C8	1	40.15	57.01	38.2	38.6	—
	2	41.35	54.42	27.9	26.2	—
	4	37.13	47.48	15.0	14.0	—
	2	44.45	57.49	27.3	25.6	—
	3	48.03	53.25	60.9	60.7	—
	2	36.72	43.12	26.1	29.4	—
	5	32.07	44.33	8.0	7.5	—
Experiment 3						
C1	1	45.05	86.83	7.75	46.60	—
	3	67.39	85.53	23.15	40.61	—
	2	84.42	65.15	52.94	10.63	—
	4	80.73	69.55	42.70	19.64	—
	5	78.40	102.64	13.74	54.55	—
	7	68.35	86.27	18.25	46.49	—
	6	82.55	77.33	59.00	12.84	—
	8	83.87	75.40	47.81	23.76	—
	5R	59.93	99.93	8.70	54.55	—
	6R	77.99	63.16	58.31	14.04	—
	2R	74.01	42.93	58.41	11.79	—
C2	4	45.56	33.79	43.30	19.93	—
	2	32.65	28.19	53.24	11.79	—
	3	43.37	50.50	21.39	43.30	—
	1	37.33	53.71	11.79	52.94	—
	8	49.22	56.50	46.15	22.22	—
	6	40.49	48.04	61.07	10.17	—
	7	53.44	60.32	24.38	45.82	—
	5	50.00	54.07	9.28	60.03	—
	2R	44.23	55.11	56.58	8.90	—
	1R	42.96	68.09	8.04	51.73	—
C3	5	61.09	76.30	11.95	55.91	—
	7	61.86	68.61	20.38	50.83	—
	6	87.79	64.00	58.65	10.47	—
	8	63.36	50.41	47.48	21.00	—
	1	64.60	70.28	10.63	55.67	—
	3	70.13	76.61	18.47	43.00	—
	2	95.75	71.97	55.67	6.31	—
	4	80.03	78.34	47.51	19.93	—
	1R	59.26	78.51	10.92	54.46	—
C4	8	59.29	50.08	49.82	23.15	—
	6	58.78	31.01	55.57	9.58	—
	7	30.96	52.12	23.45	48.82	—
	5	23.04	53.68	11.35	58.65	—
	4	39.15	35.99	43.60	19.35	—
	2	50.46	27.91	56.28	10.06	—
	3	28.79	46.80	20.52	42.40	—
	1	17.77	47.50	7.75	54.46	—
	2R	45.90	35.06	54.76	9.19	—
	4R	49.02	34.66	46.60	20.22	—