

## THE ANALYSIS OF BEHAVIORAL MOMENTUM

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Learned behavior varies in its resistance to change, depending on the rate of reinforcement. Resistance to change may be characterized as behavioral momentum, which in turn may be analyzed into terms corresponding to mass and velocity in classical physics. Behavioral mass may be inferred from changes in response rate when experimental conditions are altered. Relevant data were obtained by training pigeons to peck a key on two-component multiple variable-interval, variable-interval schedules. Six pigeons were studied on three pairs of variable-interval schedules in all possible orders. When performance stabilized, resistance to change was assessed by arranging response-independent food during periods between components and by extinction. For each operation, the data for all schedule performances converged onto a single function, permitting estimation of the ratio of behavioral masses for each pair of schedules. The response-independent food data suggested that the ratio of behavioral masses is a power function of the ratio of reinforcement rates and that behavioral mass may be measured on a ratio scale.

*Key words:* variable-interval schedules, multiple schedules, reinforcement rate, alternative reinforcement, extinction, behavioral momentum, key peck, pigeons

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Lex I. Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, nisi quatenus a viribus impressis cogitur statum illum mutare. (Newton, 1686)

All observed changes in the state of motion of bodies are due to discoverable external action.

(Holman, 1898, p. 19)

Holman's simple statement not only captures the essence of Newton's first law of motion but also suggests a paraphrase that captures the spirit of the experimental analysis of behavior: All observed changes in behavior are due to discoverable external variables. In this spirit, we propose to apply the most basic principles of classical mechanics as embodied in Newton's laws of motion to the study of changes in discriminated operant behavior.

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It is now well established that learned behavior varies in its resistance to change and that resistance to change depends lawfully on the rate of reinforcement across a wide variety of procedures. For example, when a response is reinforced frequently in one component of a multiple schedule and infrequently in the other, response rate in the first component is less sharply reduced by arranging alternative reinforcement, by presenting a stimulus correlated with inescapable shock, or by discontinuing reinforcement altogether. Moreover, these ordinal differences in resistance to change are preserved when response rates in the two components are equated through the use of DRL, DRH, or pacing schedules (for review and discussion, see Nevin, 1974b, 1979).

The persistence of behavior in the face of altered conditions suggests that it may be profitable to consider learned behavior as possessing momentum. Moreover, the differential persistence of behavior in the presence of stimuli correlated with different rates of reinforcement suggests that behavioral momentum must depend on a stimulus-specific history of reinforcement.

In classical physics, momentum is defined as the product of mass and velocity. A heavy body and a light body moving at the same

velocity differ in momentum. This difference is evident when an external force opposes motion, and it is observed that the velocity of the heavier body changes less than that of the lighter body. By analogy, when responding occurs at the same rate in two different schedule components, but one is less affected by an external variable than is the other, we suggest that the performance exhibiting greater resistance to change be construed as having greater mass. This article is concerned with the assessment of behavioral mass and its relation to rate of reinforcement.

In physics, the change of velocity of a body is proportional to the impressed force:

$$F = m \cdot \Delta v \quad \text{or} \quad \Delta v = F/m, \quad (1)$$

where  $F$  stands for force,  $m$  for mass, and  $v$  for velocity. However, it is unlikely that simple proportionality of this sort will hold generally in the study of behavior. Although a number of variables that have monotonic effects on behavior could be rescaled post hoc to yield direct proportionality, others that have non-monotonic effects cannot be thus rescaled. Pharmacological agents often have nonmonotonic effects on response rate (e.g., Waller & Morse, 1963), and so may extinction after intermittent reinforcement (e.g., Nevin, 1974b, Fig. 4). Accordingly, our treatment of behavioral momentum will use the more general form,

$$\Delta v = f\left(\frac{x}{m}\right), \quad (2)$$

where  $x$  designates the value of a particular external variable, and the function  $f$  is to be discovered for each class of external variable. The parameter  $m$  characterizes the mass-like component of behavioral momentum. For a given value of  $x$ , a large value of  $m$  implies a small change in behavior and vice versa. The parameter  $m$  thus captures that aspect of behavior that we have previously called "response strength" (Nevin, 1974b, 1979; Nevin, Mandell, & Yarensky, 1981).

To bring Equation 2 to bear on behavior, we need suitable measurement scales. For the analog to velocity, we will employ the logarithm of response rate. The logarithmic transformation has the property of rendering equal ratios as equal differences. Thus, if the response rate falls from 100 responses per min to 50 responses per min when a given variable

is applied, and then to 25 per min when the value of that variable is doubled, the successive changes in the log response rate are the same. In the following analyses, we will determine how log response rate changes relative to its baseline value when an external variable is applied. Letting  $B_o$  represent baseline response rate and  $B_x$  represent response rate when the external variable is applied at some value  $x$ , the change in log response rate is  $(\log B_x - \log B_o)$  or simply  $\log\left(\frac{B_x}{B_o}\right)$ . Thus, our analog of the change in velocity ( $\Delta v$  in Equation 2) is the logarithm of the proportion of baseline rate.

Because  $\log\left(\frac{B_x}{B_o}\right)$  is dimensionless, the ratio  $\frac{x}{m}$  in Equation 2 must also be dimensionless, implying that behavioral mass must have the same dimensions as the external variable  $x$ . Since there are many such variables, each with different dimensions (e.g., alternative reinforcers per hour, milliamps of signaled shock, milligrams of a drug per kilogram of body weight, or sessions of extinction), there cannot be an absolute scale for the measurement of behavioral mass. It is, however, possible to measure the mass of one performance relative to that of another when the same external variable is applied to both. For example, if two discriminated operant performances are maintained on a two-component multiple schedule of reinforcement, we can write (in the form of Equation 2)

$$\log\left(\frac{B_{x_1}}{B_{o_1}}\right) = f\left(\frac{x}{m_1}\right) \quad (3a)$$

and

$$\log\left(\frac{B_{x_2}}{B_{o_2}}\right) = f\left(\frac{x}{m_2}\right), \quad (3b)$$

where the numerical subscripts designate the schedule components. If, during a series of test sessions, we ascertain a pair of values of the external variable,  $x_1$  and  $x_2$ , that produce equal changes in log proportion of baseline in Components 1 and 2 respectively, we can write

$$f\left(\frac{x_1}{m_1}\right) = f\left(\frac{x_2}{m_2}\right).$$

If the function  $f$  is the same for both component performances, then

$$\frac{x_1}{m_1} = \frac{x_2}{m_2} \text{ or } \frac{x_1}{x_2} = \frac{m_1}{m_2}. \quad (4)$$

That is, the ratio of values of the external variable giving equal changes in the two discriminated operant performances, relative to their baselines, is equal to the ratio of their behavioral masses.

If the mass ratio is invariant with respect to the external variable  $x$ , as it should surely be if behavioral momentum is entirely determined by baseline reinforcement conditions, we can write

$$\log x_1 - \log x_2 = \log c = \log \left( \frac{m_1}{m_2} \right). \quad (5)$$

That is, the values of  $\log x_1$  and  $\log x_2$  must differ by a constant,  $\log c$ , for all values of  $\log x_1$  and  $\log x_2$  that yield equal changes in response rate relative to baseline for the two operants. The antilog of this constant,  $c$ , equals the ratio of their behavioral masses.

If the assumptions of a common function  $f$  and an invariant mass ratio  $\frac{m_1}{m_2}$  both hold, then it should be possible to superimpose the function relating  $\log \left( \frac{B_{x1}}{B_{o1}} \right)$  to  $\log x$  onto that relating  $\log \left( \frac{B_{x2}}{B_{o2}} \right)$  to  $\log x$  by adding a constant,  $\log c$ , on the scale of  $\log x$  to all points of one of the functions. These aspects of our approach are illustrated in Figure 1. Panel A presents hypothetical data showing arbitrary nonmonotonic relations between proportion of baseline response rate and an external variable for two performances,  $B_1$  and  $B_2$ , having behavioral masses  $m_1$  and  $m_2$  respectively, on linear coordinates. The relations were constructed by assuming that  $m_1 = 2m_2$ . When both coordinates are logarithmic as in Panel B, it becomes clear that shifting the function for  $B_2$  by an additive constant,  $\log c$ , will superimpose it on the function for  $B_1$ . The value of  $\log c$  in this case is  $.3$ . Antilogging,  $c = 2$ , which is the value of the mass ratio used to construct the hypothetical data. Thus, if any two such functions may be superimposed by horizontal shifting on a logarithmic x-axis, the extent of the shift gives a direct measure of the ratio of behavioral masses.

This paper addresses the following inter-related questions: (1) For multiple-schedule

performances maintained by different rates of reinforcement, do the functions relating log relative changes in response rate to the log rate of alternative reinforcement differ only by an additive constant? (2) Similarly, do the functions relating log relative changes in response rate to log number of extinction sessions differ only by an additive constant? (3) If so, do the additive constants (representing mass ratios) stand in an orderly relation to baseline reinforcement conditions within each assessment procedure? And finally, (4) Are

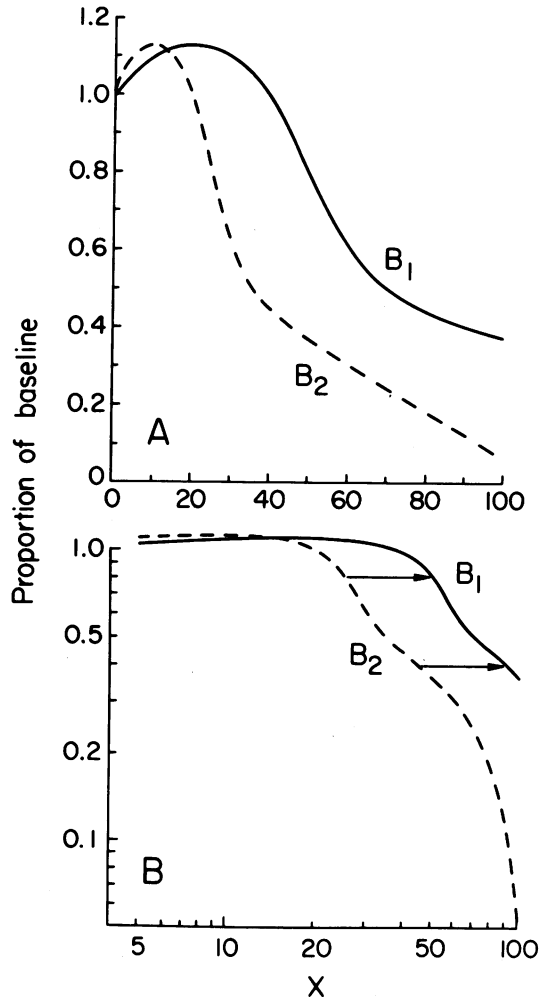


Fig. 1. Panel A: Hypothetical data showing the effects of an external variable  $x$  on proportions of baseline response rates  $B_1$  and  $B_2$  in two components of a multiple schedule. Panel B: Proportions of baseline as functions of  $x$  on logarithmic axes. Note that the function for  $B_2$  can be superimposed on that for  $B_1$  by shifting it to the right by a constant,  $\log c$ .

the mass ratios invariant across assessment procedures?

In the experiment reported here, pigeons were trained on two-component multiple schedules and were exposed successively to all three combinations of three different reinforcement rates taken two at a time. Different birds were exposed to these three pairs in each of the six possible orders. After asymptotic performance was established with each pair, resistance to change was assessed by presenting response-independent reinforcers during periods between components and by extinction. Summary data were presented by Nevin (1979; see Figure 4.1). Here, we report complete data, evaluate their convergence onto a single function characteristic of each assessment method, and inquire into the relation between the mass ratio and the ratio of reinforcement rates maintaining baseline performance.

## METHOD

### *Subjects*

Six experimentally naive White Carneaux pigeons were reduced to 80% of their free-feeding weights and maintained at that level,  $\pm 15$  g, for the duration of the experiment.

### *Apparatus*

A three-key Lehigh Valley pigeon chamber was equipped with red and green keylights, a houselight above the center key, and a grain feeder below the center key. Reinforcement consisted of 4-sec access to mixed grain. The side keys were never illuminated, and pecking was measured only on the lighted center key. A blower provided masking noise. The experiment was controlled by electromechanical equipment in an adjacent room.

### *Procedure*

All subjects were hand shaped to peck the center key in the presence of alternating red and green keylights. After the key peck was established, several sessions of fixed-ratio reinforcement were arranged to establish high rates of pecking. The experiment proper began after all birds were pecking rapidly and reliably in the presence of both red and green.

The basic multiple-schedule procedure involved 1-min periods with the key lighted red or green, and with different independent variable-interval (VI) schedules in effect while the

key was lighted, depending on its color. Red and green components alternated irregularly and were separated by 30-sec periods with the key dark. Reinforcers set up during a component but not obtained were canceled. Response rates were computed for each session separately for red and green components, corrected for duration of food access. Sessions always began with a 30-sec dark-key period and ended after the 30th component. The houselight was on throughout the session.

Reinforcers were scheduled by variable-interval tapes based on the Fleshler-Hoffman (1962) progression with average interreinforcer intervals of 28 sec, 86 sec, and 360 sec, resulting in approximately 129, 42, and 10 reinforcers per hr, respectively. In each condition of the experiment, one VI schedule was correlated with the red key and another with the green key. The schedule with the shorter interreinforcer interval was always correlated with the red. Within each condition, the subjects received 40 sessions of baseline training. Then, response-independent food was presented during dark-key periods intervening between schedule components according to variable-time (VT) schedules delivering 60, 120, 180, or 300 reinforcers per hr of dark-key time. Each dark-key VT schedule remained in effect for six sessions, and six sessions of baseline training followed each dark-key VT schedule. Finally, seven consecutive sessions of extinction were conducted. Both dark-key food presentation and extinction have previously been shown to produce consistent ordinal differences in the changes in response rate relative to baseline (Nevin, 1974b).

Following the completion of each condition, a new pair of VI schedules was arranged so that each subject experienced all three possible pairs of VI schedules, in all possible orders across subjects. The sequence of exposure to the schedules is given in Table 1.

## RESULTS

Baseline response rates are shown in Figure 2 for each subject as a function of the rate of reinforcement arranged in each schedule component. The data are averages for 15 sessions: the final three sessions preceding each of the four dark-key food assessments and preceding extinction. Only Bird 26 exhibited a consistent positive relation between the rate of re-

Table 1

Order of conditions for individual subjects. Schedules correlated with each key color are given in reinforcers per hr.

Bird	Schedules and Order of Conditions		
	Red-129 Green-42	Red-42 Green-10	Red-129 Green-10
4	1	2	3
26	3	2	1
27	3	1	2
29	1	3	2
30	2	3	1
31	2	1	3

sponding and the rate of reinforcement in a schedule component. Bird 26 also showed some evidence of behavioral contrast; for example, response rate maintained by 42 reinforcers per hr was greater when the alternated component arranged 10 reinforcers per hr than when it arranged 129 reinforcers per hr. The 30-sec dark-key periods intervening between schedule components may have served to attenuate the expected differences in response rate and contrast effects for the other birds.

The effects of dark-key food presentation are shown in Figure 3. The data were taken from the first session with each dark-key food schedule because continued exposure often reduced

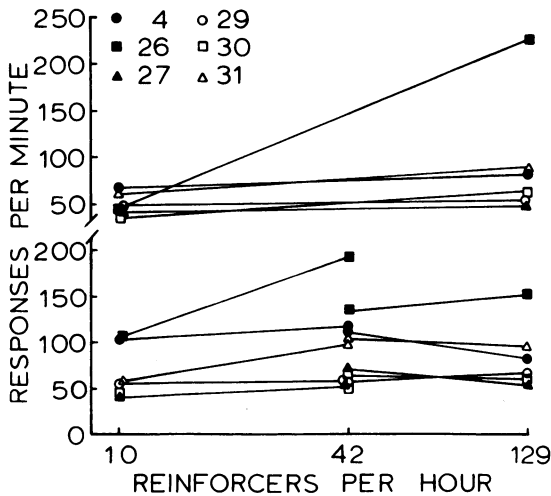


Fig. 2. Baseline response rates in two-component multiple schedules as functions of reinforcement rate in each component. The upper set of lines shows the data for 129 and 10 reinforcers per hr. The lower sets of lines show the data for 129 and 42 reinforcers per hr at the right, and for 42 and 10 reinforcers per hr on the left. Note the break in the y-axis corresponding to the upper and lower data sets.

response rates to an extent that substantially altered the obtained rates of reinforcement. The data are presented as proportions of baseline on a logarithmic scale as a function of dark-key food rate on a logarithmic scale, the

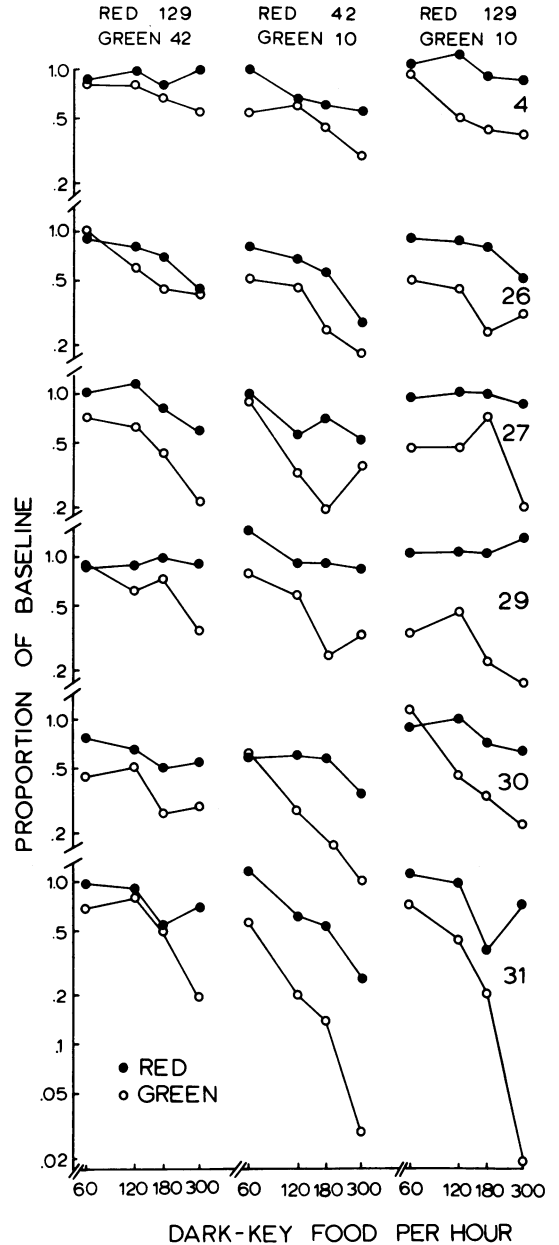


Fig. 3. Proportion of baseline response rate as a function of the rate of food presentation during dark-key periods between multiple-schedule components. Logarithmic scales are employed on both axes. The data are separated according to the reinforcement rates arranged in each schedule component, as indicated at the top of the figure.

form in which assessments of behavioral mass will be made. Overall, the proportion of baseline decreased monotonically with increasing dark-key food rate, with several exceptions. The reductions relative to baseline were greater in the green-key component than in the red-key component at each dark-key food

rate, again with a few exceptions. As the ratio of red-key to green-key reinforcement rates increased, the separation between functions generally increased as well.

The effects of extinction are shown in Figure 4. As in Figure 3, the data are presented as proportions of baseline on a logarithmic

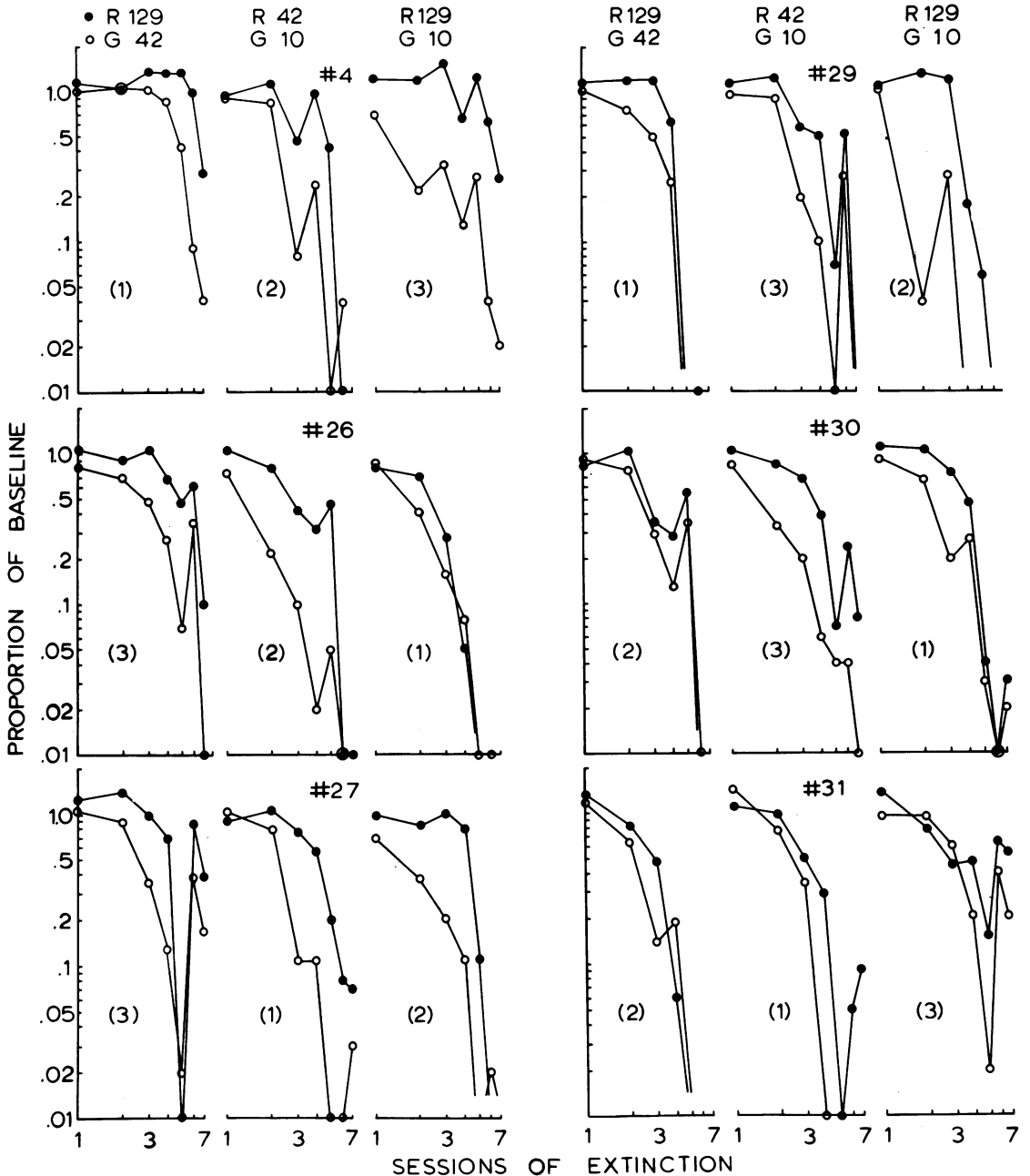


Fig. 4. Proportion of baseline response rate during successive sessions of extinction, presented in the same format as Figure 3. Data points are not plotted for proportions of baseline less than .01.

scale as a function of extinction sessions on a logarithmic scale. There is no consistent evidence of differences in extinction responding as a function of order of exposure to the various conditions; that is, repeated extinction had no consistent effects in this situation, perhaps because of the extensive training that intervened between successive extinction periods. Many subjects exhibited rate increases in the initial sessions of extinction, followed by rapid decreases. The increases tended to be confined to the red-key component, which always had the higher rate of reinforcement. With few exceptions, the data points for the red-key component are above those for the green-key component, indicating relatively more rapid extinction in the component previously correlated with less frequent reinforcement. However, there is no consistent evidence of differences in the separation of the extinction functions in relation to the ratio of reinforcement rates in baseline.

Because all subjects exhibited similar trends in the effects of dark-key food and extinction, and because intersubject differences seemed not to be systematic, we averaged the proportions of baseline across subjects before attempting to assess behavioral mass. Average proportions of baseline were plotted on logarithmic scales as functions of dark-key food rate or extinction sessions on logarithmic scales, using separate pieces of translucent graph paper for each key color in each condition. These graphs were then placed on a light table and adjusted horizontally to achieve the best possible convergence onto a single overall function as judged by eye, by all three authors. The outcomes of this procedure are shown in Figure 5. The upper panel shows the results for dark-key food, and the lower panel shows those for extinction. The smooth curves were drawn in by eye to indicate the overall trends. Clearly, it was possible to achieve convergence onto a single function for each of our assessment operations. It should be noted that conformity to each function was independent of baseline reinforcement rate for a given schedule component and also independent of the reinforcement rate in the alternated component.

We then measured the extent of positive lateral adjustment that was necessary to achieve the superimpositions shown in Figure 5 (as

shown in the hypothetical example of Figure 1). These lateral adjustments represent  $\log c$ , or the log of the ratio of behavioral masses, as described above in connection with Equation 5. The values of  $c$  (mass ratios) determined within pairs of VI schedules for dark-key food and extinction are given in Table 2. The mass ratios determined with dark-key food increase in an orderly way with the ratio of baseline

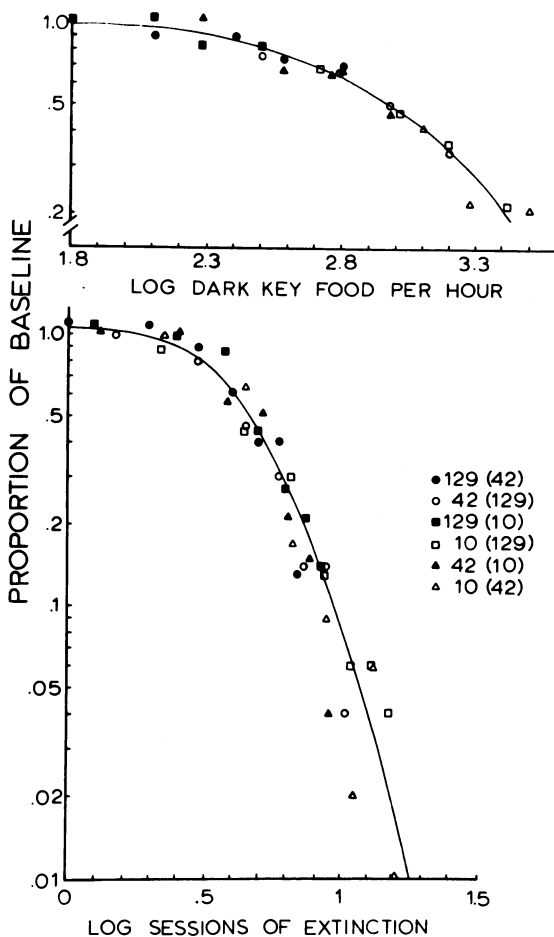


Fig. 5. The upper panel presents average proportions of baseline as a function of dark-key food rate, adjusted horizontally to provide the best possible convergence, by inspection, onto a single summary function. The lower panel presents average proportions of baseline during successive extinction sessions, similarly adjusted. The data are coded for the reinforcement rate in the relevant schedule component, with the reinforcement rate in the alternated component indicated in parentheses. The x-axis scale ranges from the logarithm of the smallest value of dark-key food rate or extinction sessions extended as necessary to incorporate the largest value plus the additive values of  $\log c$ .

Table 2

Values of  $c$ , the ratio of behavioral masses, for three pairs of VI schedules (given as reinforcers per hr) as assessed by dark-key food or extinction.

Schedules		Reinforcement rate ratio	$c$	
Red	Green	Red/Green	Dark-key food	Extinction
129	42	3.1	2.5	1.5
42	10	4.2	3.3	1.7
129	10	12.9	8.3	1.8

reinforcement rates, as expected if behavioral mass is positively related to reinforcement rate. The mass ratios determined with extinction are all above 1.0, indicating that the performance more frequently reinforced in baseline had greater mass, but there is little effect of the reinforcement rate ratio. Consideration of the individual data suggests that the weak relation to reinforcement rate ratio shown in Table 2 is not reliable.

It is obvious that mass ratios did not remain invariant across the two assessment procedures as might be expected if behavioral mass were truly independent of the assessment method. However, the mass ratios for dark-key food are internally consistent. The obtained values of  $c$  (mass ratios) satisfy the simple algebraic relation,

$$\frac{m_{129}}{m_{10}} = \frac{m_{129}}{m_{42}} \times \frac{m_{42}}{m_{10}}, \quad (6)$$

where the subscripts indicate the reinforcement rates in each determination (i.e.,  $8.3 \approx 2.5 \times 3.3$ ). The internal consistency in these ratios suggests that behavioral mass can be measured on a ratio scale.

The relations between mass ratios and reinforcement rate ratios are shown in Figure 6. For dark-key food, the results approximate a power function with an exponent of about .7, whereas the function for extinction is much less steep and may be nonlinear.

## DISCUSSION

We have suggested that maintained behavior can be analyzed into components that are formally analogous to mass and velocity as these terms are used in classical physics. Behavioral mass is identified with the tendency for responding to persist when conditions are

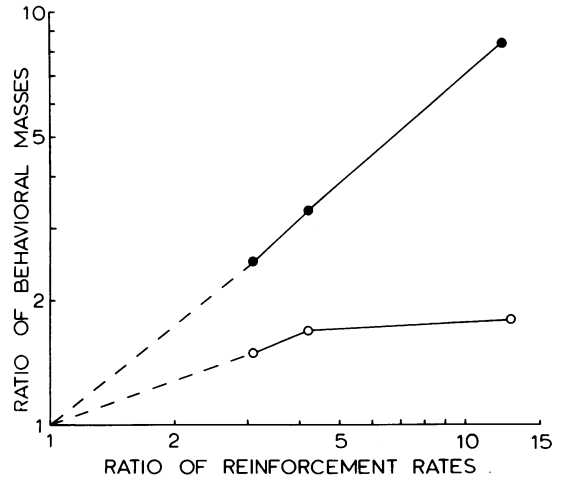


Fig. 6. The ratio of behavioral masses, derived from the data of Figure 5, as a function of the ratio of reinforcement rates in baseline, shown separately for dark-key food and extinction.

altered, and behavioral velocity is identified with the ongoing response rate. Within this formal analogy, we expressed changes in response rate as the logarithm of proportion of baseline and found that three independently determined pairs of functions relating log proportion of baseline to log dark-key food rate and log sessions of extinction converged onto a single function characteristic of each operation. Parameters identified with the behavioral masses of each operant were evaluated by the extent of lateral shifting required for convergence. When dark-key food rate was varied, the mass ratios were internally consistent for the set of schedule values we employed, and a power function characterized the relation between mass ratios and reinforcement rate ratios. Mass ratios determined during extinction were smaller and not clearly related to reinforcement rate ratios.

Why did mass ratios and their relation to reinforcement differ across the two assessment procedures? The answer depends in part on how we think about reinforcement and extinction by analogy to classical physics. If reinforcement is construed as establishing and maintaining a given value of behavioral mass, then extinction must be construed as reducing mass. When behavioral mass was assessed by introducing dark-key food, the baseline schedules remained in effect; therefore, mass should be unaltered. When behavioral mass was as-



essed by extinction, however, the assessment method itself altered the quantity being measured, and interpretation becomes more complex.

The data in the lower panel of Figure 5 suggest that although the mass of each performance may have changed during extinction, the mass ratios were preserved, so we must look elsewhere for the failure to obtain agreement with the mass ratios determined with dark-key food. Our approach requires that extinction, like dark-key food presentation, be construed as a unitary operation applied equally to both component performances. However, that supposition may be incorrect. For example, extinction of a frequently reinforced performance may be more discriminable, and hence by analogy a greater external force, than extinction of an infrequently reinforced performance. (Note that this is a restatement of the discrimination hypothesis of extinction; cf. Mackintosh, 1974). Differential action of a presumed unitary external variable like extinction would confound the measurement of behavioral mass. Stated otherwise, extinction may be an undesirable assessment procedure when ratio rather than ordinal measurement is desired.

Nevin, Mandell, and Yarensky (1981) have recently presented data suggesting that the ratio of resistances to change in two chained schedules is a power function of the ratio of food access rates in the terminal links of those schedules. Resistance to change was assessed by alternative reinforcement and by prefeeding while baseline schedules remained in effect. Although the data analysis was quite different in that paper, the results are consistent with the dark-key food results reported here.

We have not discussed the forms of the functions that relate log proportion of baseline to dark-key food or extinction (i.e., Equations 3). Figure 7 presents the smooth curves of Figure 5 in the semilogarithmic form of Equations 3:

$$\log \left( \frac{B_{xi}}{B_{oi}} \right) = f \left( \frac{x}{m_i} \right), \quad (7)$$

where the subscript *i* designates the *i*th operand. Neither function is linear over its full range, so the simple proportionality between change of velocity, force, and mass of classical physics (Equation 1) does not in general hold

for behavior. These functions could be characterized by polynomials, but in the absence of behaviorally meaningful characterization of their parameters, such functions would not advance understanding.

There is at least one class of functions that leads to an outcome of behavioral and theoretical interest, namely power functions:

$$\log \left( \frac{B_{x1}}{B_{o1}} \right) = \left( \frac{x}{m_1} \right)^p \quad (8a)$$

and

$$\log \left( \frac{B_{x2}}{B_{o2}} \right) = \left( \frac{x}{m_2} \right)^p, \quad (8b)$$

where *p* represents an unknown exponent. Then dividing 8a by 8b we obtain

$$\log \left( \frac{B_{x1}}{B_{o1}} \right) = \left( \frac{m_2}{m_1} \right)^p \log \left( \frac{B_{x2}}{B_{o2}} \right). \quad (9)$$

Assuming that the baseline rates are stable and recoverable so that they can be treated as constants, a little more algebra leads to

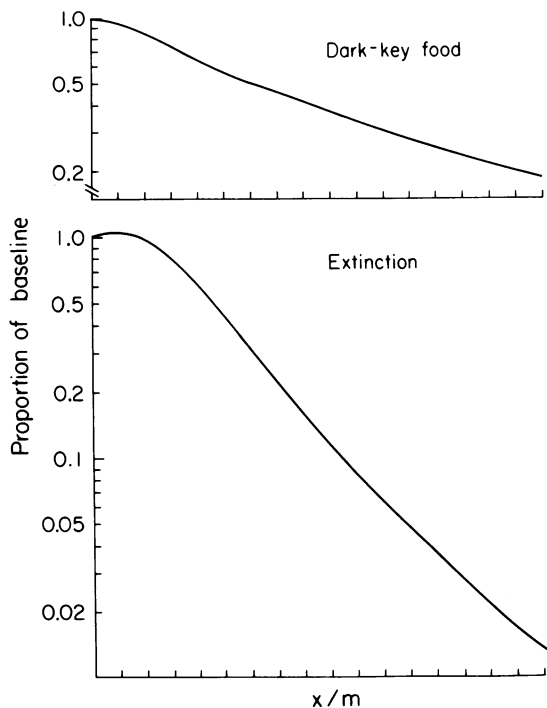


Fig. 7. The smooth functions of Figure 5, replotted on linear x-axes as functions of  $\frac{x}{m}$ , where *x* is dark-key food rate (upper panel) or sessions of extinction (lower panel).

$$B_{x1} = qB_{x2}^{(m2/m1)^p}, \quad (10)$$

where  $q = B_{o1} \cdot B_{o2}^{-(m2/m1)^2}$ . Thus, if Equation 7 is a power function, then Equation 10 should hold. That is, response rate in one schedule component should be a power function of response rate in the other component, where the exponent is the ratio of behavioral masses raised to an unknown power. Nevin (1974a) found that Equation 10 approximated the relation between response rates on multiple VI VI schedules when a concurrent fixed-interval schedule was arranged, and showed that the exponent depended on reinforcement rate ratios. Nevin (1974b, Figure 12) reported other instances of power relations between response rates and suggested that the exponent characterized the relative resistance to change of multiple-schedule performances. If the function form in Equation 7 is not itself a power function, however, the power function of Equation 10 will not hold for every case. Even if Equation 10 does hold, the value of the mass ratios remains unknown because of ignorance of the value of  $p$ . Our method for estimating mass ratios by lateral adjustment of the data is therefore more generally applicable and free from this sort of ambiguity.

Staddon (1978) derived the power function of Equation 10 from a simple model which assumed that the change in response rate relative to baseline was proportional to changes in competing behavior. His constant of proportionality plays the same role as the parameter  $m$  in Equation 7. Staddon's equations are equivalent, in our notation, to

$$\log \left( \frac{B_{x1}}{B_{o1}} \right) = \frac{1}{m_1} f(x) \quad (11a)$$

and

$$\log \left( \frac{B_{x2}}{B_{o2}} \right) = \frac{1}{m_2} f(x), \quad (11b)$$

which, when divided, lead to our Equation 9, with  $p = 1$ . In mathematical terms, Staddon's formulation and ours differ in that he expressed behavior change as a proportion of an unknown function, while we express behavior change as an unknown function of a proportion. His formulation implies that response rates must be related by a power function, whereas in our formulation the power function is a special case. More importantly,

though, his proportionality constants representing the relative sensitivity or elasticity of behavior capture exactly the same dimension of action as our notion of behavioral momentum: the relative tendency for behavior to persist when challenged by competing behavior or external variables.

The separation of behavioral momentum into its mass-like and velocity-like components will be of special value if these components depend on different aspects of the reinforcement process. It is evident that response rate depends on the reinforcement contingencies: Ratio contingencies reliably generate higher rates than do interval contingencies, for example, and precise control of response rate may be achieved through the use of DRL, DRH, or pacing contingencies. Behavioral mass, by contrast, appears to depend primarily on the rate of reinforcement correlated with particular environmental stimuli (see also Fath, Fields, Malott, & Grossett, in press, and Nevin, Note 1). It remains to be determined whether these factors suffice to give a complete account of discriminated operant behavior.

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