RESPONSE-INDEPENDENT FOOD DELIVERY AND BEHAVIORAL RESISTANCE TO CHANGE

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Response-independent food was delivered during a dark-key phase between two multiple-schedule components to explore its disruptive effects on responding. Responding in components was maintained by separate variable-interval 120-s schedules, with a 2-s reinforcer in Component 1 and a 6-s reinforcer in Component 2. Across conditions the rate and duration of response-independent food presentations were manipulated. The results showed that response rates in both components decreased as a function of the duration and the rate of response-independent food presentations; moreover, the decrease in response rate relative to the baseline level was larger in Component 1 than in Component 2. These findings were consistent with expectations from behavioral momentum theory, which predicts that if equal disruption (response-independent food in this case) is applied to responding in two components, then the ratio of response-rate change in Component 1 versus Component 2 should remain constant, irrespective of the magnitude of that disruption.

Key words: behavioral momentum, resistance to change, multiple schedules, pigeons

Behavioral momentum theory identifies two independent aspects of free-operant behavior: its overall rate of occurrence and its resistance to change in response to some disruption or change in the environment (Nevin, 1984, 1992; Nevin, Mandell, & Atak, 1983). Nevin (1992) argued that response rate and resistance to change are independent in that response rate depends on response–reinforcer contingencies whereas resistance to change depends on stimulus–reinforcer contingencies. Therefore, for example, the behavioral resistance associated with pecking a key that is lit with a red light is primarily a function of reinforcer occurrence during the presence of the red key stimulus, regardless of whether reinforcers are delivered contingent upon (Nevin et al., 1983) or irrespective of (Nevin, Tota, Torquato, & Shull, 1990) key pecking. Much of the previous research in this area has examined the resistance to change established by different rates of reinforcement assessed through the effects of short-term changes in the existing reinforcement context. The present study examined the resistance to change of steady-

state performance in multiple schedules in which the components differed in terms of the size of the reinforcers delivered contingent on key pecking by pigeons.

When assessing resistance to change, some form of disruption or alteration in the reinforcement context is typically used as a means to assess the resistance displayed by responding made in the presence of one discriminative stimulus relative to the resistance displayed by responding in the presence of an alternative stimulus. The most common ways of disrupting ongoing behavior have been to change deprivation levels by prefeeding subjects, to change the maintaining reinforcement schedules to extinction, and to present response-independent food in an alternated multiple-schedule component. For example, Nevin (1974) showed that the greater the duration of reinforcement or the shorter the delay to reinforcement in a multiple-schedule component, the less response rates decreased relative to their baseline levels following introduction of a probe session of response-independent variable-time (VT) food in a third component. That is, responding in the component that was correlated with the highest rate, longest duration, or shortest delay of reinforcement was most resistant to the disruptive effects of VT food. Similar results have been obtained when resistance has been assessed immediately after reducing the maintaining reinforcement schedules to extinction or by disrupting responding via

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prefeeding immediately prior to a test session (Fath, Fields, Malott, & Grossett, 1983; Nevin, 1974, 1992; Nevin, Mandell, & Yarensky, 1981). Thus, a general finding has been that across studies that have used a variety of techniques for assessing resistance to change, the greater the rate, the larger the amount, or the shorter the delay of reinforcement correlated with a discriminative stimulus, the greater the resistance to change of responding exhibited in the presence of that stimulus.

In an attempt to account for the resistance-to-change findings, Nevin et al. (1983) developed behavioral momentum theory. Drawing an analogy with the measurement of momentum in the physical sciences, Nevin et al. proposed the following equation:

$$m = x/\Delta B, \quad (1)$$

in which m is the mass of a response, x is the force applied to disrupt steady-state performance, and ΔB is the resulting change in response rate. The change in response rate can be measured by expressing the response rate following application of the disruptive force (e.g., response-independent food in an alternative component) as a proportion of the response rate in baseline (no disruption). It is often useful to consider the logarithm of this proportional change in response rate, that is, $\Delta B = \log(Bx/B_0)$. It is not possible to express the absolute value of behavioral mass, however, because under this formulation behavioral mass must have the same dimensions as the variable x (see Nevin et al., 1983). This problem is overcome by measuring the resistance to change (and hence mass) of one response relative to that of another when the same disrupter is applied to both. For example, if key pecking in two multiple-schedule components is disrupted simultaneously by, say, the delivery of response-independent food in a third component, then Equation 1 becomes

$$\frac{m_1}{m_2} = \frac{x/\Delta B_1}{x/\Delta B_2}, \quad (2)$$

where the numbers designate the two schedule components. Given that behavioral momentum theory states that resistance to change (and hence mass) is the result of steady-state (or baseline) stimulus-reinforcer contingencies, then Equation 2 can be elab-

orated to include the ratio of reinforcement rates:

$$\frac{m_1}{m_2} = \left(\frac{R_1}{R_2} \right)^a = \frac{x/\Delta B_1}{x/\Delta B_2}. \quad (3)$$

In Equation 3 the response-rate ratio is related to the reinforcer rate ratio (R_1/R_2) raised to a power value (a) to characterize the sensitivity of the response rate ratio to the reinforcer rate. Finally, if the disruptive force (x) is applied equally to behavior in the two target components, then the obtained value of $(x/\Delta B_1)/(x/\Delta B_2)$ should remain constant, irrespective of the type or size of force applied. Thus, with equal values of x present during each component, Equation 3 can be reduced to

$$\frac{m_1}{m_2} = \left(\frac{R_1}{R_2} \right)^a = \frac{\Delta B_2}{\Delta B_1}. \quad (4)$$

(See Nevin, 1992, for a more complete description of this model.)

Apart from accounting for much of the resistance-to-change data, several critical assumptions made by behavioral momentum theory have also been supported by subsequent findings. For example, the resistance ratio ($\Delta B_2/\Delta B_1$) appears to remain constant when the same disrupter is applied to both target components. In a reanalysis of the data from a number of experiments that differed in their methods, Nevin (1992) demonstrated that the relationship between the resistance ratio and the reinforcer ratio is well described by a power function with an exponent of about 0.35. Also, comparisons between conditions within a single experiment have suggested that unequal application of a disrupter may result in nonconstant resistance ratios being obtained. For example, Nevin et al. (1983) varied the reinforcer ratio obtained for responding in two multiple-schedule components. Then on occasional probe sessions, they delivered response-independent food in the same manner as Nevin (1974) and found that the resistance ratio in the two target schedules was a function of the reinforcer-rate ratio raised to the power of 0.7 across the different reinforcer-rate ratios. The resistance ratios were much less extreme, however, when the disrupter was extinction than when it was response-independent delivery of food (Nevin et al., 1983). Possible reasons for this

difference may have been that (a) reducing reinforcement schedules to extinction not only disrupts ongoing responding but also removes the conditions that produced the resistance differential between responding in the different components, and (b) when a resistance differential is established via a difference in reinforcer rate across components, then reduction of the reinforcer rates to zero may be considered to be a greater application of the disrupter to the response previously maintained by the higher rate of reinforcement than to the response previously maintained by the lower rate of reinforcement (e.g., the reduction in the reinforcer rate from variable-interval [VI] 30 s to extinction is greater than a reduction from VI 120 s to extinction). Thus, previous findings support the conclusion that baseline reinforcer conditions determine the resistance to change associated with responding in the presence of a discriminative stimulus. But such support has been demonstrated clearly only when a disruptive force has been applied equally to the target responses and when the reinforcement conditions establishing resistance remained constant.

Most of the evidence for behavioral momentum theory comes from the use of procedures in which a disrupter is present for a relatively short period of time (e.g., probe-session delivery of response-independent food). Steady-state behavioral data from Harper and McLean (1992) have yielded only mixed support for behavioral momentum theory. Harper and McLean assessed whether the difference in the relative change of two responses would persist once response rates had stabilized at their new levels. In their first experiment they established a resistance differential by maintaining behavior in two components of a multiple schedule with reinforcers of 2 or 6 s. They found that presenting response-independent food during a dark-key third component produced a larger proportional decrease in response rate in the component with the 2-s reinforcer than in the component with the 6-s reinforcer, even after a number of sessions of response-independent food delivery (i.e., at least 15 sessions). Thus, when disruption was applied externally to the target components (via the third component), the differential resistance to change established across the two target components

could still be observed in steady-state performance. In their second and third experiments, however, Harper and McLean found that when disruption was applied within components (i.e., by changing the maintaining reinforcer rates), there was no difference in the resistance to change shown by responding across the two components. So, despite Harper and McLean's finding in Experiment 1 that a resistance differential could be established across components using reinforcer durations, Experiments 2 and 3 showed that this differential was not evident when response rates were altered via a change to the maintaining reinforcer rates.

It may be that the mixed results of Harper and McLean (1992) were the result of confounding factors similar to those identified above with respect to disrupting performance by reducing reinforcer rates to extinction. That is, the changes in the rates of reinforcement may have functioned as unequal application of the disrupting influence across the two components which, in turn, may have caused problems for the accurate assessment of resistance in Harper and McLean's Experiments 2 and 3. Perhaps the disruption exerted by changing the reinforcer rate within components was actually a function of the reinforcer-rate change *in combination* with the reinforcer duration used in that component so that a comparatively large disruption was applied to responding in the 6-s component but a relatively smaller disruption was applied to responding in the 2-s component. Thus, as was suggested to be the case when disruption is applied using extinction, a change in the maintaining reinforcer rate may have combined with those aspects of the reinforcement context that established a resistance differential across the two components (in this case, reinforcer duration). The result of this possible confounding of the conditions establishing behavioral resistance and the disruptive force used to assess that resistance could have been that the observed behavior change was similar across the two target components.

The possibility that some procedures may confound the conditions establishing behavioral resistance with the methods used to assess that resistance indicates that we need to examine further the conditions that establish resistance and the methods used to measure it. Although a reasonable amount is known

about the factors involved in establishing behavioral resistance (e.g., Nevin, 1974, 1979), comparatively little is known about the application of disrupters that allow the assessment of that resistance. It is important to explore the conditions that determine the impact of these disrupters because the equal and unconfounded application of a disrupter across response components is essential to an accurate determination of resistance to change. Addressing this question is most straightforward if the reinforcement conditions used to establish a resistance differential across components are maintained at a constant level while different types or degrees of disruption are applied equally to behavior in the different target components. The results of Harper and McLean (1992) suggest that reinforcer rate and duration may both be important factors when response-independent food is used to disrupt responding. Thus, the focus of the present study was on the separate and combined effects of the durations and rate of response-independent food presentations on the relative resistance to change of two responses. In order not to confound the measurement of the resistance ratio across the two target components, the reinforcer rate differential maintaining responding in the two target components was held constant while disruption was exerted via response-independent food presented during an alternating third component. Across conditions, the rate and duration of the response-independent food were manipulated. Based on previous findings, it was expected that higher rates and longer durations of response-independent food would cause correspondingly greater disruption to target-component responding. Furthermore, if the assumptions made by behavioral momentum theory are accurate, then the resistance ratio shown by responding across both components ($\Delta B_2/\Delta B_1$) should remain reasonably constant, irrespective of the level of disruption caused by response-independent food. Although there is some support for this later possibility (Nevin, 1992), the issue has not been addressed with respect to steady-state performance, an area of research that has thus far shown only mixed support for behavioral momentum theory.

METHOD

Subjects

Four adult homing pigeons with prior experience in multiple schedules were maintained at 80% to 85% of their ad libitum body weights. Supplementary feed was given after the final session of the day to maintain prescribed body weights. Water and grit were continuously available in each bird's home cage.

Apparatus

Four similar experimental chambers, measuring approximately 34 cm by 34 cm by 32 cm, each contained an interface panel with a centrally mounted grain hopper and two translucent, circular response keys (2 cm diameter). A response key located 21 cm above the floor and directly above the hopper was lit from behind by either blue or yellow lights during multiple-schedule components and was darkened for 30 s between each component presentation. Each peck to the key that exceeded 0.15 N turned off the key illumination for 0.05 s and was recorded as a response. The reinforcer consisted of operating the grain hopper for a few seconds, giving the pigeon access to wheat through an opening in the front wall. During wheat presentation, the key was darkened and the hopper was illuminated white. A ventilation fan at the rear of the chamber helped to mask extraneous sounds. All experimental events were scheduled and recorded by an IBM®-compatible computer running MED-PC® software in a room adjacent to the experimental chambers.

Procedure

Experimental sessions were conducted 7 days per week, with each session composed of 26 multiple-schedule components (each was 60 s in duration and was signaled by the response key being lit either blue or yellow) presented equally often and in irregular order. Each presentation was preceded by a 30-s dark-key period during which a VT schedule was sometimes operative. During blue-key (S1) component, a VI 120-s schedule arranged 2-s reinforcers, and during yellow-key (S2) components, an independent VI 120-s schedule arranged 6-s reinforcers. Thus, S1 was correlated with reinforcement conditions

Table 1

Arranged reinforcement schedule and duration of VT food during the dark-key component.

Condition	1	Extinction
	2	VT 120 s (2 s)
	3	VT 40 s (2 s)
	4	VT 120 s (6 s)
	5	VT 40 s (6 s)
	6	VT 80 s (2 s)
	7	VT 80 s (6 s)
	8	VT 40 s (8 s)
	9	VT 120 s (8 s)
	10	VT 40 s (1 s)
	11	VT 120 s (1 s)

(shorter reinforcer duration) that should produce relatively lower resistance to change compared to S2. The timing of the components and the VI schedules was suspended during reinforcer delivery. Note that the actual obtained reinforcer rates (averaged across all subjects and over the last five sessions of every condition) were 25.7 and 26.6 reinforcers per hour for S1 and S2, respectively. No large or systematic deviations from these means were observed across conditions.

In successive conditions of the experiment, the VT schedule that operated during dark-key periods arranged response-independent presentations of the reinforcer. Subjects were trained in each condition for at least 20 sessions and until the absolute response rates were stable in both components simultaneously or until 30 sessions of training had been completed. The procedure used to assess 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 $\pm 7.5\%$ of the overall mean calculated over the entire nine sessions. In the first condition (baseline), the VT schedule arranged no food during dark-key periods, but over subsequent conditions the rate and duration of VT food delivery in the dark-key period were manipulated. Each of these dark-key VT food conditions was preceded by a return to the baseline condition in order to provide data against which to measure behavior change. Tables 1 and 2 show the reinforcement conditions and the order of exposure and number of sessions to stability for each subject.

Table 2

Order of conditions and number of sessions in each condition (in parentheses).

Subject			
C5	C6	C7	C8
1 (21)	1 (20)	1 (20)	1 (20)
2 (20)	3 (20)	4 (23)	5 (22)
1 (20)	1 (21)	1 (21)	1 (20)
3 (20)	2 (23)	5 (20)	4 (20)
1 (20)	1 (20)	1 (20)	1 (20)
4 (20)	4 (20)	2 (20)	2 (25)
1 (20)	1 (20)	1 (20)	1 (20)
5 (21)	5 (30)	3 (23)	3 (20)
1 (22)	1 (20)	1 (20)	1 (20)
7 (20)	7 (26)	6 (25)	6 (25)
1 (20)	1 (26)	1 (20)	1 (22)
6 (21)	6 (23)	7 (20)	7 (20)
1 (20)	1 (21)	1 (20)	1 (22)
8 (26)	9 (20)	10 (21)	11 (20)
1 (20)	1 (30)	1 (20)	1 (20)
9 (28)	10 (20)	11 (20)	8 (28)
1 (20)	1 (23)	1 (20)	1 (20)
10 (20)	11 (23)	8 (30)	9 (20)
1 (23)	1 (21)	1 (20)	1 (20)
11 (20)	8 (30)	9 (22)	10 (20)

RESULTS

Mean response rates were calculated by averaging across the last five sessions in each condition. Because the analyses below use derived measures (proportion of baseline), Table 3 gives responses per minute in each component for each of the conditions in the experiment.

Figure 1 shows that responding in both components generally decreased relative to baseline when dark-key response-independent food was presented. This decrease in response rate in the presence of S1 and S2 became larger as the durations of dark-key food grew longer. Figure 2 shows that increases in the rate of dark-key food also generally produced decreases in the response rate, although this decrease is clearer in Component S1 than in Component S2. Again, consistent with the data in Figure 1, there is a clear effect of dark-key food duration, particularly on responding in Component S1.

Although responding in both components generally decreased with increases in the rate or duration of dark-key food, Figures 1 and 2 indicate that responding in the 2-s reinforcer component (S1) generally changed more than did responding in the 6-s reinforcer component (S2). For all 4 subjects and for

Table 3

Mean responses per minute in Components S1 and S2 for each pigeon in each condition, and actual reinforcer rates obtained in the dark-key component averaged across all subjects. The conditions in which response-independent food was made available (2–11) are shown with their corresponding preceding baseline condition (1).

Condi- tion	C5		C6		C7		C8		Mean obtained reinforcer rate (per hour)
	S1	S2	S1	S2	S1	S2	S1	S2	
1	65.92	68.92	46.62	59.46	57.77	69.00	56.92	66.85	0
2	60.92	62.85	50.23	64.54	43.85	61.92	54.08	67.85	28.6
1	69.85	72.77	69.92	71.92	69.46	66.54	55.69	62.23	0
3	45.85	56.08	35.62	51.00	52.23	66.39	41.46	66.23	92.1
1	49.69	60.00	56.23	69.23	63.69	64.46	51.77	57.62	0
4	37.31	63.15	36.46	68.92	45.85	58.62	38.54	56.54	30.4
1	63.85	65.00	50.23	76.39	58.31	70.31	60.15	74.15	0
5	46.15	82.23	28.08	46.85	29.69	50.92	29.69	52.15	90.2
1	72.85	103.31	46.15	66.92	64.23	74.92	58.31	80.39	0
6	63.69	95.39	53.77	68.31	47.85	66.08	39.69	68.77	45.3
1	72.85	86.23	50.54	69.54	69.46	83.69	65.15	76.39	0
7	50.15	79.92	28.54	49.39	44.31	58.92	30.92	61.39	42.8
1	75.00	92.62	55.00	61.54	57.46	68.15	56.62	70.39	0
8	34.69	70.08	31.00	49.62	25.46	40.62	22.08	49.31	93.0
1	71.85	79.31	47.62	51.46	66.77	79.39	59.31	77.62	0
9	45.77	74.23	30.31	47.08	40.15	58.92	32.62	59.85	33.2
1	54.69	78.77	38.39	53.62	56.85	72.92	55.69	78.15	0
10	73.54	77.00	24.62	53.92	53.85	68.23	63.46	80.62	91.4
1	62.62	91.15	46.23	60.92	55.92	74.31	58.92	75.54	0
11	72.62	90.85	33.62	54.00	59.77	76.39	54.62	80.77	28.5

the group as a whole, there appears to be an interaction between the amount of response-rate decrease caused in S1 versus S2 and the rate or duration of dark-key food. That is, although responding in both components decreased as dark-key food rate or duration increased, this decrease was greater in S1 than in S2. These trends displayed in Figures 1 and 2 are consistent with the results from a within-subject analysis of variance (ANOVA) comparing the log proportion of baseline response rates in the two components by duration and rate (for the two extreme rates only: VT 40 s and VT 120 s). That is, at the .05 level of significance, there was a significant interaction of Component $\times$ Rate of dark-key food, $F(1, 3) = 113.3$, and Component $\times$ Duration of dark-key food, $F(3, 9) = 4.9$, and a main effect of component, $F(1, 3) = 93.7$, rate of dark-key food, $F(1, 3) = 22.7$, and duration of dark-key food, $F(3, 9) = 10.4$; there were no other significant effects.

Of major interest here was whether the ratios of response-rate changes in S1 versus S2

were affected by changes in dark-key food. That is, did the log proportion of baseline responding change relatively more in one component than in the other as the rate and duration of dark-key food changed? Because responding in both components decreased as dark-key food duration increased, the degree of divergence between these two components is not easy to determine from Figures 1 and 2. A better graphical demonstration of the relationship between the response-rate changes in S1 and S2 as dark-key food is manipulated is provided by Figure 3. Figure 3 shows a plot of the log proportion of baseline response-rate change in the presence of S1 versus the log proportion of baseline response rate in S2 for all conditions. For each subject and for the group as a whole, a structural relations analysis was performed (in preference to a standard linear regression analysis, which assumes zero variance in the x variable, see Davison & McCarthy, 1988) to provide a measure of the slope and the y -axis intercept. The extent of correlation between the log propor-

Fig. 1. Log proportion of baseline response rate in Components S1 (2-s reinforcer) and S2 (6-s reinforcer) of the multiple schedule plotted as a function of the duration of the reinforcers presented during the dark-key component. Each column shows the data from a set of conditions in which a particular VT schedule provided food during the dark-key component. Each row shows data from a different pigeon and for the group average. Response rate is presented as a proportion of the rate observed in the same component during the immediately preceding baseline condition in which no food was available during the dark-key component. The response rates used in calculating the log proportions are means from the last five sessions of the relevant conditions.

Fig. 2. Log proportion of baseline response rate in Components S1 (left column) and S2 (right column) replotted from Figure 1 as a function of response-independent food rate during the dark-key component. Circles, squares, upward triangles, and downward triangles show responding in conditions in which the duration of response-independent food was 1, 2, 6, and 8 s, respectively.

Fig. 3. Log proportion of response rate in S1 (x axis) versus log proportion of response rate in S2 (y axis) for each condition. The numbers (2–11) on the group graph correspond to the condition number that generated each data point. Lines running through the data show the structural relation describing the linear relationship (in logarithmic coordinates) between responding in S1 and responding in S2. Also shown are the y -axis intercepts and slopes of these functions.

tion of baseline response rate in the two components was also determined by calculating a correlation coefficient. Note that the current analysis is similar to that used previously by Nevin et al. (1983) to explore constancy in the resistance ratio. This method of analysis

differs from that used previously to make more qualitative comparisons (e.g., Harper & McLean, 1992¹; Nevin, 1974) in that log val-

¹ A log transformation of the Harper and McLean data does not change the ordinal effects identified in their study.

ues of the proportion of baseline response rates (rather than simply the proportion of baseline response rate) were used. However, the log proportion of baseline response rate is the most appropriate measure to use when exploring the quantitative predictions of behavioral momentum theory because it is unbounded at 0 or 1 (if the disrupter always decreases response rates) and has the property of rendering equal ratios as equal differences.

Figure 3 indicates that the relationship between the log of the response-rate proportions was reasonably linear. The values of the correlation coefficients were 0.39, 0.75, 0.90, 0.90, and 0.93 for Pigeons C5 to C8 and for the group as a whole, respectively, indicating that overall the extent of response-rate change in S1 was correlated with the extent of response-rate change in S2. Therefore, the ratio of response-rate change in S1 versus S2 remained reasonably constant, irrespective of the rate or magnitude of response-independent food delivered during the dark-key component. Also, there were no obvious systematic deviations for any particular condition or set of conditions from this function. The y-axis intercept was close to zero in all cases, and the slopes varied between 0.460 and 0.668 across individuals.

DISCUSSION

The present findings demonstrated that steady-state interventions can result in changes in response rates similar to those found with probe disruptions. The present study replicated the results of Harper and McLean (1992, Experiment 1), in that the relative changes in response rates caused by delivery of response-independent food in a third component were maintained in steady-state responding. Thus, with the current procedure at least, the implications of behavioral momentum theory for steady-state behavior can be examined. According to behavioral momentum theory, responding in S1 should have displayed lower resistance to change (i.e., possessed relatively lower behavioral mass) because the reinforcers maintaining responding in S1 were of a shorter duration than the reinforcers maintaining responding in S2. Consistent with these qualitative trends predicted by behavioral momentum theory,

responding in S1 was more disrupted (i.e., more reduced relative to baseline) than was responding in S2 when response-independent food was presented during the dark-key component.

The finding that a differential change in the response rate for S1 versus S2 was still present after extended exposure to response-independent food delivery is an important demonstration in addressing the issue of whether differences in resistance to change reflect a transient or a more long-term change in responding brought about by factors that reduce response rate. An assessment of resistance to change using probe-trial delivery of a disrupter or several sessions of extinction does not allow us to discriminate between the extent and speed of response-rate change. It is possible that the speed of change may be greater in the component associated with the shorter reinforcer duration but that the extent of change in both components may eventually be the same given a long enough exposure to the factors causing that change (in this case dark-key food). An inference from previous studies, however, is that the differential extent of change in response rates should be maintained even after long-term disruption. For example, Nevin (1988, 1992) has previously cited steady-state data (e.g., Bouzas, 1978; Pliskoff, Shull, & Gollub, 1968) in support of the conclusion that more frequently reinforced responding is more resistant to disruption. The present results are entirely consistent with such evidence. Consequently, the growing evidence that behavioral momentum theory can be applied to steady-state performance represents an important development in the generality of this theory. Furthermore, the maintenance of a differential resistance even after extended training allows us to refine our knowledge about the function of operations that are conceptualized as *force* by behavioral momentum theory. Specifically, it appears that a force does not have only a transient effect on responding but rather continues to exert an influence even after a relatively long period of time.

To date, however, there are relatively few parametric data available that would allow for the quantitative assessment of behavioral momentum theory's ability to account for steady-state behavior. Even in the study by Harper

and McLean (1992), which provided only mixed support for behavioral momentum theory, the effect of long-term exposure to dark-key food on steady-state response rates was assessed using only two different rates of dark-key food. The present study was an attempt to assess more systematically the extent to which steady-state performance may or may not conform to the quantitative predictions made by behavioral momentum theory. The present study was also designed, in part, to examine the possibility that the failure of Harper and McLean (1992) to demonstrate differences in resistance to change following changes in the maintaining reinforcement schedule was due to a confounding of the conditions establishing response resistance and the conditions causing response rate to change in their procedure. In order to provide corroborating evidence for this interpretation of Harper and McLean's results, the present study had to demonstrate that longer durations of food reinforcement during the dark-key component resulted in a greater decrease in response rates. The present results confirmed this possibility. Indeed, even over the range of reinforcer durations used by Harper and McLean (2 to 6 s), there were obvious differences in the size of the decrease for response rates in the two target components. Thus, these results are consistent with the possibility that in Harper and McLean's Experiments 2 and 3, a greater level of disruption or force was applied to responding in the long reinforcer-duration component compared to the short reinforcer-duration component. In such a situation, behavioral momentum theory would predict that there would be relatively little difference in the size of the response-rate change observed across components.

A quantitative examination of the present results demonstrated that steady-state interventions can yield invariances in relative resistance to change similar to those found with the more short-term disruptions. Behavioral momentum theory predicts that if disruption is applied equally to components but is varied in magnitude while the maintaining reinforcement schedules within components are held constant, then the ratio of resistance to change (see Equations 3 and 4) should be invariant with respect to the magnitude of the disrupter. The use of dark-key food as a dis-

rupter should have ensured that the disruptive influence was applied equally to both components and external (i.e., in another component) to the target components in which the resistance differential was established. Thus, unlike the situation in Harper and McLean's Experiments 2 and 3 (1992), or when extinction is used to disrupt behavior (e.g., Nevin et al., 1983), there was no apparent procedural confounding of the reinforcement conditions establishing the resistance differential across components with the reinforcement conditions used to assess resistance.

The present results revealed a linear relationship between log proportions for response-rate change in S1 versus S2 with no systematic deviations from this function dependent upon rate or duration of response-independent food. That is, the response-rate changes observed in one component were accompanied by a consistent degree of change in the other component across different levels of disruption. The implication of this finding is that, consistent with behavioral momentum theory, the observed resistance ratio remained constant across different levels of disruption or force. Thus, by taking the slope of the linear function relating log proportion of change in S1 versus S2, a measure of the average resistance ratio can be obtained. Also, because the resistance ratio is the inverse of the mass ratio (see Equation 4), the inverse of the slope provides an estimated average mass ratio of 2.18, 1.48, 1.50, 2.04, and 2.19 for C5 to C8 and the group as a whole, respectively. That is, for the group as a whole the relative change in S2 is slightly less than half that for S1. This means that responding associated with Component S2 (maintained by 6-s reinforcers) had slightly more than double the mass (as conceptualized by behavioral momentum theory) of the responding associated with Component S1 (maintained by 2-s reinforcers).

Although the current findings are generally consistent with behavioral momentum theory, one aspect of the data not readily accounted for was the tendency for responding to show *increases* relative to baseline at very low durations of response-independent food. In many cases there were increases in relative response rates (occasionally in both components) following introduction of the response-independent food when that food was

delivered for a duration of 1 or 2 s. The reasons for this positive induction effect are unclear. However, one thing that is clear is that when force is exerted via a change in reinforcement conditions, the duration of the reinforcers must be taken into account when predicting the degree of change caused in the target responses.

In conclusion, the present results indicate that both qualitative and quantitative predictions from behavioral momentum theory can be successfully applied to changes in steady-state response rates as long as possible confounding effects between the conditions establishing behavioral resistance and the disruptive forces used to determine that resistance are minimized. Unfortunately, many procedures for exploring steady-state behavior involve just such effects, because alterations in the maintaining reinforcement conditions not only exert a force but also alter the conditions responsible for establishing behavioral resistance (e.g., Harper & McLean, 1992).

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