

*TESTS OF BEHAVIOR MOMENTUM IN SIMPLE AND MULTIPLE SCHEDULES WITH RATS AND PIGEONS*

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Four experiments examined the relationship between rate of reinforcement and resistance to change in rats' and pigeons' responses under simple and multiple schedules of reinforcement. In Experiment 1, 28 rats responded under either simple fixed-ratio, variable-ratio, fixed-interval, or variable-interval schedules; in Experiment 2, 3 pigeons responded under simple fixed-ratio schedules. Under each schedule, rate of reinforcement varied across four successive conditions. In Experiment 3, 14 rats responded under either a multiple fixed-ratio schedule or a multiple fixed-interval schedule, each with two components that differed in rate of reinforcement. In Experiment 4, 7 pigeons responded under either a multiple fixed-ratio or a multiple fixed-interval schedule, each with three components that also differed in rate of reinforcement. Under each condition of each experiment, resistance to change was studied by measuring schedule-controlled performance under conditions with prefeeding, response-independent food during the schedule or during timeouts that separated components of the multiple schedules, and by measuring behavior under extinction. There were no consistent differences between rats and pigeons. There was no direct relationship between rates of reinforcement and resistance to change when rates of reinforcement varied across successive conditions in the simple schedules. By comparison, in the multiple schedules there was a direct relationship between rates of reinforcement and resistance to change during most tests of resistance to change. The major exception was delivering response-independent food during the schedule; this disrupted responding, but there was no direct relationship between rates of reinforcement and resistance to change in simple- or multiple-schedule contexts. The data suggest that rate of reinforcement determines resistance to change in multiple schedules, but that this relationship does not hold under simple schedules.

*Key words:* behavior momentum, resistance to change, response strength, multiple schedules, response-independent food, key peck, lever press, rats, pigeons

Behavior momentum (Nevin, 1992) is the product of response rate ("velocity" of behavior) and resistance to change ("mass"). Whereas variables that affect the rate of operant responding have been examined extensively, less is known about variables that affect resistance to change, that is, the relative change in steady-state operant responding when it is disrupted by altering environmental conditions. Nevin (1974, 1979) has argued that responses producing higher rates of reinforcement, more immediate delivery of reinforcement, or greater amounts of reinforcement in the presence of a discriminative stimulus are more resistant to change than are responses producing smaller amounts of reinforcement, less often, and with less immediacy. For example, Bouzas (1978) reinforced pigeons' re-

sponses according to a multiple (mult) variable-interval (VI) 1-min VI 4-min schedule of reinforcement and delivered response-contingent electric shocks in both components. As expected, this punishment procedure reduced response rates, but responding was reduced relatively less in the VI 1-min component. In another demonstration (Nevin, Mandell, & Yarensky, 1981), pigeons' responding was maintained under a chained schedule of reinforcement. Providing alternative reinforcement for responses on another key or feeding subjects before the session lowered response rates relatively more in the initial link than in the terminal link. Resistance to change was also enhanced by providing more food in the terminal link or decreasing terminal-link duration.

Recent evidence suggests that response rate is determined by response-reinforcer contingencies and resistance to change is determined by stimulus-reinforcer (Pavlovian) contingencies (Mace et al., 1990; Nevin, 1984, 1992; Nevin, Smith, & Roberts, 1987; Nevin, Tota, Torquato, & Shull, 1990). In a clear demonstration of this, Nevin et al. (1990) reinforced pigeons' key pecks with food according

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to a mult VI 1-min VI 1-min schedule. In some conditions response-independent food was also delivered in one of the components. These added "free" reinforcers degraded the response-reinforcer contingency and lowered response rates. However, this manipulation also increased the rate of reinforcement in the component and enhanced the stimulus-reinforcer contingency. Consequently, responding in the component with added reinforcers was less affected by tests involving satiation and extinction than was responding in the alternative component, demonstrating greater resistance to change as a result of the enhanced Pavlovian contingency.

Analyses of response strength from a behavior-momentum perspective (e.g., Nevin, 1979, 1992; Nevin, Mandell, & Atak, 1983) have accommodated a large and diverse body of evidence. However, there are data that do not show a direct relationship between rate of reinforcement and resistance to change, suggesting the need for additional systematic research in this area (cf. Nevin, 1992). For example, with discrete-trial procedures there is less resistance to extinction under conditions of continuous compared with intermittent reinforcement (i.e., the partial-reinforcement-extinction effect, PREE) (Nevin, 1988). Cohen (1986) showed that a direct relationship between resistance to change and rate of reinforcement does not occur when drugs are used as disruptive stimuli. In one experiment, for example, rats responded for food under a mult fixed-interval (FI) 30-s FI 120-s schedule of reinforcement. Drugs (e.g., *d*-amphetamine) were administered in tests of resistance to change, and relative reductions in response rates were the same in both components of the multiple schedule, despite large differences in reinforcement rates. Harper and McLean (1992) showed that systematically varying the rates of reinforcement in two components of a multiple schedule that differed in reinforcement magnitude produced equivalent changes in overall response rates in both components.

Cohen, Furman, Crouse, and Kroner (1990) also reported data that failed to show a direct relationship between resistance to change and rate of reinforcement. Rats were trained to press a lever according to simple fixed-ratio (FR) schedules that varied across successive conditions from FR 40 to FR 240. After responding stabilized under each condition, lever pressing was disrupted by response-indepen-

dent food delivery and extinction. Previous research (e.g., Nevin, 1974) suggested that baseline response rates under the FR 240 schedule (lowest reinforcement rates) should have been more disrupted than response rates under the FR 40 schedule (highest reinforcement rates). Instead, response-independent food disrupted responding equally in all of the FR schedules. Furthermore, in the extinction test, responding was more resistant to change under the larger FRs than under the smaller FRs.

The purpose of the present study was to investigate variables that could account for the results of Cohen *et al.* (1990), and that might establish the boundaries of conditions in which there is a direct relationship between resistance to change and rate of reinforcement (i.e., in the behavior-momentum hypothesis). It is not readily apparent what aspects of Cohen *et al.*'s (1990) experiment might be responsible for their contradictory data. Their study used simple FR schedules of reinforcement, involved rats as subjects, varied rates of reinforcement across conditions, and tested for resistance to change in each successive condition. Most tests of behavior momentum (Fath, Fields, Malott, & Grossett, 1983; Harper & McLean, 1992; Lattal, 1989; Mandell, 1980; Mellon & Shull, 1986; Nevin, 1974, 1979, 1984, 1988; Nevin *et al.*, 1981, 1983, 1987, 1990) have used pigeons as subjects, keylights as discriminative stimuli, and grain as reinforcers. However, data consistent with most research on behavior momentum have been reported with rats (Cohen, 1986) and humans (Mace *et al.*, 1990), using different reinforcers and discriminative stimuli. Most tests of behavior momentum have used multiple or chained schedules rather than simple schedules of reinforcement. Under these more complex schedules, discriminative stimuli signal different reinforcement frequencies, and subjects are exposed to different frequencies within the same session rather than across successive conditions. Church and Raymond (1967), however, trained two independent groups of rats under either a VI 5-min or a VI 12-s schedule and superimposed response-dependent shocks according to a VI 2-min schedule. Response suppression was greater under the VI 5-min schedule, consistent with research on behavior momentum (e.g., Nevin, 1974). Finally, most studies on behavior momentum (e.g., Nevin, 1974; Nevin *et al.*, 1983) have tested resistance to change with VI rather than FR schedules of reinforcement. Fantino

(1965) reported data using pigeons under concurrent-chain schedules of reinforcement with FR terminal links that were inconsistent with research on behavior momentum, suggesting that resistance to change might not be sensitive to reinforcement parameters with FR schedules. In summary, Cohen et al.'s (1990) study differed from most, but not all, momentum-related studies by using rats rather than pigeons, simple rather than multiple or chained schedules of reinforcement, ratio rather than interval schedules, and fixed rather than variable schedules.

Perhaps some combination of conditions unique to Cohen et al.'s study (1990) (e.g., rats under simple FR schedules of reinforcement) was responsible for their unusual results. The first experiment of the present study was a systematic replication of Cohen et al.'s experiment, with the addition of three groups of rats responding under simple VI, variable-ratio (VR), and FI schedules of reinforcement. The second experiment studied pigeons under simple FR schedules of reinforcement. The third and fourth experiments examined resistance to change in rats and pigeons, respectively, responding under multiple FR and FI schedules of reinforcement. Taken together, the present experiments compared simple with multiple schedules, ratio with interval schedules, fixed with variable schedules, and rats with pigeons. It is sometimes difficult to compare the results of momentum-related experiments across laboratories because studies do not always use the same resistance-to-change tests. All of the present experiments used uniform tests of resistance to change.

### EXPERIMENT 1: SIMPLE SCHEDULES WITH RATS

A major question raised by Cohen et al.'s (1990) data was whether a direct relationship between resistance to change and rate of reinforcement can be obtained with simple schedules. Recent accounts of behavior momentum have emphasized the importance of Pavlovian (stimulus-reinforcer) contingencies in the determination of resistance to change (Mace et al., 1990; Nevin, 1984, 1992; Nevin et al., 1987, 1990). The strength of a stimulus-reinforcer contingency is determined by the probability of a reinforcer in the presence of a stimulus compared to the probability in its absence. This relationship is clearly evident in

multiple schedules in which responses are differentially reinforced when component stimuli are correlated with different rates of reinforcement, but it is not explicitly evident in simple schedules in which responses are not differentially reinforced. Thus, a direct relationship between resistance to change and reinforcement rate might not be expected with simple schedules. Nonetheless, systematic tests of resistance to change in simple schedules are necessary to establish firmly the boundaries of the behavior-momentum phenomenon, particularly in light of Nevin's (1988, 1992) inclusion of simple-schedule research into his accounts of behavior momentum. In addition, research on the role of context (e.g., Thomas, 1985) in the development of stimulus-reinforcer associations suggests that Pavlovian conditioning may occur in the absence of explicit differential reinforcement.

The present experiment replicated and extended the results of Cohen et al. (1990). Rats were trained across successive conditions under FR 40, 80, and 160 schedules of reinforcement. After responding stabilized under each condition, three types of resistance-to-change tests were conducted. First, response-independent food was presented during the session according to variable-time (VT) 40-s (90 reinforcers per hour) and VT 20-s (180 reinforcers per hour) schedules. Typically (e.g., Nevin, 1974), response-independent food is delivered during the timeouts that separate components of multiple schedules. With simple schedules of reinforcement, free-food presentations can only be given while the maintaining schedule is in effect. However, this situation is somewhat similar to the procedure used by Nevin et al. (1981), in which signaled alternative reinforcement was given for responses on another key while a chained schedule was in effect. Second, rats were fed different amounts of food before the session. Third, extinction sessions were conducted. This experiment also examined resistance to change in other rats responding under simple VI, VR, and FI schedules of reinforcement to assess whether the results of Cohen et al. were limited to FR schedules.

### METHOD

#### *Subjects*

Twenty-eight male Sprague-Dawley albino rats (Camm Research) were used. Eight rats were experimentally naive, and 20 had been

trained by undergraduate experimental psychology students for approximately 20 sessions under FR 40 schedules of reinforcement. The rats weighed between 270 and 310 g after food deprivation and were maintained at 80% of their free-feeding weights. Water was freely available in their home cages, where a 12:12 hr light/dark cycle was maintained (lights on at 6:00 a.m.).

#### *Apparatus*

Seven operant conditioning chambers (Coulbourn Instruments) for rats were housed in sound-attenuating cubicles. Each chamber contained a recessed food cup in the bottom center of the work panel. The response lever was 22 mm from the right wall and 28 mm from the grid floor, and operated with a minimum force of approximately 0.24 N. A 28-V houselight was located above the food cup near the top of the chamber. A Gerbrands or Coulbourn feeder delivered 45-mg Noyes food pellets. White noise was present during the session to mask extraneous sounds. Contingencies were controlled by an IBM-PC computer, Coulbourn Instruments Lab-Linc interface, and Pascal programming.

#### *Procedure*

Rats were randomly divided into VR, FR, VI, and FI groups ( $n = 7$ ). The 8 naive rats (2 per group) were trained to press the lever by being placed into the operant chamber overnight and exposed to a continuous reinforcement (FR 1) schedule; a free food pellet was delivered every 20 min independently of behavior. Each of these rats then received two 45-min sessions of FR 1 and one session of FR 2 before being exposed to their assigned schedule. The 20 experienced rats, previously hand-shaped to lever press, were exposed directly to their assigned schedule of reinforcement.

*Variable-ratio schedule.* Each rat was assigned to an operant chamber and received one session of VR 5, two sessions of VR 10, and one session of VR 20. Responding then was maintained under a VR 40 schedule until overall response rates stabilized (i.e., no increasing or decreasing trends for at least five consecutive sessions). Under the VR 40 schedule, food was delivered after an average of 40 responses. The ratios of the VR schedule were randomly selected (with replacement) from a range of 1 to

80 responses. The houselight was on during each 45-min session, and it was turned off and the white feeder light was turned on for 1 s during food delivery. The response lever was not operable during the 1-s feeder cycle. Sessions were conducted Monday through Saturday, and all rats were studied simultaneously.

Each rat's responding was stable after 36 sessions of VR 40, and five resistance-to-change tests were then conducted. First, response-independent food was delivered during the entire session according to a variable-time (VT) 40-s schedule. Under this schedule, food was delivered independently of responding after an average of 40 s, during which time the houselight was turned off and the feeder light was turned on for 1 s. The response lever was operable during the 1-s feeder cycle. The intervals of the VT schedule were randomly selected (with replacement) from a continuous range from 0 to 80 s. Second, response-independent food was delivered according to a VT 20-s schedule (range, 0 to 40 s). Third, rats were prefed 1% of their ad libitum body weights of Purina® rat chow in their home cage 1.5 hr before the session. Body weight was returned to 80% before baseline sessions resumed. Fourth, rats were prefed 3% of their ad libitum body weights before the session. Fifth, three consecutive 60-min extinction sessions were conducted in which reinforcers were no longer delivered. Successive resistance-to-change tests were separated by at least two baseline sessions, and response rate on the session before each test had to be within the range of response rates of the five baseline sessions preceding the first test. The VR schedule remained in effect during each test (except extinction).

After the last extinction test, responding was recovered, all rats were trained under VR 80 (range 1 to 160 responses) for 27 sessions, and the resistance-to-change tests were repeated. The schedule was increased to VR 160 (range, 1 to 320 responses) for 29 sessions, and the tests were repeated once again. Finally, the VR 40 schedule was replicated for 27 sessions, and the final set of resistance-to-change tests were conducted. Some rats did not maintain responding under larger valued ratios, and these rats were dropped from the experiment until the VR 40 was redetermined.

*Fixed-interval schedule.* These rats were treated identically to rats on the VR schedule

except that an FI schedule was in effect. Rats received one session of FI 5 s, two sessions of FI 10 s, and one session of FI 20 s, and then were maintained under an FI 30-s schedule until response rates stabilized. Under the FI 30-s schedule, food was delivered for the first response after 30 s. Rats received 33, 26, 29, and 27 baseline sessions under FI 30-s, FI 60-s, FI 120-s, and FI 30-s schedules, respectively, before receiving resistance-to-change tests under each schedule value as outlined above.

*Fixed-ratio schedule.* Rats received one session of FR 5, two sessions of FR 10, and one session of FR 20, and then were maintained under an FR 40 schedule until response rates stabilized. These rats received 33, 28, 34, and 26 baseline sessions under FR 40, FR 80, FR 160, and FR 40 schedules, respectively, before receiving resistance-to-change tests under each schedule value.

*Variable-interval schedule.* Rats received one session of VI 5 s, two sessions of VI 10 s, and one session of VI 20 s, and then were maintained under a VI 30-s schedule until response rates stabilized. Under the VI 30-s schedule, food was delivered for the first response after an average of 30 s. The VI schedule contained 20 intervals that were derived from the formula of Catania and Reynolds (1968, p. 380). An interval was randomly chosen following each food presentation until the entire set of 20 intervals was exhausted and the selection process was repeated. Rats received 34, 27, 27, and 25 baseline sessions under VI 30-s, VI 60-s, VI 120-s, and VI 30-s schedules, respectively, before receiving resistance-to-change tests under each schedule value.

## RESULTS AND DISCUSSION

Response rate was calculated by dividing total session responses by session time (not including feeder cycles). The results of each resistance-to-change test were expressed as a ratio of the response rate during a test session to the response rate on the immediately preceding baseline session ("proportion of baseline"), because the behavior-momentum hypothesis predicts changes relative to baseline response rates. Absolute response rates during each test and mean response and reinforcement rates of the sessions immediately preceding each of the five test sessions (baseline) are presented in Appendices 1 to 4.

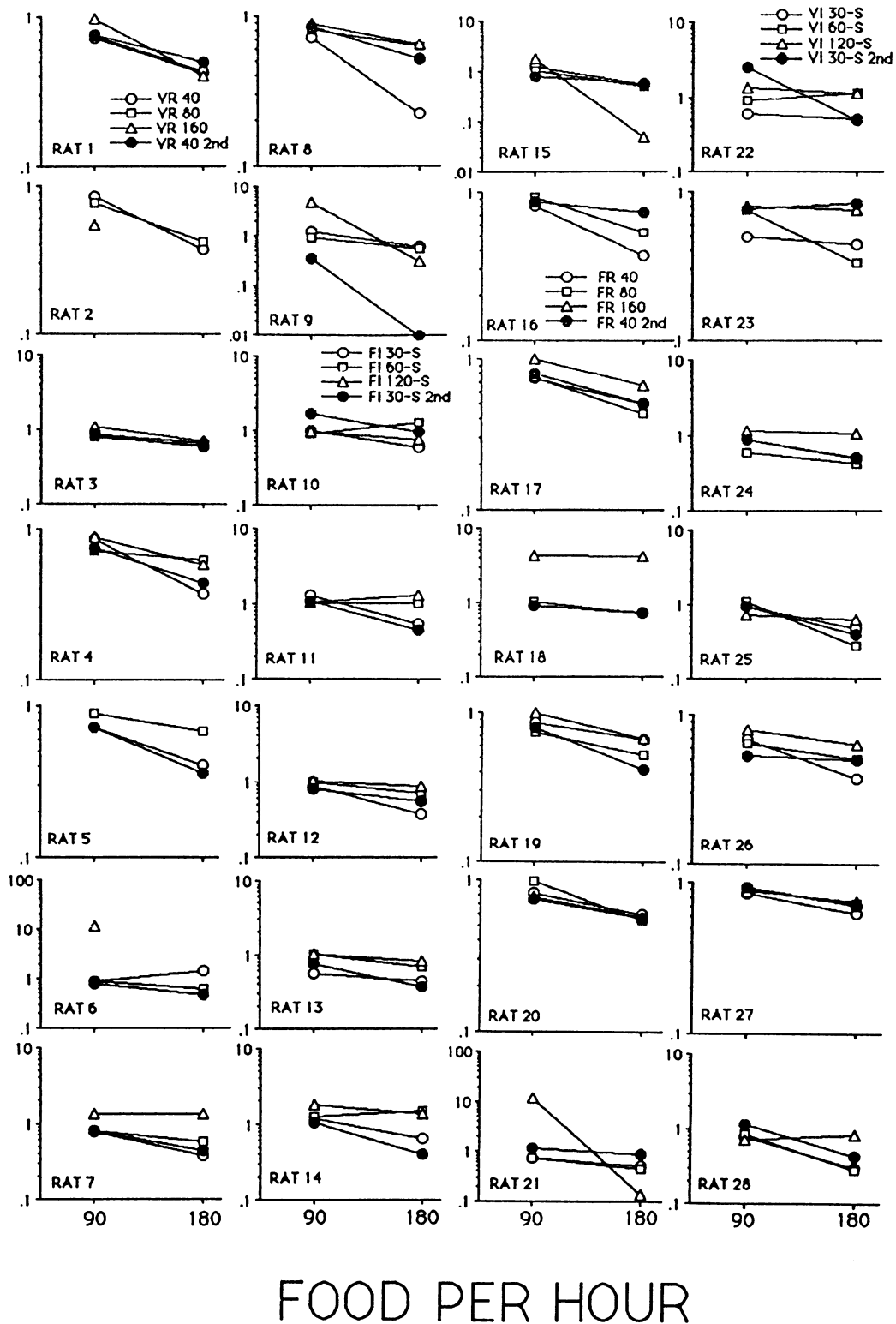
*Response-independent food.* Figure 1 shows the results of presenting response-independent food on proportion of baseline response rates under each schedule value for all four groups. Proportion of baseline is presented on a logarithmic scale, and the slope of each line indicates the change in response rate from VT 40-s (90 reinforcers per hour) to VT 20-s (180 reinforcers per hour) conditions. Response-independent food presentations lowered response rates from baseline levels, and greater reductions often occurred under VT 20-s compared to VT 40-s schedules. Figure 1 shows that reductions in response rates were not consistently greater under schedules with lower baseline rates of reinforcement. If anything, many animals showed more reductions under schedules generating higher rates of reinforcement, particularly under the FI schedule.

*Prefeeding.* Figure 2 shows the effects of 1% and 3% prefeeding on proportion of baseline response rates. Only small reductions in response rates occurred after 1% prefeeding, but greater reductions sometimes were evident after 3%. No consistent differences in proportion of baseline response rates were observed across schedule values under FR, FI, VR, or VI conditions.

*Extinction.* Figure 3 presents the data from the three consecutive extinction sessions. Response rates declined progressively across sessions, but resistance to extinction was not directly related to baseline reinforcement rate. Instead, there was a tendency for response rates to decline more quickly under schedules generating higher baseline rates of reinforcement (e.g., VI 30 s compared to VI 120 s), although many individual exceptions occurred under all four schedules.

*Weighted mean proportion ( $\bar{p}$ ) of baseline response rates.* Quantitative summaries of the data in Figures 1 to 3 are shown in Table 1. These data are weighted mean proportions of baseline response rates (Nevin et al., 1981) that combine the proportions of baseline rates under the same disruptive operations (e.g., 1% and 3% prefeeding) into a single value that gives greater weight to operations intended to produce more response disruption. This value,  $\bar{p}$ , serves as a convenient index for comparing resistance to change at each disruptive operation across the four schedule conditions. The index is calculated by multiplying the proportion of baseline response rate by the value of

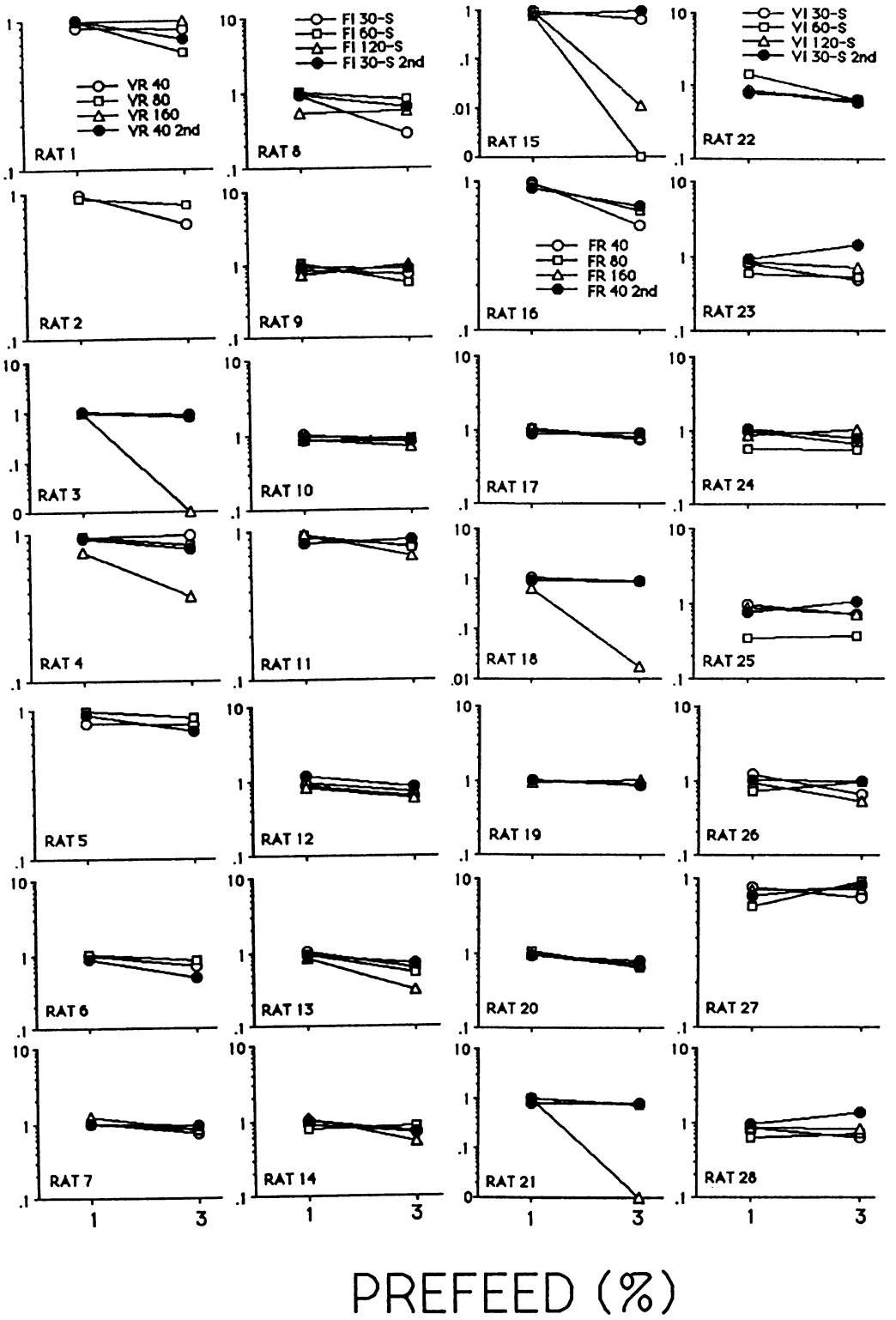
PROPORTION OF BASELINE



FOOD PER HOUR

Fig. 1. Experiment 1. The ratio of response rate during a resistance-to-change test to rate on the immediately preceding baseline session (proportion of baseline). In the tests, response-independent food was delivered during the schedule according to VT 40-s (90 reinforcers per hour) and VT 20-s (180 reinforcers per hour) schedules. Data are shown for individual rats for four successive conditions under VR, FI, FR, and VI schedules. The vertical axes are logarithmic.

PROPORTION OF BASELINE



PREFEED (%)

Fig. 2. Experiment 1. Proportion of baseline response rates when rats were fed 1% and 3% of their ad libitum weights before the session. Details as in Figure 1.

PROPORTION OF BASELINE

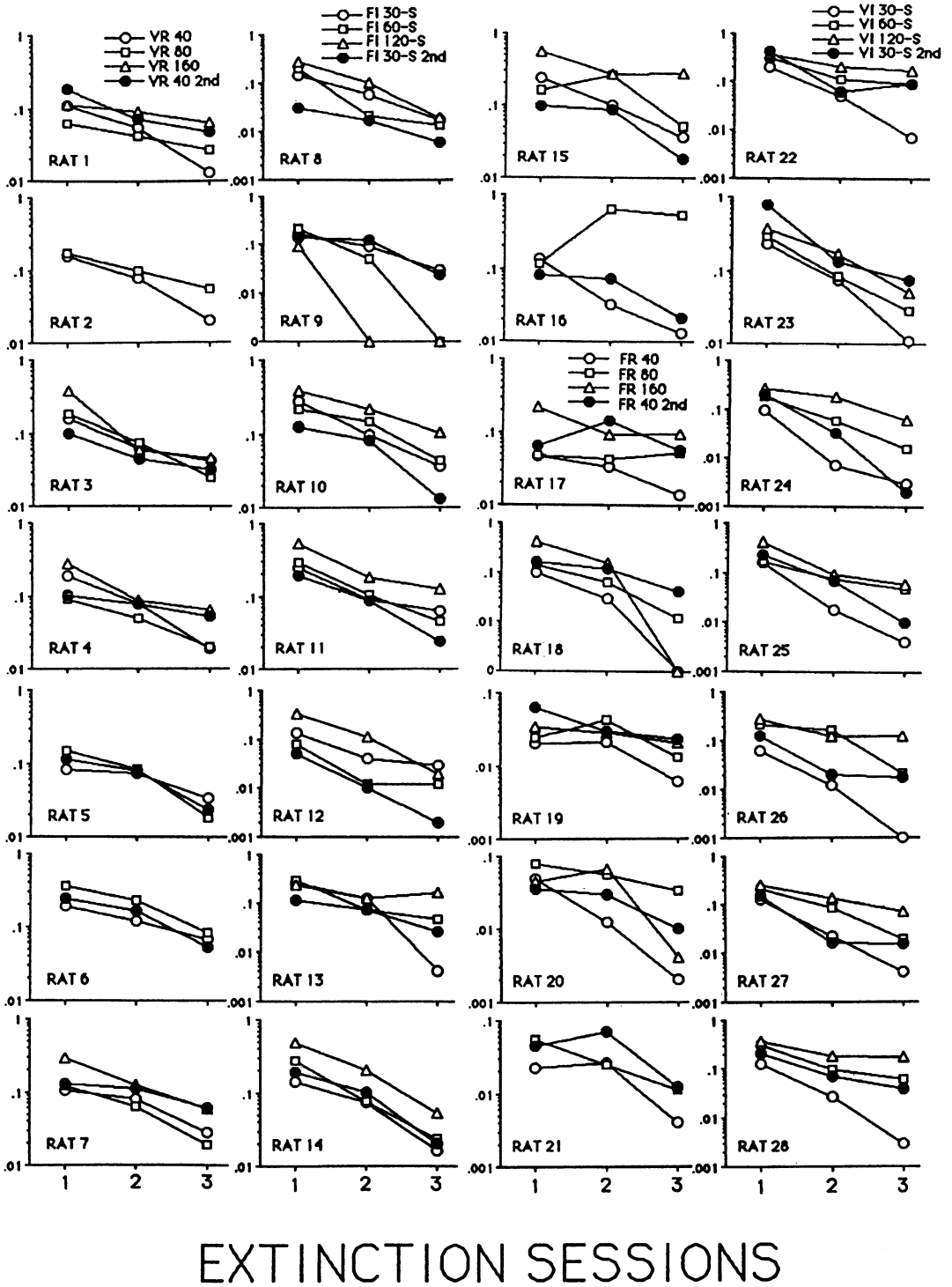


Fig. 3. Experiment 1. Proportion of baseline (the session immediately preceding the first extinction session) response rates during three extinction sessions. Details as in Figure 1.



Table 1

Experiment 1. Weighted mean proportion of baseline response rates ( $\bar{p}$ ) for Rats 1 to 28 under simple VR, FI, FR, and VI schedules during prefeeding, response-independent food, and extinction test sessions.

Rat	Prefeeding				Response-independent food				Extinction			
	VR				VR				VR			
	40	80	160	40	40	80	160	40	40	80	160	40
1	0.87	0.69	0.98	0.80	0.52	0.54	0.59	0.58	0.04	0.04	0.08	0.08
2	0.70	0.85			0.53	0.53	0.54		0.06	0.09		
3	0.85	0.84	0.25	0.89	0.66	0.66	0.82	0.71	0.12	0.07	0.10	0.05
4	0.96	0.87	0.47	0.82	0.54	0.66	0.68	0.54	0.07	0.04	0.11	0.07
5	0.80	0.91		0.77	0.51	0.75		0.48	0.05	0.06		0.06
6	0.78	0.89		0.58	1.25	0.69	11.2	0.57	0.10	0.18		0.12
7	0.81	0.86	0.92	0.94	0.51	0.66	1.32	0.56	0.06	0.05	0.12	0.09
	FI (s)				FI (s)				FI (s)			
	30	60	120	30	30	60	120	30	30	60	120	30
8	0.45	0.87	0.57	0.72	0.39	0.69	0.73	0.63	0.05	0.05	0.09	0.01
9	0.77	0.69	0.96	0.92	0.81	0.69	1.78	0.13	0.07	0.05	0.02	0.08
10	0.87	0.94	0.75	0.85	0.73	1.16	0.83	1.2	0.10	0.11	0.19	0.06
11	0.83	0.83	0.76	0.87	0.79	1.02	1.2	0.66	0.10	0.11	0.21	0.07
12	0.68	0.78	0.65	0.93	0.54	0.80	0.93	0.64	0.05	0.02	0.10	0.01
13	0.74	0.65	0.45	0.78	0.47	0.79	0.90	0.50	0.09	0.10	0.16	0.06
14	0.76	0.86	0.67	0.83	0.82	1.41	1.51	0.62	0.06	0.08	0.17	0.08
	FR				FR				FR			
	40	80	160	40	40	80	160	40	40	80	160	40
15	0.75	0.19	0.25	0.96	0.80	0.69	0.64	0.66	0.09	0.14	0.32	0.05
16	0.62	0.71		0.73	0.52	0.66		0.78	0.04	0.50		0.05
17	0.79	0.82	0.85	0.90	0.58	0.54	0.78	0.60	0.03	0.05	0.12	0.09
18	0.91	0.89	0.18	0.89	0.79	0.80	4.24	0.76	0.03	0.05	0.12	0.09
19	0.88	0.88	1.0	0.90	0.73	0.59	0.78	0.54	0.01	0.02	0.03	0.03
20	0.75	0.76	0.80	0.83	0.68	0.69	0.64	0.62	0.01	0.05	0.03	0.02
21	0.83	0.81	0.25	0.80	0.59	0.55	4.17	0.97	0.01	0.02		0.04
	VI (s)				VI (s)				VI (s)			
	30	60	120	30	30	60	120	30	30	60	120	30
22	0.67	0.84	0.69	0.65	0.54	1.06	1.21	1.16	0.05	0.13	0.21	0.13
23	0.56	0.54	0.75	1.3	0.46	0.47	0.77	0.81	0.07	0.09	0.14	0.21
24	0.73	0.55	0.97	0.84	0.64	0.48	1.08	0.62	0.02	0.06	0.14	0.05
25	0.77	0.36	0.74	0.98	0.62	0.54	0.64	0.57	0.03	0.08	0.13	0.07
26	0.79	0.89	0.63	0.98	0.48	0.55	0.69	0.51	0.01	0.10	0.15	0.04
27	0.77	0.87	0.84	0.86	0.70	0.79	0.79	0.78	0.03	0.07	0.12	0.04
28	0.68	0.69	0.82	1.28	0.45	0.47	0.79	0.67	0.03	0.11	0.21	0.08

its disruptive operation, summing these values, and dividing by the sum of the values of the disruptive operations:

$$\bar{p} = \sum (x_i p_i) / \sum (x_i),$$

where  $x_i$  represents the value of the disruptive operation and  $p_i$  is the proportion of baseline response rate at that value (see Nevin et al., 1981). For example, if proportion of baseline response rates was 0.90 under 1% prefeeding and 0.45 under 3% prefeeding, then

$$\bar{p} = [(1 \times 0.90) + (3 \times 0.45)] / (1 + 3) = 0.56.$$

A value of 0 indicates complete cessation of responding during each resistance-to-change test, and a value of 1.0 indicates no change in response rates. With some exceptions (e.g., Rats 3, 4, 13, and 21 after prefeeding), the data generally agree with Figures 1 to 3 in their failure to show consistently greater response-rate reductions under schedule values providing lower rates of baseline reinforcement. In many cases, responding was disrupted more under schedule values controlling higher rates of reinforcement, particularly during extinction tests.

The results of this experiment are generally

consistent with those of Cohen *et al.* (1990). Response-independent food delivery produced the same relative degree of response reduction under FR 40, 80, and 160 schedules, despite disparate rates of reinforcement (see Appendix 3). Resistance to extinction tended to be greater under the FRs with lower rates of reinforcement, although individual exceptions make this an unreliable effect. In the present study, three daily extinction tests were conducted, and relative changes in session response rates were analyzed. Cohen *et al.* used only one extinction session, and response rates were analyzed within 5-min segments of the session. Despite these differences, neither study found greater resistance to extinction following higher baseline rates of reinforcement. Satiating subjects before the session in this experiment produced data consistent with the other tests of resistance to change; response rates were reduced, but no consistent differences were observed across schedule values.

Overall, the results under FR schedules of reinforcement were consistent with those under VR, VI, and FI schedules, suggesting that the data reported by Cohen *et al.* (1990) were not unique to FR schedules. Prefeeding did not produce functional relationships between response reductions and reinforcement rates. Similar results were obtained with response-independent food, except under the FI schedule, in which response rates were reduced relatively more under the FI 30-s schedule than under the FI 60-s and FI 120-s schedules. Resistance to extinction tended to be greater under schedule values controlling the lowest reinforcement rates, although this effect was most consistent under VI and FI schedules of reinforcement. In summary, the results of Experiment 1 did not agree with previous research (e.g., Nevin, 1974, 1979) on behavior momentum showing that behavior controlled by schedules generating higher rates of reinforcement is more resistant to change than is behavior controlled by schedules generating lower rates of reinforcement. These inconsistent data were found in simple schedules that varied reinforcement rates along both ratio-interval and fixed-variable dimensions.

## EXPERIMENT 2: SIMPLE SCHEDULES WITH PIGEONS

As previously noted, studies of behavior momentum have typically examined pigeons re-

sponding under multiple VI schedules of reinforcement. Experiment 2 studied pigeons under simple FR schedules of reinforcement. This was a partial replication of Cohen *et al.* (1990), and tested whether their results were unique to rats responding under simple schedules. The scope of this experiment was more limited than Experiment 1, in that only FR schedules were used. However, Experiment 1 suggested that the type of schedule should not be a major factor.

## METHOD

### *Subjects*

Three male White Carneau pigeons (Palmetto Pigeon Plant) were maintained at 80% of their free feeding body weights (80% weights between 438 and 448 g). Experimental histories included differential-reinforcement-of-low-rate (Bird 1699), FR (Bird 1894), and progressive-ratio schedules (all pigeons). Water was freely available in their home cages, where a 12:12 hr light/dark cycle was maintained (lights on at 6:00 a.m.).

### *Apparatus*

Three operant conditioning chambers (Coulbourn Instruments) for pigeons were housed in sound-attenuating cubicles. The key (2.5 cm diameter) was located in the center of the work panel, 6.0 cm from the ceiling, and was transilluminated by an IEE one-plane readout. A minimum force of 0.10 N operated the key. Mixed grain was presented through an aperture below the key, which was illuminated white during each food-presentation cycle. A 28-V shielded houselight (light directed upward) was located in the upper left corner of the intelligence panel but was not used in this experiment. White noise was present during the session to mask extraneous sounds. Contingencies were controlled by an IBM-PC computer, Coulbourn Instruments Lab-Linc interface, and Pascal programming.

### *Procedure*

Each pigeon was assigned to an operant chamber, received one session of FR 10, two sessions of FR 20, and two sessions of FR 30, and then was maintained under FR 40 for 43 to 49 sessions before overall response rates stabilized (i.e., no increasing or decreasing trends for at least five consecutive sessions) and resistance-to-change tests began. Under the FR 40 schedule, 40 responses on a red key turned

the keylight off, turned on the white feeder light, and operated the food magazine for 3 s. The response key was not operable during the 3-s feeder cycle. Sessions were 1 hr long and were conducted Monday through Saturday.

After response rates stabilized, Pigeons 7901 and 1894 were prefed 5%, 2%, 5%, and 2% of their ad libitum body weights in their home cages 1 hr before each of four test sessions. Pigeon 1699 was prefed 5%, 7%, 5%, and 7%. Body weights were recovered after each test before baseline sessions continued. Next, response-independent food was delivered during the entire session on four occasions according to VT 40-s, 20-s, 40-s, and 20-s schedules (see Experiment 1 for details on interval distributions), respectively. When food was delivered under the VT schedule, the keylight was turned off, the feeder light was turned on, and food was presented for 3 s, and any responses on the key during the food-presentation cycle counted toward the FR contingency. As in Experiment 1, the FR contingency was in effect during each test. Finally, three successive 1-hr extinction sessions were conducted, in which the session ran as usual but reinforcers were not delivered. Successive resistance-to-change tests were separated by at least two baseline sessions, and response rate during the session before each test had to be within the range of response rates of the five baseline sessions preceding the first test.

Response rates were recovered after extinction, and the FR schedule value was increased to FR 60 for one session. Responding was then maintained under FR 80 for 25 sessions until rates stabilized, and the same resistance-to-change tests described above were conducted. The FR schedule was increased to FR 120 for one session and was maintained under FR 160 for 26 to 38 sessions before resistance-to-change tests were conducted a third time. Finally, the schedule value was reduced to FR 40 for 20 to 23 sessions, and resistance-to-change tests were conducted a fourth time.

## RESULTS AND DISCUSSION

Figure 4 presents the effects of prefeeding, response-independent food delivery, and extinction on the proportion of baseline response rates (response rate during a test divided by the rate in the immediately preceding session). For each analysis, ratios of test to pretest response rates were averaged when redeterminations of resistance-to-change tests were con-

ducted (e.g., the two VT 40-s tests). In most cases, response rates were lowered below baseline levels during resistance-to-change tests. As in Experiment 1, there was no consistent relationship between the amount of response reduction and the value of the FR schedule of reinforcement under any of the three resistance-to-change operations. For example, Pigeon 1894 showed the same degree of response reduction after 5% prefeeding under FR 40 (first determination) and FR 80 schedules and relatively little reduction under the FR 160 schedule. Resistance to extinction was greatest under the FR 160 schedule during the first extinction session, but no consistent differences were observed during Sessions 2 and 3.

Appendix 5 shows absolute response rates (mean values in cases of redeterminations) during each resistance-to-change test and the mean baseline response and reinforcement rates (means of the nine sessions immediately preceding each test) under each FR schedule. Table 2 presents  $\bar{p}$  values for each resistance-to-change test. The  $\bar{p}$  values failed to show a consistent relationship between the degree of response reduction and rate of reinforcement under tests of prefeeding, response-independent food, or extinction.

In summary, the data of Experiment 2 are in agreement with those of Experiment 1, indicating that the results of previous research on behavior momentum (e.g., Nevin, 1974, 1979) are not consistent with the results of experiments using simple schedules of reinforcement, whether rats or pigeons are used as subjects.

## EXPERIMENT 3: MULTIPLE SCHEDULES WITH RATS

Most studies of behavior momentum have used complex schedules of reinforcement such as multiple, chained, and concurrent schedules (e.g., Nevin, 1974; Nevin et al., 1981, 1983, 1990). Under these schedules, different stimuli (i.e., key color or location) are associated with different rates of reinforcement, and the subject is exposed to these rates within the experimental session. These conditions do not exist with simple schedules, in which reinforcers are not differentially associated with stimuli and shifts in exposure to reinforcement rates may span months. Experiment 3 examined resistance to change in rats using multiple schedules. Except for the use of multiple

rather than simple schedules, the conditions were identical to Experiment 1. Thus, the same strain of rats, operant chambers, response levers, houselight stimuli, tests of resistance to change, and so on, were used, resulting in a more direct comparison than examining experiments across laboratories. This study also examined multiple FR and FI schedules (in contrast to the commonly used VI schedules) for a further test of the generality of the behavior-momentum hypothesis. Finally, Experiment 3 used an additional resistance-to-change test: Response-independent food was delivered during the timeout separating components of the multiple schedules. This was done to compare the effects of free-food delivery during the schedule (Experiment 1) with the more traditional method of delivering free food (i.e., in the timeout).

## METHOD

### *Subjects and Apparatus*

Fourteen male Sprague-Dawley albino rats (Camm Research) were previously trained by undergraduate experimental psychology students for approximately 20 sessions under FR 40 schedules of reinforcement. Rats weighed between 316 and 369 g after food deprivation and were maintained at 80% of free-feeding body weights. The same apparatus described in Experiment 1 was used.

### *Procedure*

*Multiple FR FR.* Seven rats were assigned to a mult FR FR schedule of reinforcement and to an operant chamber. The two components of the multiple schedule were signaled by constant and flashing (0.5 s on, 0.5 s off) illumination of the houselight, respectively. Each component lasted 3 min and was separated by a 60-s timeout, during which the houselight was turned off and lever presses had no scheduled consequences. Component 1 was signaled by the constant houselight for 4 rats and by the flashing houselight for 3 rats. Sessions terminated after each component was on eight times. Components 1 and 2 were scheduled in pairs, and one of the two components within each pair was chosen randomly to occur first.

Rats were exposed first to a mult FR 1 FR 2 schedule. One response in Component 1 produced a food pellet, turned off the houselight,

and turned on the feeder light for 1 s; two responses produced these consequences in Component 2. As the size of the FR was increased, several rats failed to maintain responding; thus the FRs were adjusted for each rat until stable responding was maintained. The ratio in Component 1 was always smaller than in Component 2. Table 3 presents the FR schedule values in each component and the number of sessions under each, the number of sessions under transition ratios before the terminal ratios were reached, and the average rate of reinforcement for the last five baseline sessions before the first resistance-to-change test.

*Multiple FI FI.* Seven rats were assigned to a mult FI 30-s FI 120-s schedule of reinforcement. The experiment started with a mult FI 3-s FI 6-s schedule, and the values of the fixed intervals were gradually increased over 10 sessions to mult FI 30 s FI 120 s. This schedule was in effect for 45 to 48 sessions before the first resistance-to-change test. Conditions were identical to the mult FR FR, except that FI 30-s and FI 120-s schedules were arranged in Components 1 and 2, respectively, and the component presentations terminated following the first reinforcement after 240 s. A component terminated automatically after 300 s if food was not delivered between 240 and 300 s of component onset.

*Resistance-to-change tests.* Tests of prefeeding, response-independent food presentations, and extinction began when overall response rates in both components showed no increasing or decreasing trends for at least five consecutive sessions. First, rats in the mult FR FR group were fed 3% of their ad libitum body weights in their home cages 1.5 hr before the session. This condition was conducted twice and was followed by a test in which rats were given 50 g of food for 22 hr before the session. A greater amount of food was prefed than in Experiment 1 because 1% did not substantially affect response rates. Rats in the mult FI FI group were given 2.5%, 5%, 2.5%, 5%, and 50 g prefeeding. Second, response-independent food was delivered during both components of the multiple schedule according to VT schedules of reinforcement, as described in Experiment 1. The sequence of conditions was VT 40 s, 20 s, 10 s, 40 s, 20 s, and 10 s. The range of intervals was always 0 s to double the VT value (see Experiment 1). Third, response-independent food was delivered according to VT

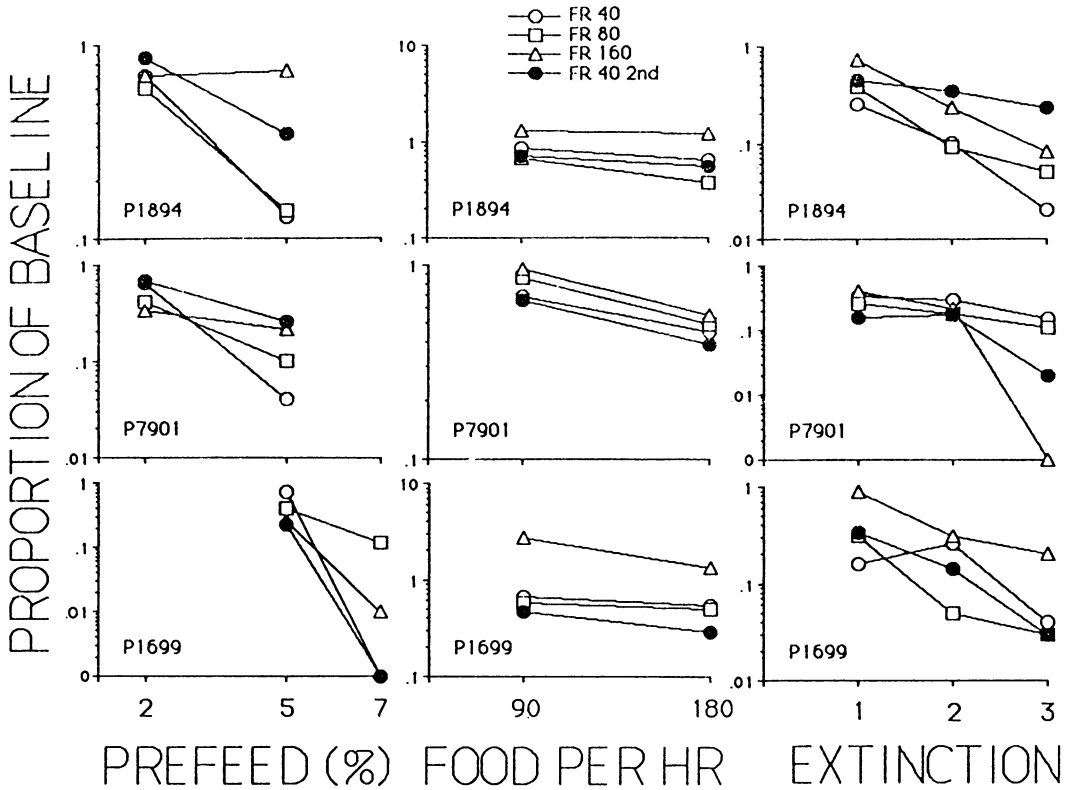


Fig. 4. Experiment 2. Proportion of baseline response rates when pigeons were fed before the test session, given response-independent food during the schedule according to VT 40-s (90 reinforcers per hour) and VT 20-s (180 reinforcers per hour) schedules, and given three extinction sessions. Data for individual pigeons under four successive conditions of the FR schedule are shown. The vertical axes are logarithmic.

schedules during the 60-s timeout separating components. The sequence of conditions was VT 40 s, 20 s, 10 s, 5 s, 10 s, and 5 s. Rats in the mult FI FI group were also given a VT 2.5-s condition. Finally, three successive extinction sessions were conducted, in which the session ran as usual, but reinforcers were not delivered and component duration was 180 s under the ratio schedules and 240 s under the interval schedules. Successive resistance-to-change tests were separated by at least two baseline sessions, and response rate during the session before each test had to be within the range of response rates of the five baseline sessions preceding the first test.

RESULTS AND DISCUSSION

Absolute response rates during each test (means presented in cases of redetermined tests) and mean response and reinforcement rates for the sessions (16 under mult FR FR and 19

under mult FI FI) immediately preceding each test session are presented in Appendices 6 and 7.

*Prefeeding.* Figure 5 (left panel) presents the effects of 3% and 50 g prefeeding on proportion of baseline response rates for rats under the mult FR FR schedule. Both prefeeding operations lowered response rates, especially after 50 g access. Most importantly, rates were reduced relatively more in the component with the larger FR schedule (lower rate of reinforcement). Similar results were obtained under the mult FI FI schedule (right panel).

*Response-independent food during the component.* Figure 6 (left panel) shows the effects of delivering response-independent food (VT 40 s, 20 s, and 10 s) during each component of the mult FR FR schedule. Response-rate reduction was a direct function of the rate of free-food delivery. The prediction of greater response-rate reductions in the component

Table 2

Experiment 2. Weighted mean proportion of baseline response rates ( $\bar{p}$ ) during prefeeding, response-independent food, and extinction test sessions for pigeons under simple FR 40, 80, 160, and 40 schedules.

Pigeon	FR	Prefeed	Response-independent food	Extinction
1894	40	0.29	0.72	0.17
	80	0.27	0.47	0.12
	160	0.73	1.2	0.24
	40	0.49	0.61	0.30
7901	40	0.21	0.53	0.23
	80	0.19	0.61	0.16
	160	0.17	0.68	0.14
	40	0.37	0.48	0.09
1699	40	0.30	0.58	0.13
	80	0.24	0.52	0.08
	160	0.11	1.8	0.35
	40	0.10	0.35	0.12

controlling lower reinforcement rates was not evident. In fact, most animals (except Rat 33) showed greater reductions in the component with the smaller FR. Free-food delivery also lowered response rates under the mult FI FI schedule (right panel), and there were no consistent differences between the FI 30-s and FI 120-s components in the amount that response rates were reduced.

*Response-independent food during the timeout.* Figure 7 (left panel) presents the results of delivering response-independent food (VT 40 s, 20 s, 10 s, and 5 s) during the timeout separating components for rats under the mult FR FR schedule. In most cases, relative response-rate reduction was a direct function of the rate of free-food delivery. Furthermore, there were greater reductions in response rates in the components with the larger FR in 21

Table 3

Experiment 3. Ratio values for each rat in Components 1 and 2 of the multiple FR FR schedule, the number of transition sessions before the terminal ratio values were reached, the number of sessions under the terminal schedules, and the mean rate of reinforcement for the last five baseline sessions before the first resistance-to-change test.

Rat	FR		Transition sessions	Terminal sessions	Rein/hr	
	Component 1	Component 2			Component 1	Component 2
31	40	160	21	48	246	69
33	10	20	51	16	310	251
34	10	30	23	45	368	72
35	20	80	26	42	351	166
36	40	120	33	33	238	37
37	40	120	52	15	127	22
38	30	120	40	28	256	78

of 28 comparisons. Relative reductions in response rates were also a direct function of the rate of free-food delivery in the mult FI FI schedule (right panel), but there were no consistent differences between the FI 30-s and FI 120-s components in the relative amount that response rates were reduced.

*Extinction.* Figure 8 presents the effects of three extinction sessions. Response rates declined progressively across sessions for rats in the mult FR FR (left panel) and mult FI FI (right panel) groups. Although individual exceptions can be noted (e.g., Rat 33 in Sessions 2 and 3), response rates declined relatively more quickly under the schedules controlling lower baseline rates of reinforcement, and the slopes of the extinction curves for most subjects were steeper in the component with the larger FR and FI schedules.

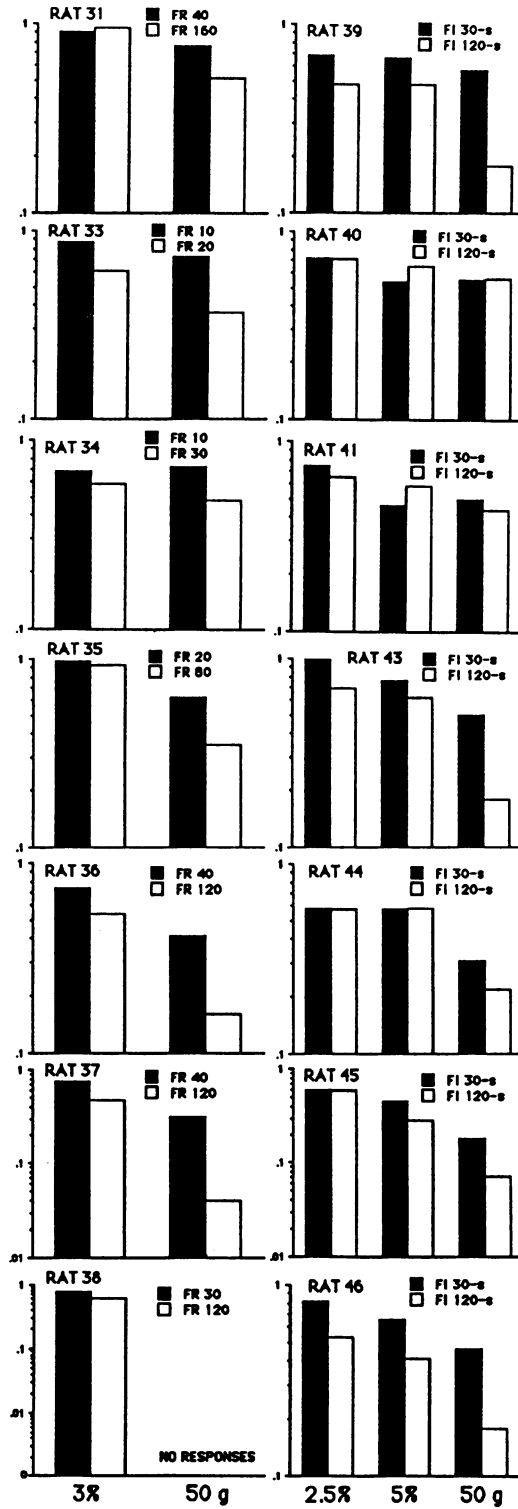
*Weighted mean proportion of baseline.* Table 4 presents  $\bar{p}$  values for each resistance-to-

Fig. 5. Experiment 3. Proportion of baseline response rates when rats were fed before the test session. The left panels show results from the component of the mult FR FR schedule containing the smaller valued FR (filled bars) and the component containing the larger valued FR (open bars). The right panels show results from components of the mult FI 30-s (filled bars) FI 120-s (open bars) schedule. Data for individual rats are shown. The vertical axes are logarithmic.

Fig. 6. Experiment 3. Proportion of baseline response rates when rats were given response-independent food during the schedule according to VT 40-s (90 reinforcers per hour), VT 20-s (180 reinforcers per hour), and VT 10-s (360 reinforcers per hour) schedules.

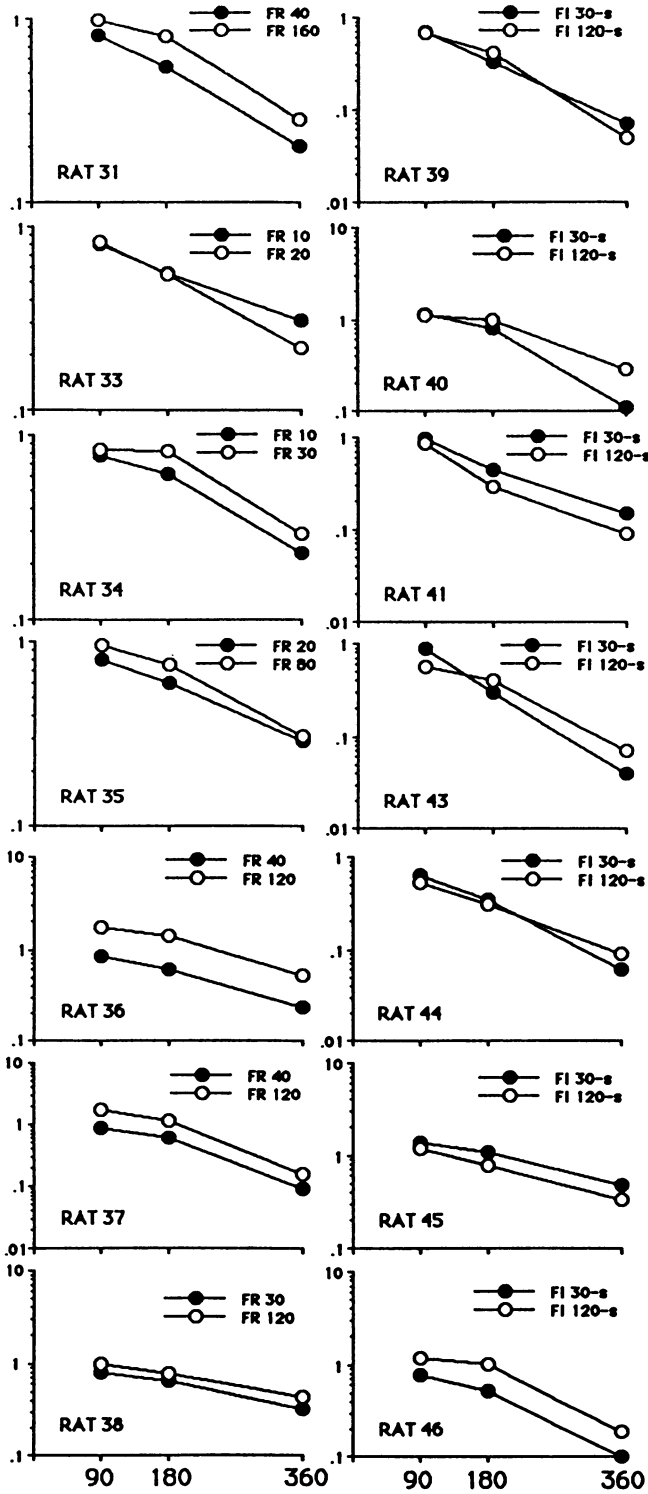
Fig. 7. Experiment 3. Proportion of baseline response rates when rats were given response-independent food during the timeout separating multiple-schedule components according to VT 40-s (90 reinforcers per hour), VT 20-s (180 reinforcers per hour), VT 10-s (360 reinforcers per hour), VT 5-s (720 reinforcers per hour), and VT 2.5-s (1,440 reinforcers per hour) schedules.

PROPORTION OF BASELINE



PREFEEDING

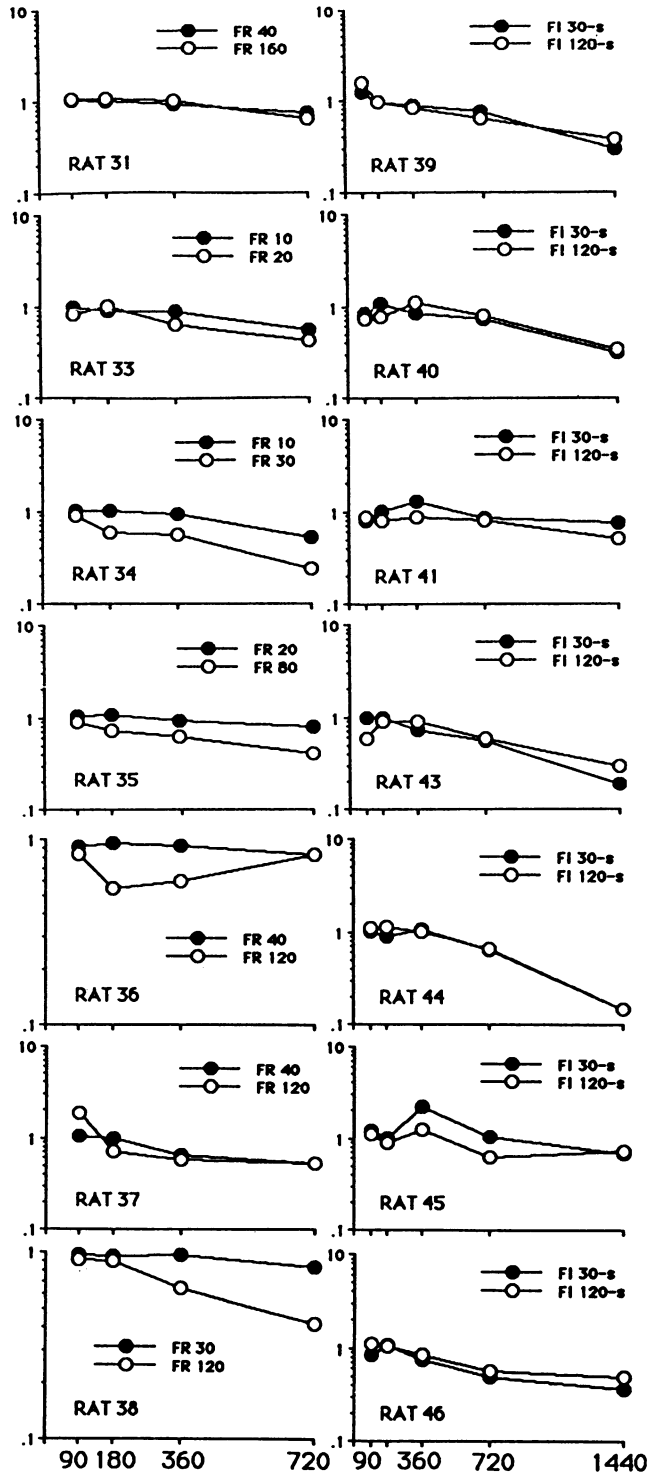
PROPORTION OF BASELINE



FOOD PER HOUR



PROPORTION OF BASELINE



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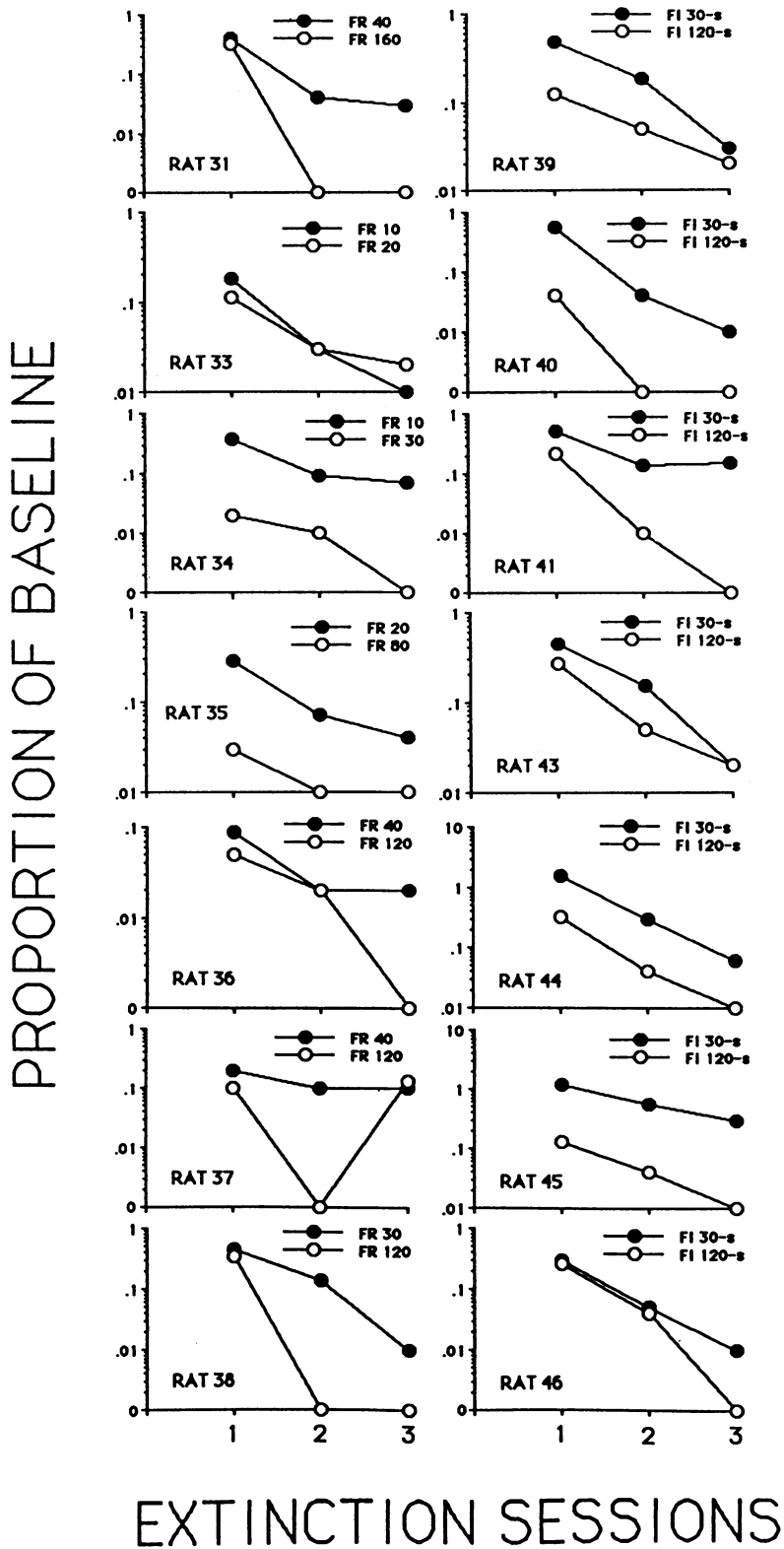


Fig. 8. Experiment 3. Proportion of baseline response rates during three extinction sessions.

Table 4

Experiment 3. Weighted mean proportion of baseline response rate ( $\bar{p}$ ) for Rats 31 to 38 under the multiple FR FR schedule and Rats 39 to 46 under the multiple FI 30-s FI 120-s schedule during test sessions with prefeeding, response-independent food delivered during the schedule and during the timeout between schedule components, and extinction.

Rat	Prefeeding		Response-independent food		Response-independent food (timeout)		Extinction	
	FR		FR		FR		FR	
	Small	Large	Small	Large	Small	Large	Small	Large
31	0.80	0.64	0.38	0.53	0.84	0.81	0.10	0.06
33	0.77	0.45	0.45	0.40	0.71	0.59	0.05	0.04
34	0.70	0.53	0.42	0.52	0.73	0.42	0.13	0.01
35	0.74	0.54	0.45	0.53	0.89	0.54	0.09	0.01
36	0.53	0.30	0.42	0.96	0.88	0.74	0.03	0.02
37	0.47	0.19	0.35	0.67	0.66	0.65	0.12	0.08
38	0.23	0.19	0.48	0.61	0.90	0.59	0.13	0.06
	FI		FI		FI		FI	
	30	120	30	120	30	120	30	120
39	0.62	0.34	0.23	0.25	0.56	0.58	0.15	0.05
40	0.58	0.62	0.46	0.61	0.55	0.60	0.11	0.01
41	0.53	0.53	0.35	0.26	0.87	0.66	0.21	0.04
43	0.69	0.44	0.24	0.23	0.43	0.50	0.14	0.07
44	0.45	0.40	0.22	0.22	0.48	0.49	0.39	0.07
45	0.36	0.24	0.78	0.58	1.02	0.80	0.53	0.04
46	0.59	0.32	0.32	0.57	0.51	0.62	0.07	0.06

change operation. Under each prefeeding operation, rats were prefed a fixed percentage of their body weights (which was almost always consumed) and were given access to 50 g for 22 hr. In the latter case, for the purpose of the  $\bar{p}$  calculations, the amount of food eaten during the 22 hr was measured, and this value was converted to percentage of body weight for each rat (range, 5% to 7%). Every rat in the mult FR FR group showed greater relative reductions in response rate in the component with the larger FR schedule after prefeeding, response-independent food during the *timeout*, and extinction. In contrast, 6 of 7 rats reduced response rates relatively more in the component with the smaller FR schedule when response-independent food was delivered during the *component*. Five of 7 rats in the mult FI FI group showed greater relative reductions in response rates in the component with the larger FI schedule after prefeeding, and every rat showed greater reductions after extinction. However, no consistent differences were observed between components when response-independent food was delivered, regardless of whether it was delivered during the component or the timeout.

*Postreinforcement pause (PRP)*. The PRP

was measured in order to determine the extent that response-independent food delivery during the timeouts altered response patterns under the FR and FI schedules (data for other disruptive operations are not presented; see General Discussion for a more thorough rationale). The time from each food delivery to the first response was measured, and mean PRPs were calculated for each component of the session. The PRP did not include the time from food delivery to component termination if the subject did not respond before the end of the component. Proportion of baseline PRP was calculated by dividing the PRP during a VT test session by the PRP in the immediately preceding baseline session. Under the mult FI 30-s FI 120-s schedule, free food during the timeout increased, decreased, or did not affect the PRP, and no functional relationships were observed between proportion of baseline PRP, VT value, and the size of the FI. However, an analysis of the number of times that free-food delivery substantially altered the PRP (arbitrarily defined as a 10% or more increase or decrease from baseline pausing) revealed that free food during the timeout may have affected response patterns. Table 5 presents the number of times that the PRP changed by

Table 5

Experiment 3. The number of times that free-food delivery during the timeout (VT 40 s, 20 s, 10 s, 5 s, and 2.5 s under mult FI FI and VT 40 s, 20 s, 10 s, and 5 s under mult FR FR) increased or decreased the PRP by 10% or more from baseline (PRP on the session immediately preceding the test session), summed for all 7 rats under each schedule. Also shown are the median and range of percentage change in the PRP from baseline during the VT test.

	FI 30 s	FI 120 s	Small FR	Large FR
Increase	9	7	11	14
Median (%)	32	25	18	38
Range	13-91	11-40	11-56	11-154
Decrease	12	22	2	7
Median (%)	19	43.5	14.5	30
Range	11-31	10-69	14-15	14-67

10% or more from baseline under the two components of the multiple FI FI schedule during tests of response-independent food, summed across 7 rats and five VT schedules (the mean change in PRPs was used in cases of redeterminations). A maximum score of 35 in Component 1 would indicate, for example, that the PRP changed substantially from baseline for every rat under every VT test condition. In several cases, response-independent food lengthened the PRP in both FI components. Interestingly, free food shortened the PRP from baseline levels in many more test sessions, particularly in the FI 120-s component. Analysis of the PRP can also be used as a measure of resistance to change during free-food delivery. The proportion of baseline PRP in an FI 30-s component was compared to the proportion of baseline in its respective FI 120-s component during each of the 35 test sessions. When any change from baseline pausing was considered (not just 10% or greater), the change in PRP was greater in the FI 120-s component on 24 of 35 comparisons ( $z = 2.03$ ,  $p < .05$ , binomial test).

There was also no functional relationship between the proportion of baseline PRP, VT value, and the size of the FR under the mult FR FR schedule. Table 5 shows the number of times that the PRP changed by 10% or more during tests of response-independent food in the two components of the mult FR FR schedule, summed across 7 rats and four VT schedules. Response-independent food increased the PRP in both FR components in many VT test sessions and decreased the PRP in relatively

few sessions. Comparisons of proportion of baseline PRPs in a small FR component with the proportion in its respective larger FR component during each of the 28 test sessions showed that the change (any change) in PRP was greater in the larger FR component on 21 of 28 comparisons ( $z = 2.46$ ,  $p < .05$ ).

The data from Experiment 3 were, for the most part, consistent with previous studies on behavior momentum (e.g., Nevin, 1979). Feeding rats before the session reduced response rates relatively less in the components of both multiple schedules that provided higher rates of reinforcement. Similarly, resistance to extinction was greater in those same components. Thus, data from prefeeding and extinction tests indicated that baseline rate of reinforcement is a good predictor of response strength in multiple schedules, and, furthermore, that this relationship holds in multiple FR and FI schedules with rats as subjects. As in Experiments 1 and 2, however, delivering response-independent food while the schedule was in effect did not reduce response rates relatively more in components providing less reinforcement; similar degrees of response disruption were observed in both components of the mult FI 30-s FI 120-s schedule, and more relative disruption was observed in the smaller components of the mult FR FR schedule.

When response-independent food was delivered during the timeouts separating components, responding was reduced relatively more in the larger FR component—a result consistent with previous research on behavior momentum (e.g., Nevin, 1974, 1979). However, no consistent differences were observed between components of the mult FI 30-s FI 120-s schedule. This finding suggests that predictions of behavior momentum might have to account for schedule differences under certain tests of resistance to change. Even under the multiple FR schedules, the magnitude of effect was not as large or consistent as that reported under multiple VI schedules (e.g., Harper & McLean, 1992; Nevin, 1974); Figure 7 (left panel) showed that under the mult FR FR schedule, greater response reductions were observed in the larger FR component in 21 of 28 comparisons (75%), contrasted with 12 of 14 comparisons (86%) with prefeeding (Figure 5) and 17 of 21 comparisons (81%) with extinction (Figure 8). The momentum effect thus appeared somewhat less robust under the free-

food test compared with prefeeding and extinction. The question remains whether weaker or absent differential effects on response rates during tests of free food during the timeout represented a schedule (fixed vs. variable) difference or a species (rats vs. pigeons) difference.

Interestingly, resistance to change in the PRP was directly related to rate of reinforcement in the components of both multiple schedules under tests of free-food delivery during the timeout. This relationship was even evident in the multiple FI schedule, in which free-food delivery during the timeouts failed to affect response rates differentially. This finding suggests that the analysis of the PRP during tests of resistance to change might provide a useful supplement to the analysis of response rates in determinations of behavior momentum.

#### EXPERIMENT 4: MULTIPLE SCHEDULES WITH PIGEONS

The last experiment completed the comparison of species and schedules by examining resistance to change in pigeons under multiple FR and multiple FI schedules of reinforcement. This experiment resembled other studies using multiple schedules of reinforcement (e.g., Harper & McLean, 1992; Nevin, 1974), except that FR and FI rather than VI schedules were used, and three-component multiple schedules rather than two-component schedules were used. Three components were used to explore further the limits of behavior momentum. As in Experiment 3, four different tests of resistance to change were conducted.

#### METHOD

##### *Subjects and Apparatus*

Seven experimentally naive male White Carneau pigeons (Palmetto Pigeon Plant) were maintained at 80% of their free feeding body weights (80% weights between 377 g and 483 g). Water was freely available in their home cages, where a 12:12 hr light/dark cycle was maintained (lights on at 6:00 a.m.). The apparatus was as described in Experiment 2.

##### *Procedure*

*Multiple FR FR FR.* Three pigeons were assigned to a mult FR schedule of reinforcement

and to an operant chamber. Pecking a red key was established and maintained by an autoshaping procedure for three to five sessions. Responding was then maintained for two sessions under an FR 3 schedule and for one session each under FR 10, 20, and 40 schedules before initiating the multiple schedule.

The three components of the multiple schedule were signaled by red, green, and yellow keylights, respectively. The houselight was on for the entire session, except during food presentations. Each component lasted 3 min and was followed by a 60-s timeout, during which the center keylight was turned off and key pecks had no scheduled consequences. Sessions terminated after each component appeared five times. Components 1, 2, and 3 were scheduled in blocks, and components were randomly arranged within each block. The size of the FR within each component was gradually increased over 9 to 15 sessions until each pigeon was responding under a mult FR 30 FR 60 FR 90 schedule of reinforcement. Under each FR schedule, a fixed number of responses turned off the keylight and houselight, turned on the feeder light, and presented food for 3 s.

The multiple schedule was in effect for 60 to 69 sessions before response rates stabilized within each component and resistance-to-change tests began. First, pigeons were fed a percentage of their ad libitum body weights in their home cages 1 hr before the session. Pigeon 1896 was prefed 5%, 10%, 5%, and 10%. Pigeon 1693 was prefed 5%, 2.5%, 2.5%, 5%, and 2.5%. Pigeon 3867 was prefed 5%, 10%, 15%, 10%, 15%, 10%, and 15%. Second, response-independent food was delivered during each component according to a VT 40-s, 20-s, 40-s, and 20-s schedule of reinforcement. Third, response-independent food was delivered during the timeout separating components. Pigeon 1896 received VT 40 s, 20 s, 10 s, 40 s, 20 s, 10 s, 5 s, and 5 s. Pigeon 1693 received VT 40 s, 20 s, 10 s, 5 s, 40 s, 20 s, 10 s, and 5 s. Pigeon 3867 received VT 40 s, 20 s, 10 s, 5 s, 2.5 s, 40 s, 20 s, 10 s, 5 s, and 2.5 s. Finally, each pigeon received three consecutive extinction tests in which the session ran as usual but key pecks had no scheduled consequences.

*Multiple FI FI FI.* Four pigeons were assigned to a mult FI schedule of reinforcement and to an operant chamber. Pecking a red key

was established and maintained by an auto-shaping procedure for three to five sessions. Responding was then maintained for two sessions under an FR 3 schedule and for one session each under FR 5 and FR 20 before initiating the multiple schedule.

The multiple schedule was identical to the mult FR schedule except that components contained fixed FI schedules, and a component terminated following the first food delivery after 240 s from component onset, or 300 s from component onset if food was not delivered after 240 s. The first session was a mult FI 10-s FI 10-s FI 10-s schedule, in which the first response after 10 s produced food in each component. The size of the fixed intervals was gradually increased over six to eight sessions until each pigeon was responding under mult FI 30 s FI 60 s FI 120 s.

This schedule was in effect for 62 sessions before response rates stabilized within each component and resistance-to-change tests began. First, pigeons were fed a percentage of their ad libitum body weights in their home cages 1 hr before the session. Pigeons 1672, 3276, and 1654 were prefed 5%, 10%, 5%, 10%, 5%, and 10%, and Pigeon 4835 was prefed 5%, 10%, 5%, and 10%. Second, response-independent food was delivered during each component according to VT 40-s, 20-s, 40-s, and 20-s schedules of reinforcement. Pigeon 3276 died of unknown reasons after these tests were completed. Third, response-independent food was delivered during the timeout separating components. Pigeon 1672 received VT 40 s, 20 s, 10 s, 5 s, 40 s, 20 s, 10 s, 5 s, 2.5 s, and 2.5 s. Pigeon 1654 received VT 40 s, 20 s, 10 s, 5 s, 40 s, 20 s, 10 s, and 5 s. Pigeon 4835 received VT 40 s, 20 s, 40 s, and 20 s. Finally, each pigeon received three consecutive extinction sessions in which key pecks had no scheduled consequences and component duration was 240 s. Under both multiple schedules, successive resistance-to-change tests were separated by at least two baseline sessions, and response rate during the session before each test had to be within the range of response rates of the five baseline sessions preceding the first test.

## RESULTS AND DISCUSSION

Absolute response rates during each test session (means of redeterminations) and mean response and reinforcement rates for the ses-

sions immediately preceding each test are presented in Appendices 8 and 9.

*Prefeeding.* Figure 9 presents the results of prefeeding on proportion of baseline response rates. With both multiple schedules, prefeeding lowered response rates to a greater extent in the component providing the lower baseline rates of reinforcement. This effect was evident in all 3 pigeons under the multiple FR schedules (left panel), with the exception of Pigeon 1693, who did not respond after 5% prefeeding. It was also evident in all 4 pigeons under the multiple FI schedules (right panel), with the exception of Pigeon 4835 under 5% prefeeding, for whom slightly more response reduction occurred in the FI 30-s component than in the FI 60-s component.

*Response-independent food during the component.* Figure 10 shows the results of presenting response-independent food during each component of the multiple schedule. There was no consistent relationship between changes in response rates during free-food delivery and baseline rates of reinforcement under either the multiple FR (left panel) or FI (right panel) schedules.

*Response-independent food during the timeout.* Figure 11 shows the results of presenting response-independent food during the timeouts separating components of the multiple schedules. Free food altered (decreased but sometimes increased) baseline response rates to a greater degree in components of the multiple schedules providing the lowest rates of reinforcement. Under the multiple FR schedules (left panel), the smallest deviations from baseline response rates occurred in the FR 30 component under all rates of free-food delivery for Pigeons 1896 and 1693, and under 360, 720, and 1,440 reinforcers per hour for Pigeon 3867. Under the multiple FI schedule (right panel), Pigeons 1654 and 4835 showed the smallest deviations from baseline response rates in the FI 30-s component under all rates of free-food delivery, and Pigeon 1672 showed the smallest deviation in the FI 30-s component under 90, 180, and 360 reinforcers per hour.

*Extinction.* Figure 12 presents the results of three extinction sessions. Response rates declined progressively across sessions in the multiple FR (left panel) and FI (right panel) schedules. Under the multiple FI schedules, response rates declined relatively more quickly

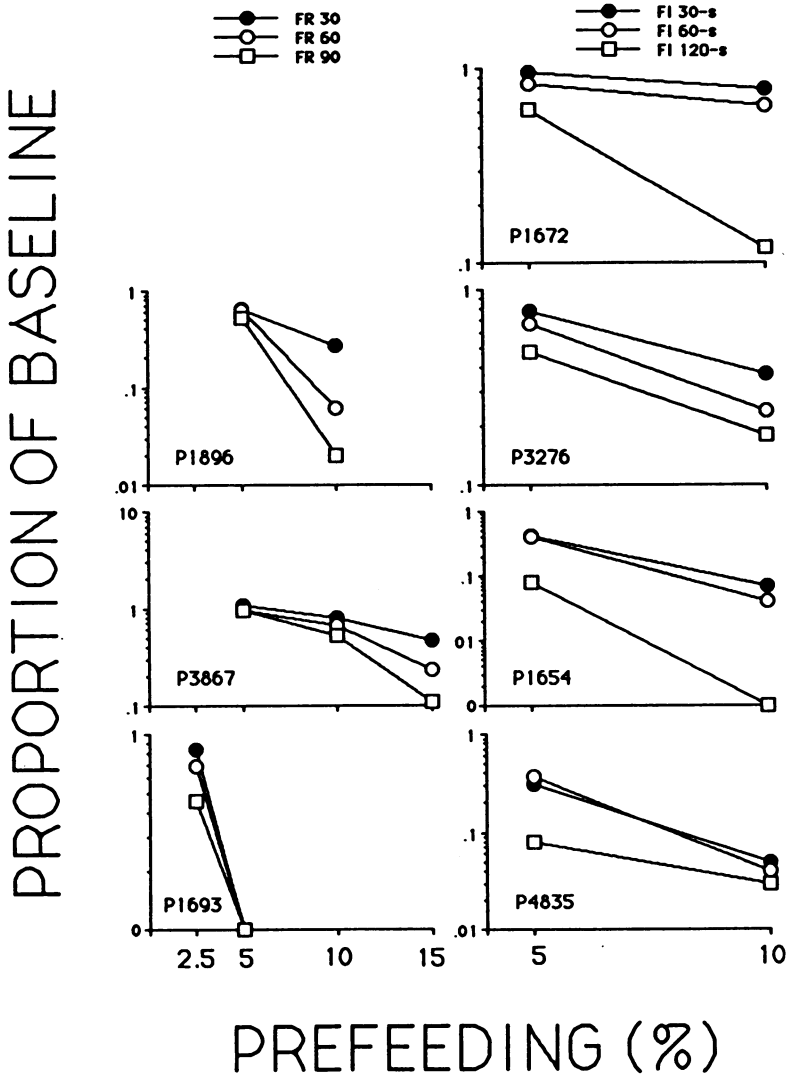


Fig. 9. Experiment 4. Proportion of baseline response rates when pigeons were fed before the session. The left panel shows proportion of baseline response rates in components of the mult FR 30 (filled circles) FR 60 (open circles) FR 90 (open squares) schedule. The right panel shows proportion of baseline response rates in components of the mult FI 30-s (filled circles) FI 60-s (open circles) FI 120-s schedule (open squares). Data for individual pigeons are shown. The vertical axes are logarithmic.

under the schedules providing lower baseline rates of reinforcement. A more complex pattern was evident under the multiple FR schedules. Consistent with the momentum view, Pigeons 1896 and 1693 showed the greatest resistance to extinction in the FR 30 component and the least resistance in the FR 90 component in Sessions 1 and 3, but no consistent relationship was evident in Session 2. The least resistance to extinction was observed in the FR 30 component with Pigeon 3867.

*Weighted mean proportion of baseline.* Table 6 presents  $\bar{p}$  values for each resistance-to-change operation. In both multiple schedules, prefeeding and response-independent food during timeout periods lowered response rates the most in components with the lowest baseline rates of reinforcement. Under extinction, a similar pattern was evident in all pigeons trained under the multiple FI schedule, but not in those trained under the multiple FR schedule, where Pigeon 3867 showed the

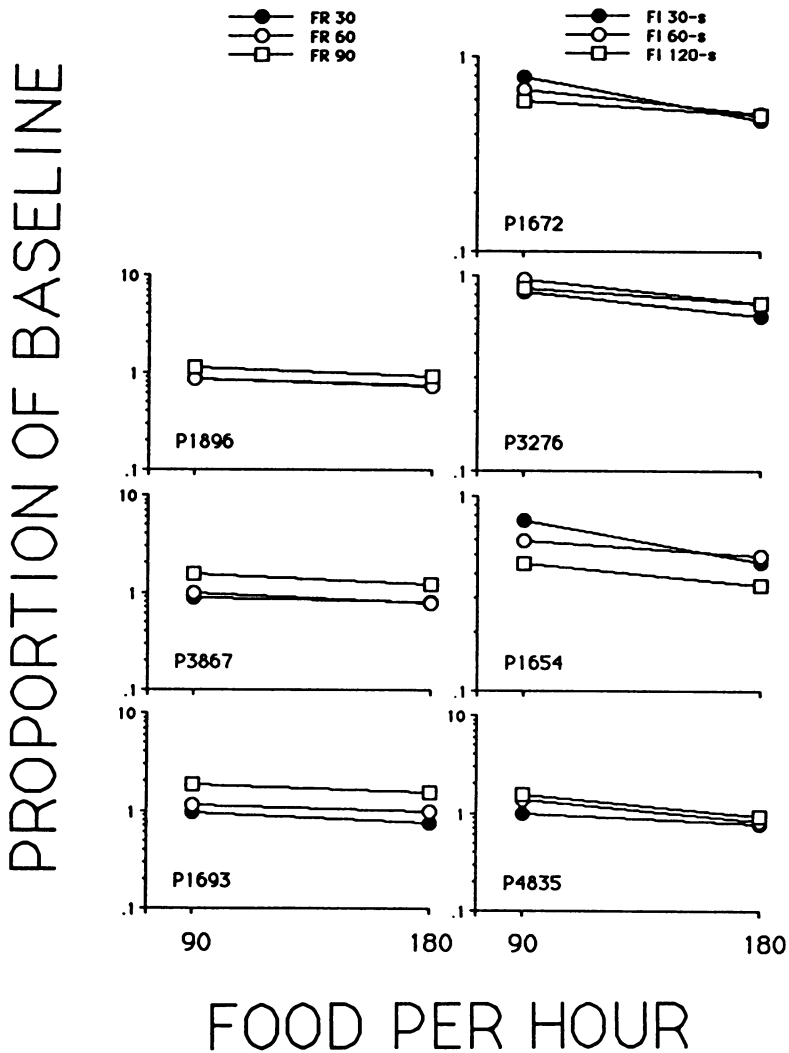


Fig. 10. Experiment 4. Proportion of baseline response rates when pigeons were given response-independent food during the schedule according to VT 40-s (90 reinforcers per hour) and VT 20-s (180 reinforcers per hour) schedules. Details as in Figure 9.

greatest resistance to extinction in the FR 90 component. Free-food delivery *during the component* failed to produce consistent alterations in  $\bar{p}$  values under the three components of either multiple schedule, although large increases over baseline response rates under the FR 90 component were clearly evident in 2 of the 3 pigeons.

*Postreinforcement pause.* As in Experiment 3, the PRP was recorded in each component of the multiple schedules during tests of free-food delivery in the timeouts, and proportion of baseline PRP was calculated as described above. Free food during the timeout increased,

decreased, or did not affect the PRP, and no functional relationships were observed between PRP, VT value, and the size of the schedule values. Table 7 presents the number of times that the PRP changed by 10% or more under the three components of both multiple schedules, summed across 3 pigeons and five VT schedules. (There were a total of 11 test sessions under the multiple FI schedule and 13 test sessions under the multiple FR schedule.) As in Experiment 3, pigeons showed both increases and decreases in PRP from baseline levels during free-food delivery under both multiple FI and FR schedules. The PRP de-



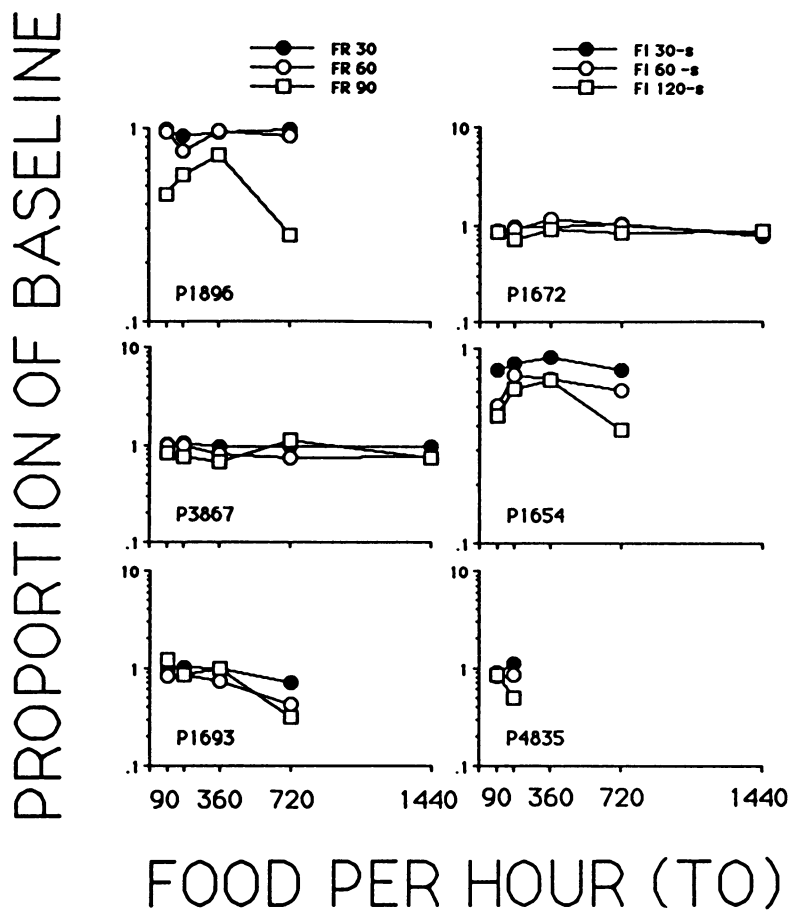


Fig. 11. Experiment 4. Proportion of baseline response rates when pigeons were given response-independent food during the timeout separating components according to VT 40-s (90 reinforcers per hour), VT 20-s (180 reinforcers per hour), VT 10-s (360 reinforcers per hour), VT 5-s (720 reinforcers per hour), and VT 2.5-s (1,440 reinforcers per hour) schedules. Details as in Figure 9.

creased from baseline levels in a number of test sessions, suggesting some impact on response patterning from free-food delivery. Unlike with rats, however, a change in PRP was no more likely to occur in components providing lower rates of reinforcement (e.g., FI 120 s) than components providing higher rates of reinforcement (e.g., FI 30 s).

The results of Experiment 4 are consistent with previous research on behavior momentum (e.g., Nevin, 1974, 1979). With prefeeding, responding under multiple FR and FI schedules was most resistant to change in components with the highest frequency of reinforcement. This effect has been reported under two-component multiple VI schedules (e.g., Nevin et al., 1990) and is now reported here in three-component multiple FR and FI sched-

ules. As in Experiment 3, there was a direct relationship between resistance to extinction and rate of reinforcement in components of the multiple FI schedule. However, the relationship was not as clear in the multiple FR schedule, in which data were consistent with the momentum hypothesis in two of three extinction sessions in 2 of 3 pigeons. It is unclear why these extinction data did not fall more consistently in line with those of the other multiple schedule.

As in the previous experiments, delivering response-independent food while the maintaining schedule was in effect did not reduce response rates relatively more in schedules providing less reinforcement. Presenting free food during the timeout, however, did alter response rates relatively more in low-rein-

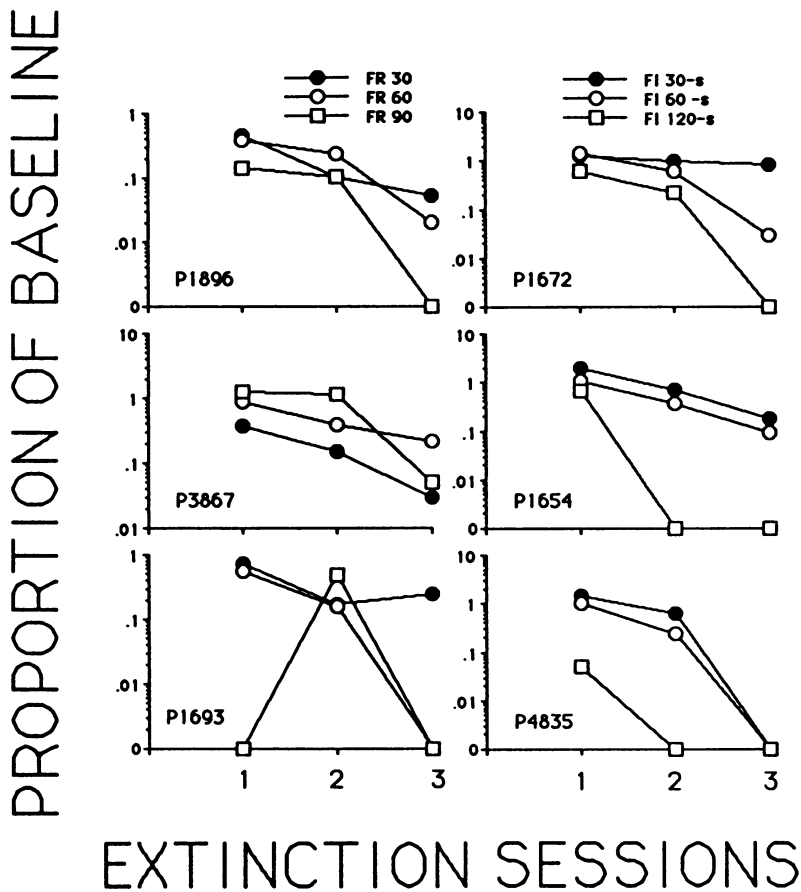


Fig. 12. Experiment 4. Proportion of baseline response rates during three extinction sessions. Details as in Figure 9.

forcement-rate components of both multiple schedules. Although these data (i.e., free food during the timeout) are clearly consistent with other research on behavior momentum, the magnitude of effect is not as great as that reported in multiple VI schedules (e.g., Harper & McLean, 1992; Nevin, 1974; Nevin *et al.*, 1983), as was also noted in Experiment 3. However, because the present experiments did not examine multiple VI schedules, it is impossible to make quantitative statements comparing multiple VI schedules with multiple FR and FI schedules with a high degree of certainty.

#### GENERAL DISCUSSION

One purpose of the present study was to establish the boundary conditions within which resistance to change and rate of reinforcement

are directly related. First, there were no consistent differences in the outcome of resistance-to-change tests between rats and pigeons, indicating that the relationship between baseline rates of reinforcement and resistance to change generalizes across these species. Second, there is ample evidence showing that resistance to change is greater for responses emitted in the component of a multiple VI VI schedule that provides a higher rate of reinforcement (e.g., Nevin, 1974, 1979). This evidence is consistent with the results of the present study, in which resistance to change was measured in multiple FR and multiple FI schedules with two and three components. Third, unlike the relationship observed in multiple schedules, we found no consistent relationship between resistance to change and rate of reinforcement under simple FR, VR, FI, and VI schedules of reinforcement. Fourth, with the exception of ex-

Table 6

Experiment 4. Weighted mean proportion of baseline response rate ( $\bar{p}$ ) for pigeons under the multiple FR 30 FR 60 FR 90 schedule and the multiple FI 30-s FI 60-s FI 120-s schedule during prefeeding test sessions, test sessions of response-independent food during the schedule and during the timeout, and extinction.

Pi-geon	FR	Prefeed	Response-independent food	Response-independent food (timeout)	Extinction
1896	30	0.39	0.76	0.97	0.13
	60	0.24	0.76	0.91	0.15
	90	0.19	0.96	0.45	0.07
3867	30	0.68	0.83	0.96	0.13
	60	0.50	0.84	0.78	0.38
	90	0.39	1.32	0.83	0.62
1693	30	0.28	0.83	0.91	0.30
	60	0.23	1.05	0.71	0.15
	90	0.15	1.66	0.65	0.16
	FI (s)				
1672	30	0.85	0.58	0.87	0.98
	60	0.71	0.57	0.9	0.47
	120	0.29	0.53	0.84	0.18
1654	30	0.19	0.57	0.81	0.64
	60	0.16	0.52	0.64	0.35
	120	0.03	0.38	0.50	0.11
4835	30	0.14	0.85	1.04	0.47
	60	0.15	1.0	0.84	0.25
	120	0.05	1.14	0.62	0.01
3276	30	0.44	0.69		
	60	0.32	0.8		
	120	0.16	0.77		

tion (Nevin, 1988), research on behavior momentum has not systematically explored the relationship between resistance to change and the nature of the events disrupting the behavioral baselines. The present study suggests that

the nature of the disrupting event may be an important factor to consider. Overall, satiation, extinction, and response-independent food delivery during timeout periods reduced relative response rates more in components of multiple schedules providing lower rates of reinforcement. However, there was no systematic relationship between the relative amount of disruption and rates of reinforcement when response-independent food was delivered at the same time that the schedule of reinforcement was in effect.

Another purpose of the present study was to investigate the variables that might account for the failure of Cohen et al. (1990) to obtain a direct relationship between resistance to change and rate of reinforcement. Cohen et al. tested for resistance to change as the size of an FR schedule was varied across successive conditions. Response-independent food produced equal changes in proportion of baseline response rates under each FR schedule, and resistance to extinction was inversely related to rate of reinforcement. These results can now be explained by Cohen et al.'s method of varying rates of reinforcement and testing for resistance to change across successive conditions rather than in the context of multiple schedules. In addition, one of their two tests of resistance to change was response-independent food delivery during the schedule, a test that does not provide data consistent with the behavior-momentum hypothesis under simple or multiple schedules.

*Simple Versus Multiple Schedules*

Perhaps the most significant finding of this investigation was the failure to find that resistance to change was a direct function of rate

Table 7

Experiment 4. The number of times that free-food delivery during the timeout (VT 40 s, 20 s, 10 s, 5 s, and 2.5 s under mult FI FI FI and mult FR FR FR) increased and decreased the PRP by 10% or more from baseline (PRP on the session immediately preceding the test session), summed for all 3 pigeons under each schedule. Also shown are the median and range of percentage of change in the PRP from baseline during the VT test.

	FI 30 s	FI 60 s	FI 120 s	FR 30	FR 60	FR 90
Increase	0	2	4	6	9	2
Median (%)		22.5	73	18	52	23.5
Range		22-23	25-119	10-57	10-73	13-34
Decrease	6	8	2	0	0	8
Median (%)	30	29	33.5			22.5
Range	12-46	12-72	18-49			12-42

of reinforcement when rate of reinforcement varied across successive conditions. Although research on behavior momentum has clearly emphasized response strength in multiple, chained, and concurrent schedules of reinforcement (Nevin, 1979; Nevin *et al.*, 1983), the behavior-momentum position has not differentiated between simple and more complex schedules (Nevin, 1988, 1992). Accordingly, performance under the control of a schedule providing a low rate of reinforcement (e.g., VR 160) is predicted to be more easily disrupted than is performance under the control of a schedule providing a higher rate of reinforcement (e.g., VR 40), whether or not the schedules occur within the same session, in separate groups of subjects, or across successive conditions. The finding that resistance to change was not related to rate of reinforcement in simple FR, VR, FI, and VI schedules questions the application of the behavior-momentum hypothesis in this context.

The failure to find data consistent with most research on behavior momentum agrees with other studies that have varied rates of reinforcement across successive conditions or in separate groups of subjects (Ayres, 1968; Ayres & Quinsey, 1970; Clark, 1958; Hancock & Ayres, 1974; Jenkins, 1978; Leslie, 1977; Pavlik & Carlton, 1965). Leslie (1977), for example, trained rats under a VI 1-min schedule, and varied the concentrations of sucrose reinforcement across two conditions. A stimulus that terminated in response-independent shock suppressed response rates equally in both conditions. Clark (1958) trained three groups of rats under either VI 1-, 2-, or 3-min schedules of reinforcement, and then prefed them 1 hr before the session. All groups showed equivalent reductions in response rates relative to baseline (i.e., 23 hr food deprivation). Jenkins (1978) prefed six groups of rats lever pressing under either FR 1 or random-ratio (RR) 5 to RR 40 schedules of reinforcement. Of all the schedules, response-rate resistance to prefeeding was greatest under FR 1 and RR 5; however, no differences were found among RR 10 to RR 40 groups, and resistance to extinction was greatest under the larger valued RR schedules (see also the extinction data of Church & Raymond, 1967; Pavlik & Carlton, 1965). Although these data are contradictory to most research on behavior momentum (e.g., Nevin, 1974, 1979), Blackman (1968) re-

ported data consistent with the momentum position. He reinforced responding in separate groups of rats under VI 30-s, VI 60-s, or VI 90-s schedules, and presented a stimulus that was previously, but no longer, paired with shock. Responding was suppressed during the stimulus, and recovery from suppression was faster under the schedule with the higher frequency of reinforcement (see also Church & Raymond, 1967). It is presently unclear why some studies using independent groups of subjects report data consistent with the momentum hypothesis and other studies do not.

What factors are responsible for the fact that the behavior-momentum hypothesis functions well in multiple-schedule contexts but not so well in simple-schedule contexts? Multiple and simple schedules differ in two important ways that may account for the different results. First, in multiple schedules, the subject is exposed to different reinforcement frequencies over relatively brief time spans (e.g., usually 1 to 5 min), whereas in simple schedules, the subject is exposed to different schedules over periods of several weeks, or in the case of separate-group designs, only a single schedule is experienced. Second, in multiple schedules, different frequencies of reinforcement are associated with different discriminative stimuli, whereas the same stimulus context is used when reinforcement frequency is varied across conditions or in separate groups. Although the present experiments cannot establish the importance of these factors, other evidence suggests the importance of discriminative stimuli. Hancock and Ayres (1974) had rats lick 8% and 32% sucrose solutions from a dipper on alternate days, with no change in stimulus conditions from day to day. A tone paired with shock suppressed licking equally under both reinforcement conditions. Leslie (1977) reported similar results when rats pressed a lever for different sucrose concentrations on alternate days, and the stimulus context was unchanged from day to day. Millenson and de Villiers (1972), however, using a similar conditioned-suppression procedure, alternated sessions of 8% and 32% sucrose reinforcement with different stimulus conditions for each reinforcement magnitude; greater relative response suppression was reported with 8% compared to 32% sucrose.

Further research will determine the importance of discriminative stimuli and the tem-

poral spacing of baseline reinforcement parameters within and across sessions. The importance of discriminative stimuli is consistent with Nevin's (Mace et al., 1990; Nevin, 1984, 1992; Nevin et al., 1987, 1990) emphasis on Pavlovian stimulus-reinforcer contingencies as a determinant of resistance to change. In multiple schedules, each component stimulus is associated with a different rate of reinforcement, both of which contrast the timeout separating components (zero rate of reinforcement). In single schedules, however, it is unclear as to what aspect of the experimental context serves as the conditioned stimulus, the extent to which different stimuli share associations with reinforcement, and the extent to which the stimulus-reinforcer associations change when reinforcement frequencies change across conditions.

One factor that should be considered in the present study is that the sequence of conditions in Experiments 1 and 2 started with a high rate of reinforcement and descended to lower rates of reinforcement, until the high reinforcement-rate condition was replicated. If the behavioral mass for lever pressing or key pecking was established in this first condition, and once established became irreversible, then changes in reinforcement rates in later conditions would not be reflected in resistance-to-change tests. Further research should vary the sequence of conditions.

#### *Tests of Resistance to Change*

In the present experiments, four different tests of resistance to change were conducted. Each test was intended to disrupt response rate and measure behavioral mass. Ideally, the results of different resistance-to-change tests should be highly correlated with each other, and that was found with prefeeding and extinction. Prefeeding did not differentially disrupt performance under simple schedules (Experiments 1 and 2), but resistance from prefeeding was directly related to reinforcement frequency in multiple FI and FR schedules in rats and pigeons (Experiments 3 and 4). Resistance to extinction was not directly related to rate of reinforcement in simple schedules, but responding under multiple schedules was more resistant to extinction in rats in FR and FI components providing the highest rates of reinforcement. This "reverse PREE" (cf. Pavlik & Carlton, 1965) was also

observed with pigeons responding under multiple FI schedules, but the data were less consistent under the multiple FR schedule. Thus, with one exception, prefeeding and extinction in multiple schedules provided data consistent with most other research on behavior momentum.

*Response-independent food presented during the timeout.* A more complex relationship was observed when behavioral mass was indexed by presenting food during timeouts separating components (Experiments 3 and 4). There was a direct relationship between rate of reinforcement and resistance to change under the multiple FR schedule with rats and under multiple FR and FI schedules with pigeons, although as noted above, the magnitude of effect did not appear as large as in previous experiments with multiple VI schedules. However, with rats no consistent differences in resistance to change were observed between FI 30-s and FI 120-s components. Although multiple VI schedules were not examined in the present study, a comparison of response patterns engendered by VI, FR, and FI schedules might suggest a possible reason for resistance-to-change differences under these schedules. Both FR and FI schedules of reinforcement produce well-known response patterns consisting of a PRP followed by either a high constant or a positively accelerated response rate, whereas VI schedules engender a relatively constant rate. It is easy to assume that delivering free food during timeouts separating components would lower response rates in a component without affecting response patterns, because free food could reduce food deprivation but not degrade the response-reinforcer correlation. However, if response patterns are affected, then resistance-to-change measurements under FR and FI schedules might also be affected, whereas no effect would be revealed under VI schedules. In the present study an attempt was made to index response patterns by measuring PRP (Experiments 3 and 4). An increase in the PRP could occur without changing the overall response patterns; however, decreases in PRP would suggest that patterning changed to a more constant rate. An unexpected finding of the present study was that response-independent food deliveries during the timeouts decreased the PRP in a substantial number of test sessions (Tables 5 and 7). The shortening of the PRP was evident to some degree in rats

and pigeons under both interval and ratio schedules, but it was particularly evident in rats under the mult FI 30-s FI 120-s schedule. Although reasons for the decrease in PRP are unclear, it suggests that the effects of free food on response patterns might account for the failure to find large and consistent differences between the components of the multiple schedules during these resistance-to-change tests, particularly in rats under the multiple FI schedule. These data further suggest that when free-food delivery is used to measure resistance to change, the type of schedule that maintains responding, and any alterations in response patterns, should be considered in determinations of behavioral mass.

*Response-independent food presented during the schedule.* Response-independent food presented simultaneously with response-contingent food did not produce data consistent with other research (e.g., Nevin, 1974, 1979) on behavior momentum; resistance to change was not directly related to rate of reinforcement in simple or in multiple schedules. It could be argued that the inconsistent data were caused by changes in response patterns from response-independent food's alterations of the response-reinforcer correlation. Lattal and Bryan (1976) showed that free food presented to subjects responding on an FI baseline altered the positively accelerated response patterns to a more constant rate, mitigating the rate-reducing effects of the free food. Free food may have altered response patterns in the present study and affected the functional relationship between resistance to change and baseline reinforcement rate. However, free-food delivery had similar effects (Experiment 1) on baselines that generated constant response rates (VR and VI) and those that generated nonconstant rates (FR and FI), suggesting that the failure to find a functional relationship between reductions in baseline response rates and rates of reinforcement was not due simply to alterations in response patterns.

The present data are consistent with other studies that have delivered response-independent food simultaneously with response-contingent food (Nevin, 1984; Smith, 1974; Zeiler, 1979). In one study, Zeiler (1979) delivered free food according to fixed-time schedules as pigeons responded under simple FR 180 and FR 300 schedules of reinforcement in successive conditions; there were no consistent dif-

ferences in disruption of baseline response rates under the two FR schedules (see also Burgess & Wearden, 1986). In a second study, Smith (1974) trained pigeons under a four-component multiple schedule. In a positive conditioned-suppression procedure, a stimulus that terminated in response-independent food either increased or decreased baseline response rates, depending upon stimulus duration. Significantly, the relative change in response rates during the stimulus was not a function of the rate of reinforcement in the component; rather, it was a function of baseline rate of response. Nevin (1984) also failed to find a direct relationship between rate of reinforcement and resistance to change when response-independent food was delivered in a serial six-component multiple schedule.

The failure to find a functional relationship between relative response-rate reductions from free-food delivery and rate of response-contingent reinforcement is consistent with Harper and McLean's (1992) failure to find different functions between response and reinforcement rates in two multiple-schedule components that differed in reinforcement magnitude. Implicit in Harper and McLean's (1992) conclusions is that presenting response-independent food during the maintaining schedule might confound measurements of behavior momentum. They made the distinction between behavioral disruptions from outside components of a multiple schedule (e.g., free food during timeouts) and disruptions from within a component. They argued that using positive reinforcers within the component to disrupt responding might actually alter the behavioral mass of the target response under control of the maintaining schedule and confound resistance-to-change tests. Consider, for example, free food delivered in a component of a multiple schedule in which responding is maintained by an FR 40 schedule. The component stimulus is correlated with reinforcement delivered under the FR 40 schedule plus the extra response-independent reinforcers; thus free food could increase the behavioral mass of the target response at the same time that the operant response-reinforcer contingency is degraded (see Nevin *et al.*, 1990). Strengthening the stimulus-reinforcer correlation (increasing resistance to change) by the same operation intended to disrupt responding (testing for resistance to change) could alter the functional

relationships predicted by the behavior-momentum hypothesis. This argument could explain why experiments using food to disrupt responding during the maintaining schedule (e.g., the present study; Nevin, 1984; Smith, 1974; Zeiler, 1979) failed to find data consistent with the momentum hypothesis, whereas studies using aversive stimuli (e.g., Blackman, 1968; Bouzas, 1978) found consistent data.

In summary, much of the present data were consistent with the behavior-momentum hypothesis. However, the data illustrated conditions under which a direct relationship between resistance to change and rate of reinforcement is not found. These conditions include, primarily, simple schedules of reinforcement and disruptions in responding from free food during the maintaining schedule. Further research is needed to determine the mechanisms that produced these inconsistent data.

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## APPENDIX 1

Experiment 1. Responses per minute in resistance-to-change test sessions with prefeeding (1% and 3% of ad lib weights), response-independent food (VT 40-s or 20-s schedules), and extinction (three sessions), and the mean response (R/min) and reinforcement (Rn/hr) rates of the baseline sessions immediately preceding each resistance-to-change test for each rat under VR 40, 80, 160, and 40 schedules.

Rat	VR	Baseline		Prefeed (%)		VT (s)		Extinction		
		R/min	Rn/hr	1	3	40	20	1	2	3
1	40	130	188	117	111	90	54	14.8	7.5	1.8
	80	226	171	220	138	155	97	15.3	10.4	6.6
	160	271	101	272	258	250	107	33.5	26.8	15.7
	40	181	265	175	129	147	88	34	13.2	8.8
2	40	121	177	120	70	100	44	20.3	10.1	2.6
	80	159	118	141	127	111	64	31.8	18.6	10.1
	160	172	67			93				
	40									
3	40	123	177	121	100	105	70	18.5	7.3	4.9
	80	166	121	160	129	126	99	31.3	12.7	4.4
	160	158	59	146	0	158	116	61.9	9.5	7.5
	40	175	259	172	153	146	111	17.6	7.7	5.5
4	40	146	213	141	123	128	55	28.3	12.5	2.9
	80	222	159	198	201	149	139	21	11.7	4.6
	160	170	62	119	61	156	106	48	15.3	11.1
	40	157	230	147	119	121	68	15.7	11.9	8
5	40	157	229	140	120	114	65	11.8	10.5	4.7
	80	167	121	166	144	149	114	25.9	14.2	3.1
	160									
	40	148	221	143	103	107	54	17.3	11.9	3.5
6	40	127	190	123	86	116	202	21.7	13.7	7.6
	80	147	106	142	123	123	92	54.5	35.5	12.7
	160	3.5	1			39				
	40	68	100	56	33	51	32	18.3	12.4	3.9
7	40	100	146	102	74	76	38	10.5	7.9	2.8
	80	145	105	135	128	106	86	18.3	9.3	2.9
	160	98	35	118	100	101	98	35.3	15.2	7.3
	40	138	215	121	143	104	63	18.7	16.1	8.8



## APPENDIX 2

Experiment 1. Responses per minute in resistance-to-change test sessions with prefeeding (1% and 3% of ad lib weights), response-independent food (VT 40-s or 20-s schedules), and extinction (three sessions), and the mean response (R/min) and reinforcement (Rn/hr) rates of the baseline sessions immediately preceding each resistance-to-change test for each rat under FI 30-s, 60-s, 120-s, and 30-s schedules.

Rat	FI (s)	Baseline		Prefeed (%)		VT (s)		Extinction		
		R/min	Rn/hr	1	3	40	20	1	2	3
8	30	87	114	83	26	68	18	11.6	4.7	1.4
	60	69	58	73	54	55	42	14.3	1.6	1
	120	53	30	27	29	57	33	13.4	4.9	1
	30	66	116	64	43	56	34	2	1.1	0.4
9	30	24	113	18	18	32	16	3.7	2.1	0.7
	60	28	58	25	16	24	17	6.5	1.5	0.01
	120	21	30	11	11	57	16	1.3	0	0
	30	39	117	30	30	24	0.3	4.5	4.2	0.8
10	30	35	114	35	30	39	20	9	3.2	1.2
	60	42	58	39	39	38	45	10.4	7	2.1
	120	24	30	20	17	23	19	8.7	5	2.4
	30	15	116	11	16	21	16	2	1.3	0.2
11	30	44	113	44	37	55	21	10.1	3.8	2.6
	60	46	58	45	37	45	43	14	5.1	2.2
	120	40	29	42	29	40	52	17.9	6.1	4.3
	30	38	117	30	32	43	18	7.1	3.2	0.9
12	30	88	114	83	63	83	32	8.7	2.5	1.9
	60	86	58	89	58	76	68	6.8	1	1
	120	66	29	56	45	63	58	19.9	7	1.2
	30	102	117	118	91	74	63	5	1	0.1
13	30	28	110	25	17	21	12	6.4	3.1	0.1
	60	23	56	21	11	27	16	6.8	1.7	1.1
	120	23	29	18	8	28	17	5.4	2.9	3.8
	30	27	113	26	18	17	10	3.5	2.2	0.8
14	30	86	115	73	61	113	55	11.5	5.9	1.3
	60	59	60	55	51	77	79	14.6	4	1.2
	120	49	30	44	25	95	83	20.9	8.8	2.3
	30	54	118	51	40	65	22	9.6	5.1	1

## APPENDIX 3

Experiment 1. Responses per minute in resistance-to-change test sessions with prefeeding (1% and 3% of ad lib weights), response-independent food (VT 40-s or 20-s schedules), and extinction (three sessions), and the mean response (R/min) and reinforcement (Rn/hr) rates of the baseline sessions immediately preceding each resistance-to-change test for each rat under FR 40, 80, 160, and 40 schedules.

Rat	FR	Baseline		Prefeed (%)		VT (s)		Extinction		
		R/min	Rn/hr	1	3	40	20	1	2	3
15	40	71	106	71	55	52	41	19.5	8.4	3
	80	93	69	76	0	91	52	12	19.5	3.9
	160	22	8	21	0.2	40	0.9	15.6	7.6	7.9
	40	110	164	93	118	81	58	11.3	10.1	2.1
16	40	89	133	85	48	74	33	11.3	2.6	1.1
	80	77	57	74	47	74	40	9.1	5.8	3.1
	160	40	101	151	96	75	91	55	8.8	7.9
17	40	128	191	124	97	92	62	6.1	4.4	1.8
	80	184	137	182	130	135	82	9.5	8.4	10.6
	160	143	53	157	120	154	84	29.6	12.6	12.9
	40	121	181	113	111	94	58	7.6	17.6	6.8
18	40	85	126	89	81	63	58	9.3	2.7	0.04
	80	104	77	101	100	93	74	13.9	6.4	1.2
	160	22	8	18	0.5	61	60	10.4	3.9	0
	40	88	131	82	79	77	58	14.8	10.9	3.9
19	40	191	287	185	168	160	124	4	4.3	1.2
	80	309	231	297	262	220	166	7.6	13.6	4.1
	160	339	127	358	331	328	226	10.9	9	6.4
	40	217	325	216	186	174	94	13.8	6.5	5
20	40	96	140	95	69	76	54	4.6	1.1	0.1
	80	94	70	95	56	92	55	8	5.6	3.4
	160	203	76	191	153	149	118	9.7	14	0.8
	40	162	243	160	134	117	84	5.8	4.8	1.7
21	40	134	200	129	109	96	67	3	3.6	0.6
	80	170	127	174	125	126	76	9.3	4.1	1.8
	160	3	1	4	0	44	0.5			
	40	79	118	70	62	92	57	3.8	6	1

## APPENDIX 4

Experiment 1. Responses per minute in resistance-to-change test sessions with prefeeding (1% and 3% of ad lib weights), response-independent food (VT 40-s or 20-s schedules), and extinction (three sessions), and the mean response (R/min) and reinforcement (Rn/hr) rates of the baseline sessions immediately preceding each resistance-to-change test for each rat under VI 30-s, 60-s, 120-s, and 30-s schedules.

Rat	VI (s)	Baseline		Prefeed (%)		VT (s)		Extinction		
		R/min	Rn/hr	1	3	40	20	1	2	3
22	30	48	109	38	36	32	20	8.3	2	0.3
	60	7	48	7	5	8	8	2.5	0.9	0.7
	120	7	24	5	5	10	7	2.2	1.2	1
	30	15	86	12	9	35	8	6.9	1	1.4
23	30	31	108	28	14	16	14	6.1	2	0.3
	60	27	57	17	15	17	8	9.1	2.6	0.9
	120	13	28	11	9	14	8	5	2.3	0.7
	30	12	100	11	13	12	10	8.3	1.4	0.8
24	30	82	114	79	50	80	47	7.1	0.5	0.2
	60	46	58	28	25	29	21	6.9	2.2	0.6
	120	10	27	5	6	17	10	3.5	2.4	0.8
	30	83	117	87	70	63	38	19	3	0.2
25	30	49	111	44	34	44	25	8.1	0.9	0.2
	60	27	58	9	10	19	10	4.3	1.9	1.2
	120	11	29	8	7	9	8	4.8	1.1	0.7
	30	30	111	26	28	28	11	7.2	2.2	0.3
26	30	86	113	94	64	54	29	5.7	1.1	0.1
	60	60	58	48	59	39	27	12.5	9.4	1.2
	120	22	29	19	11	23	12	5.6	2.4	2.4
	30	70	116	66	68	40	34	9.3	1.5	1.3
27	30	51	110	45	33	46	34	6.8	1.2	0.2
	60	40	59	28	31	36	32	7.9	3.2	0.7
	120	17	28	12	14	16	12	4.3	2.3	1.2
	30	45	113	31	33	36	24	11.3	1.2	1.1
28	30	72	113	68	48	58	21	7.5	1.6	0.2
	60	52	57	33	41	35	16	16.1	5.1	3.2
	120	30	29	23	24	24	23	11.6	5.7	5.3
	30	41	106	32	47	39	21	10.9	3.8	2.1

## APPENDIX 5

Experiment 2. Responses per minute in resistance-to-change test sessions with prefeeding (2%, 5%, or 7% of ad lib weights), response-independent food (VT 40-s or 20-s schedules), and extinction (three sessions), and the mean response (R/min) and reinforcement (Rn/hr) rates of the baseline sessions immediately preceding each resistance-to-change test for each pigeon under FR 40, 80, 160, and 40 schedules. See text for details.

Pigeon	FR	Baseline		Prefeeding (%)			VT (s)		Extinction		
		R/min	Rn/hr	2	5	7	40	20	1	2	3
1894	40	220	329	153	32		180	140	47.7	50.6	20.5
	80	293	219	180	42		196	105	108.3	25.2	15.2
	160	240	90	188	185		247	250	233.8	76.3	27.3
	40	182	273	138	57		128	114	91.1	71.0	46.5
7901	40	108	162	64	4		85	49	33.4	28.5	14.2
	80	194	145	78	18		165	103	50.9	35.5	20.9
	160	153	57	45	30		44	86	74.3	38.9	0.1
	40	102	153	78	28		70	35	13.1	14.1	1.7
1699	40	94	141		27	0	68	58	16.1	27.1	4.0
	80	113	85		53	14	59	47	32.6	5.4	3.4
	160	22	8		3	0.1	46	32	41.6	14.5	9.2
	40	123	185		34	0.4	52	33	36.6	14.5	3.0

## APPENDIX 6

Experiment 3. Responses per minute in resistance-to-change test sessions with prefeeding (3% of ad lib weights or 50 g), response-independent food (VT 40-s, 20-s, 10-s, or 5-s schedules) during the component and between components (timeout), and extinction (three sessions), and the mean response (R/min) and reinforcement (Rn/hr) rates of the baseline sessions immediately preceding each resistance-to-change test for each rat under the multiple FR FR schedule. See text for details.

Rat	Baseline		Prefeeding		VT (s)			VT (timeout)				Extinction		
	FR	R/min Rn/hr	3%	50 g	40	20	10	40	20	10	5	1	2	3
31	40	178 264	155 132	136 96	37 193	169 167	137 69	7.7 4.9						
	160	201 75	167 100	195 153	58 227	220 206	140 62	0.9 0						
33	10	57 338	46 39	43 33	17 61	51 52	33 10.6	1.5 0.4						
	20	95 382	54 32	70 53	21 86	91 64	45 11.0	2.5 2.3						
34	10	62 370	43 48	50 39	14 66	61 57	31 23.8	5.7 4.7						
	30	107 212	31 43	102 88	33 113	64 67	28 2.5	0.7 0.1						
35	20	123 365	113 81	102 71	37 134	122 119	102 32.5	7.7 4.7						
	80	213 158	207 77	197 159	64 187	151 133	90 5.7	2.1 2.5						
36	40	169 251	114 69	147 110	43 183	173 169	152 48.1	15.9 4.5						
	120	87 43	41 11	144 121	53 90	63 51	80 19.8	4.5 2.2						
37	40	89 133	63 28	76 56	9 97	84 60	48 46.3	17.5 8.5						
	120	50 25	19 2	69 60	9 75	32 35	31 31.1	6.0 0.3						
38	30	138 273	103 0.1	105 87	44 142	132 138	121 62.3	20.5 0.9						
	120	150 74	96 0.2	143 124	72 137	130 93	65 49.8	0 0						

## APPENDIX 7

Experiment 3. Responses per minute in resistance-to-change test sessions with prefeeding (2.5% or 5% of ad lib weights or 50 g), response-independent food (VT 40-s, 20-s, 10-s, 5-s, or 2.5-s schedules) during the component and between components (timeout), and extinction (three sessions), and the mean response (R/min) and reinforcement (Rn/hr) rates of the baseline sessions immediately preceding each resistance-to-change test for each rat under the multiple FI 30-s FI 120-s schedule. See text for details.

Rat	FI (s)	Baseline		Prefeeding			VT (s)			VT (timeout)					Extinction		
		R/min Rn/hr	2.5%	5%	50 g	40	20	10	40	20	10	5	2.5	1	2	3	
39	30	29 29	20 21	17 18	9 2.4	28 21	26 20	9 19.3	7.4 1.2								
	120	34 112	16 14	6 20	13 1.9	39 33	31 25	13 5.4	2.4 0.7								
40	30	57 30	37 33	32 64	47 7	45 54	50 39	16 31.8	2.1 0.3								
	120	51 114	41 40	32 63	53 17	33 37	47 35	16 1.3	0.1 0								
41	30	23 29	34 21	20 16	7 2.5	16 15	16 11	13 7.8	2.2 2.4								
	120	28 108	23 20	15 18	7 1.9	23 25	23 22	16 5.8	0.2 0								
43	30	40 29	38 30	19 31	12 1.8	38 44	32 23	8 14.9	5 0.6								
	120	27 114	18 19	6 17	11 1.6	15 20	20 17	9 7.2	1.2 0.4								
44	30	52 30	29 28	14 29	19 3	64 54	56 36	8 52.7	10.2 2.2								
	120	64 114	40 39	16 33	17 6	58 57	66 43	9 15.4	1.7 0.4								
45	30	22 29	21 16	5 37	30 7	11 13	21 11	7 17.8	8.2 4.4								
	120	27 106	16 10	3 35	24 7	18 15	23 11	15 3.8	1.2 0.2								
46	30	64 30	54 38	28 47	35 7	53 68	52 32	23 18.9	3 0.4								
	120	45 114	30 19	8 48	44 9	38 44	38 26	22 12.3	2 0								

