# ALTERNATIVE REINFORCEMENT INCREASES RESISTANCE TO CHANGE: PAVLOVIAN OR OPERANT CONTINGENCIES?

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Two multiple-schedule experiments with pigeons examined the effect of adding food reinforcement from an alternative source on the resistance of the reinforced response (target response) to the decremental effects of satiation and extinction. In Experiment 1, key pecks were reinforced by food in two components according to variable-interval schedules and, in some conditions, food was delivered according to variable-time schedules in one of the components. The rate of key pecking in a component was negatively related to the proportion of reinforcers from the alternative (variable-time) source. Resistance to satiation and extinction, in contrast, was positively related to the overall rate of reinforcement in the component. Experiment 2 was conceptually similar except that the alternative reinforcers were contingent on a specific concurrent response. Again, the rate of the target response varied as a function of its relative reinforcement, but its resistance to satiation and extinction varied directly with the overall rate of reinforcement in the component stimulus regardless of its relative reinforcement. Together the results of the two experiments suggest that the relative reinforcement of a response (the operant contingency) determines its rate, whereas the stimulus–reinforcement contingency (a Pavlovian contingency) determines its resistance to change.

*Key words:* alternative reinforcement, response rate, resistance to change, concurrent schedules, multiple schedules, satiation, extinction, key peck, pigeon

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Experimental analysis has distinguished two aspects of operant behavior: the rate of a response and the resistance of that rate to reduction by procedures such as satiation and extinction. These two aspects of behavior are of interest because they vary in orderly ways as functions of rate of reinforcement (Catania & Reynolds, 1968; Nevin, 1974, 1979; Skinner, 1938, 1950) and because of their relation to the theoretical concept of response strength. Although response rate has been taken as equivalent to response strength (Skinner, 1938, 1950), a case can be made that resistance to change corresponds better to our conceptions of what a measure of response strength ought

to be (Nevin, 1974, 1979; Smith, 1974). Consequently, it is of some importance to examine the variables that influence resistance to change (Fath, Fields, Malott, & Grossett, 1983; Nevin, 1974, 1979, 1984; Nevin, Mandell, & Yarensky, 1981; Nevin, Smith, & Roberts, 1987).

The rate of a target response maintained by a given rate of reinforcement decreases when reinforcers are added concurrently from an alternative source. This decrease occurs both when reinforcers are added noncontingently (Rachlin & Baum, 1972) and when they are contingent on a different, concurrent response (Catania, 1963). Adding reinforcers from an alternative source may be viewed as degrading the operant contingency, in that the correlation between the occurrence of the target response and the reinforcer is thereby weakened. Thus, alternative reinforcement might reduce response rate by degrading the operant contingency.

If a target response's rate and resistance to change are correlated manifestations of the effect of reinforcement on operant behavior (i.e., its strength) then one might expect that degrading the operant contingency would reduce resistance to change as well as response rate.

Specifically, one would expect its resistance to be reduced if the operant contingency were degraded by adding alternative reinforcement. However, recent data suggest just the opposite: Alternative reinforcement (added successively rather than concurrently) may actually enhance resistance to change rather than reduce it (Nevin, 1984; Nevin et al., 1987).

Although adding concurrent alternative reinforcers degrades the operant contingency, it increases the rate of reinforcement received in the presence of the stimulus in which the response occurs and thereby enhances the stimulus–reinforcer correlation—a Pavlovian contingency. Perhaps the stimulus–reinforcer contingency rather than the operant contingency determines a response's resistance to change, as suggested by Nevin (1984).

This paper describes two experiments examining the effects of alternative reinforcement on the rate of a target response and the resistance of that response rate to change. In both experiments, a target response was reinforced at particular rates in different, independent components of multiple schedules signaled by distinctive stimuli. In one component, alternative reinforcers were presented either noncontingently (Experiment 1) or contingent upon a concurrent response (Experiment 2). In both experiments, target response rate and resistance to change were examined in relation to the rates of contingent and alternative reinforcement in order to evaluate the possibility that the relative reinforcement of a response determines its rate, whereas the overall rate of reinforcement correlated with a stimulus determines the resistance to change of that response rate.

## EXPERIMENT 1

If response-independent food is presented according to a variable-time (VT) schedule in one component of a two-component multiple variable-interval, variable-interval (VI VI) schedule with equal VI food schedules, response rate should be lower in the component with added VT food (as found by Rachlin & Baum, 1972). However, the added VT reinforcers may enhance resistance to change in the concurrent VI VT component relative to the simple VI component because the overall reinforcer rate in that component is higher. Conversely, if the schedules in the first com-

ponent are chosen so as to give food at the same overall rate as that arranged by the VI schedule in the second component, resistance to change may be similar between components even though baseline response rates differ. Experiment 1 explores these possibilities.

### METHOD

#### Subjects

Three experimentally naive White Carneau pigeons were maintained at 80% of their free-feeding weights, ±15 g, by feedings of Purina Pigeon Chow® as needed after each experimental session. Water and grit were available continuously in each bird's home cage. By coincidence, all 3 birds had identical free-feeding weights of 580 g. The birds were trained to peck a key lighted red or green by the method of successive approximations.

#### Apparatus

The experiment was conducted in a standard single-key Lehigh Valley pigeon chamber equipped with a stimulus projector behind the key, a houselight centered above the key, and a grain feeder filled with wheat centered below the key. A blower provided ventilation and masking noise. Food schedules were constructed from the progression provided by Fleshler and Hoffman (1962) and arranged by standard tape timers. The experiment was controlled and data were recorded by electromechanical equipment in an adjacent room.

#### Procedure

*Baseline.* Throughout the experiment, daily sessions consisted of 12 multiple-schedule components, each 3 min in length and separated by 1-min periods with no food available, signaled by three white dots projected on the key. The food components, signaled by red and green keylights, were presented in strict alternation; the first component on a given day varied irregularly from red to green. The key was darkened during each food presentation, which was always 4 s except during Condition 3 (see below), when it was reduced to 2.5 s to prevent the birds from gaining excessive weight. Sessions always began with a 1-min no-food period and ended immediately after the 12th schedule component. The houselight was on throughout the session. Sessions were conducted 7 days a week if the birds were within 15 g of their 80% weights.

Over the course of seven successive conditions, various VI and VT schedules were arranged during red-key components. The green-key component was always VI 1 min. These conditions are summarized in Table 1. Conditions 1, 4, and 7 arranged identical VI 1-min schedules in both components. Conditions 2 and 3 had identical VI 1-min schedules in both components, but also had alternative food presented according to VT schedules during red-key components. In Condition 2, the VI tape operated during VT food presentations. Because this increased the rate of VI food presentations obtained per hour with the key lighted, the VI tape was stopped during VT food presentations in all subsequent conditions. Conditions 5 and 6 had different VI and VT schedules during red-key components, chosen to make the arranged food rates equal in the two components and to match the proportions of VI and VT food presentations scheduled in the red-key component in Conditions 2 and 3. This procedure permits assessment of the effects of both absolute and relative numbers of VT food presentations on response rate in the red component, with response rate in the constant green component for comparison.

*Stimulus compounding.* After the completion of baseline training in Condition 2, two sessions (separated by three more baseline sessions) were conducted with the three white dots, which signaled no-food periods, superimposed on the red and green keys. These compound tests were intended to assess resistance to change; however, the effects were small, inconsistent, and transient, so the data are not reported below.

*Prefeeding (satiation).* In Conditions 2, 3, 5, and 6, after completion of baseline training (or after stimulus compounding in Condition 2) the birds were prefed various amounts of pigeon chow or wheat in their home cages, 1 hr before their regular sessions, to assess the resistance of their baseline response rates to change. Five prefeeding sessions were conducted; after each prefeeding, 80% body weights were recovered and a minimum of three baseline sessions preceded the next prefeeding session. Amounts prefed were 40 g, 60 g, or 80 g of chow or 40 g of wheat, in orders that varied across conditions except that the first prefeeding was always 40 g of chow and the fourth was always 40 g of wheat. No prefeed-

Table 1

Sequence of experimental conditions, nominal food presentation rates, and duration of baseline training in Experiment 1.

| | Red-key food/hr | | Green-key food/hr | |
| Condition | VI | VT | (VI) | Sessions |
| --- | --- | --- | --- | --- |
| 1 | 60 | 0 | 60 | 30 |
| 2 | 60 | 120 | 60 | 40 |
| 3 | 60 | 240 | 60 | 40 |
| 4 | 60 | 0 | 60 | 30 |
| 5 | 20 | 40 | 60 | 40 |
| 6 | 12 | 48 | 60 | 40 |
| 7 | 60 | 0 | 60 | 30 |

ings were arranged in Conditions 1, 4, and 7 because these conditions served primarily to equalize baseline response rates and to provide a baseline against which the effects of VT reinforcement on response rate in the red component could be assessed.

*Extinction.* After the fifth prefeeding in Conditions 2, 3, 5, and 6, the birds received 12 additional sessions of baseline training followed by 7 to 11 sessions of extinction to provide a separate assessment of resistance to change. Extinction sessions were arranged exactly like baseline sessions except that food was never presented. No extinction sessions were conducted in Conditions 1 and 4, for reasons noted above. However, on the basis of extinction data obtained in Conditions 5 and 6, 10 sessions of extinction were also conducted after Condition 7 to check for key-color biases after training with equal VI food schedules.

RESULTS

*Baseline Response Rates*

Figure 1 presents the average response rates in red and green components during the final five baseline sessions of Conditions 1, 4, and 7 (VI 60/hr in both components) and pooled for the five-session blocks that preceded each test of resistance to change in Conditions 2, 3, 5, and 6. These response rates are shown as a function of the ratio of VT to VI food rates obtained in the red component. These response rates are also presented in Table 2, together with the obtained food rates and response-rate ratios. In the green component, response rates were not affected consistently by the red-component schedules; neither were they affected

Table 2

Mean response rates and obtained food rates in each component for the last five sessions of baseline in each condition of Experiment 1. In Conditions 2, 3, 5, and 6, means are given separately for five-session blocks before prefeeding (pf) and before extinction (ext).

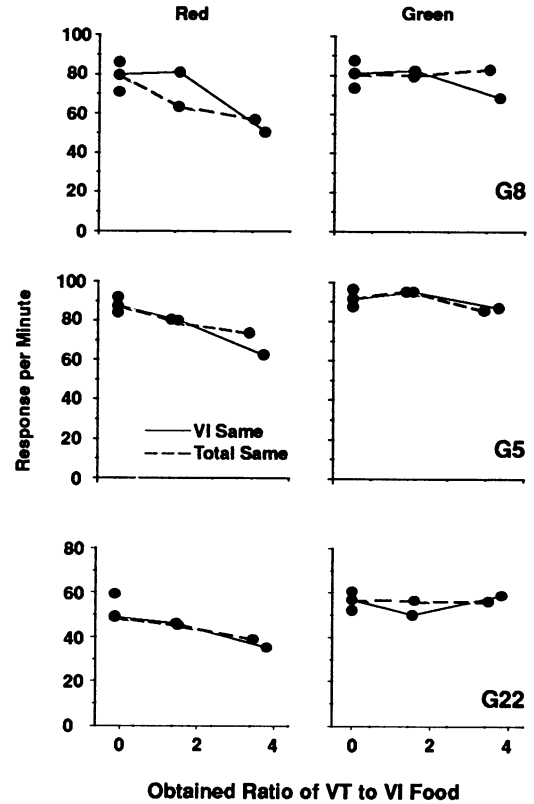| Condi-tion | Red | | | Green | | Red/green |
|---|---|---|---|---|---|---|
| | R/min | VI/hr | VT/hr | R/min | VI/hr | |
| **Bird G8** | | | | | | |
| 1 | 79.4 | 65.4 | 0 | 81.1 | 64.2 | .98 |
| 2 (pf) | 88.4 | 73.2 | 119 | 92.1 | 63.6 | .96 |
| 2 (ext) | 73.2 | 71.4 | 114 | 72.9 | 65.4 | 1.00 |
| 3 (pf) | 59.1 | 61.2 | 233 | 74.9 | 65.4 | .79 |
| 3 (ext) | 42.3 | 61.8 | 237 | 62.5 | 62.4 | .68 |
| 4 | 71.0 | 65.1 | 0 | 73.6 | 65.1 | .96 |
| 5 (pf) | 64.5 | 23.8 | 38.3 | 79.5 | 63.8 | .81 |
| 5 (ext) | 62.8 | 25.3 | 38.3 | 79.5 | 62.1 | .79 |
| 6 (pf) | 56.2 | 14.6 | 47.7 | 82.0 | 65.4 | .68 |
| 6 (ext) | 57.7 | 12.3 | 47.7 | 84.3 | 63.8 | .68 |
| 7 | 86.2 | 63.7 | 0 | 87.6 | 65.2 | .98 |
| **Bird G5** | | | | | | |
| 1 | 87.4 | 64.8 | 0 | 87.6 | 66.6 | 1.00 |
| 2 (pf) | 87.3 | 73.8 | 116 | 98.8 | 63.6 | .88 |
| 2 (ext) | 72.6 | 73.8 | 121 | 91.2 | 63.6 | .80 |
| 3 (pf) | 65.1 | 61.2 | 234 | 84.3 | 62.4 | .77 |
| 3 (ext) | 59.8 | 61.2 | 233 | 89.2 | 64.8 | .67 |
| 4 | 92.2 | 60.4 | 0 | 96.4 | 66.7 | .96 |
| 5 (pf) | 81.3 | 25.2 | 38.3 | 91.2 | 66.8 | .89 |
| 5 (ext) | 79.7 | 26.0 | 34.6 | 98.6 | 64.4 | .81 |
| 6 (pf) | 74.4 | 13.0 | 44.7 | 85.8 | 63.1 | .87 |
| 6 (ext) | 72.5 | 13.0 | 44.7 | 85.2 | 65.2 | .85 |
| 7 | 83.8 | 59.8 | 0 | 91.6 | 65.2 | .91 |
| **Bird G22** | | | | | | |
| 1 | 59.4 | 64.8 | 0 | 60.4 | 63.6 | .99 |
| 2 (pf) | 46.3 | 74.4 | 120 | 49.8 | 65.4 | .93 |
| 2 (ext) | 45.4 | 73.8 | 116 | 50.1 | 66.0 | .91 |
| 3 (pf) | 35.1 | 59.4 | 235 | 60.3 | 63.0 | .58 |
| 3 (ext) | 35.1 | 60.0 | 235 | 57.4 | 63.0 | .61 |
| 4 | 48.9 | 60.6 | 0 | 56.8 | 63.6 | .86 |
| 5 (pf) | 47.1 | 26.1 | 38.4 | 57.9 | 63.7 | .81 |
| 5 (ext) | 43.4 | 21.7 | 40.4 | 54.6 | 67.6 | .79 |
| 6 (pf) | 40.2 | 12.3 | 47.7 | 54.6 | 67.9 | .74 |
| 6 (ext) | 36.9 | 14.5 | 47.8 | 57.2 | 67.7 | .65 |
| 7 | 49.2 | 60.6 | 0 | 52.0 | 65.7 | .95 |



Fig. 1. Responses per minute during baseline in red and green components of the multiple schedule in Experiment 1, as functions of the ratio of food rates obtained for key pecking (VI) and presented independently of pecking (VT). In Conditions 2 and 3, the same VI schedule was arranged in red and green and the VT schedule in red varied (VI same); in Conditions 5 and 6, the total food rate arranged by VI and VT schedules in red was the same as that arranged by the VI schedule in green (total same). In Conditions 1, 4, and 7, all food was contingent on key pecking on VI 60-s schedules; these data points appear above 0 on the *x* axis, with functions drawn from the median point.

consistently by the use of shorter food presentations in Condition 3 relative to the other conditions. In the red component, response rates were a decreasing function of the ratio of VT to VI food rates (with the exception of G8, Condition 2). Food rate ratios varied in two ways. In Conditions 2 and 3, the VI schedule was constant and the ratio was increased by adding VT food presentations. By contrast, in Conditions 5 and 6, the VI and VT schedules were chosen to give the same ratios with constant overall food rates. The absence of consistent differences in these pairs of conditions

suggests that response rate was determined primarily by the ratio of VT to VI food presentations and not by overall food intake.

*Prefeeding*

In general, response rates in prefeeding sessions were lower than in baseline, but were not systematically related to amount prefed. Accordingly, the relative effects of prefeeding on response rates in red and green components during each prefeeding session were evaluated by the relation between proportions of baseline response rates in each prefeeding session. For each prefeeding session, response rates in each component were expressed as proportions of

the mean response rates in the three immediately preceding baseline sessions and plotted against each other. The results are shown in Figure 2. If the proportional effects of prefeeding were the same in both components, the data should fall along the main diagonal, as is generally true for Conditions 5 and 6. However, if response rates in the red component were less reduced relative to baseline than in green, the points would fall above the major diagonal, as is true for Conditions 2 and 3 (except for G5, Condition 2). More specifically, Figure 2 shows that the data points are generally farthest above the main diagonal for Condition 3, in which the total food rate in the red component was five times that in green; intermediate in Condition 2, in which the total food rate in red was three times that in green; and on or below the major diagonal in Conditions 5 and 6, in which the food rates were equal in the two components.

*Extinction*

Response rates throughout the course of extinction in Conditions 2, 3, 5, 6, and 7 are shown in Figure 3, expressed as proportions of baseline and averaged in two-session blocks. It is clear that responding decreased sooner or more rapidly in green than in red for all 3 birds in Conditions 2 and 3, consistent with the prefeeding results above. In Conditions 5 and 6, responding decreased sooner or more rapidly in red than in green for G8 and G5, but there was no consistent difference for G22.

Because there had been little evidence of consistent differences in resistance to prefeeding in Conditions 5 and 6, 10 sessions of extinction were conducted in Condition 7, which had equal VI schedules in the two components, to assess the possibility that the weakening of the operant contingency by VT food presentations was responsible for the red–green differences observed for 2 birds during extinction in Conditions 5 and 6. Here, G8 and G5 again exhibited relatively more rapid extinction in red than in green, as they had in Conditions 5 and 6, even though the baseline food schedules were identical. Indeed, for all 3 subjects, performance during extinction in Condition 7 closely resembled that in Conditions 5 and 6. Thus, the differential resistance to extinction in red and green components did not depend on the different arrangements of VI and VT food schedules in the red component in these three conditions, all of which arranged the same
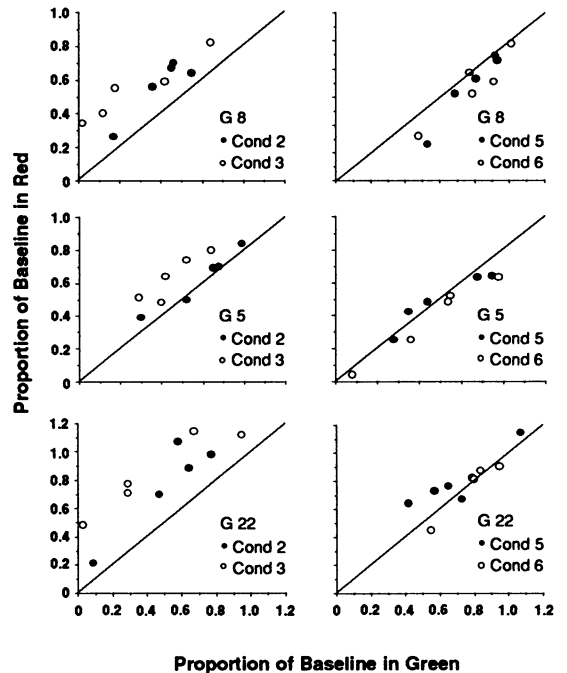


Fig. 2. Each data point shows the response rates in red and green components in prefeeding sessions of Experiment 1, expressed as proportions of baseline response rates averaged for the three preceding sessions and plotted against each other. The left-hand column presents data for Conditions 2 and 3, in which alternative VT food was arranged in red concurrently with a VI schedule identical to that in green. The right-hand column presents data for Conditions 5 and 6, in which the sum of VI and VT food rates in red was the same as that provided by the VI schedule in green.

total food rates in the red and green components. Accordingly, differential resistance to extinction in these conditions may be ascribed to a color bias (see Lander, 1968, for an instance of red–green color bias in pigeons during extinction after training with white keylights only). When key-color biases in extinction are discounted, resistance to extinction was a positive function of the overall food rate in a schedule component during training and was unaffected by the proportion of VT food presentations when overall food rates were equal.

*Comparison of Resistance to Prefeeding and Extinction*

Baseline response rates and the effects of prefeeding and extinction may be compared and summarized by the relation between the ratio and the sum of the response rates in red and green components for those procedures.
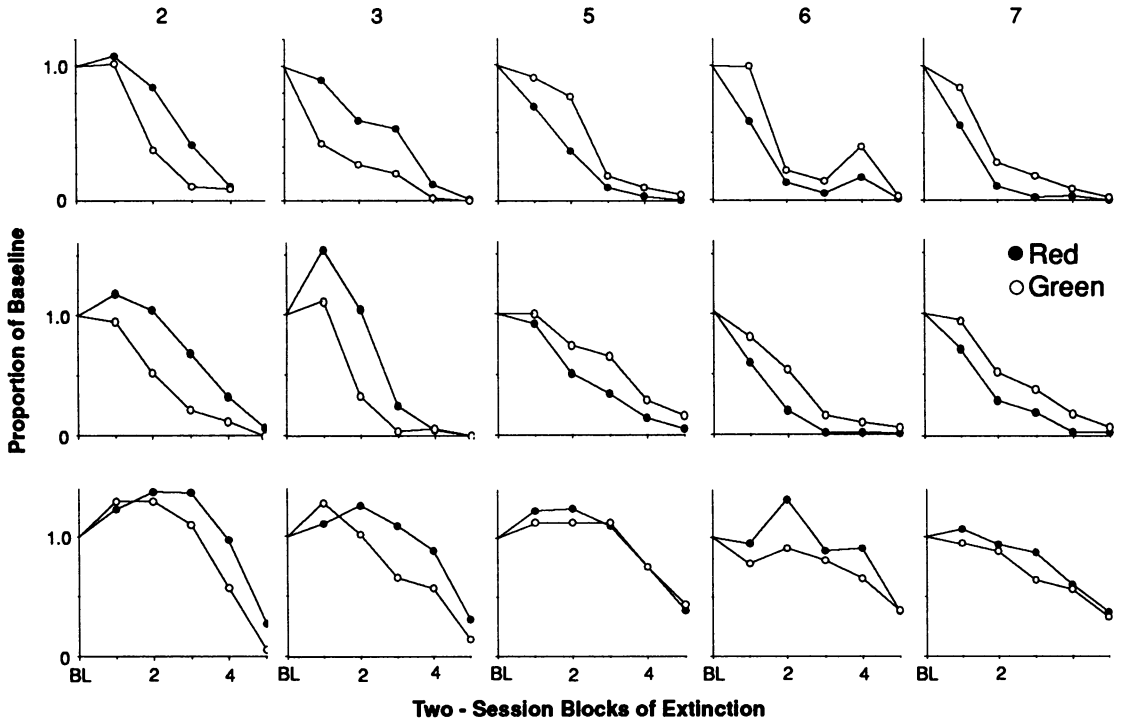
Fig. 3.    Response rates in two-session blocks of extinction at the end of the indicated conditions of Experiment 1, expressed as proportions of baseline response rates averaged for the preceding five sessions and presented separately for red and green components. Data are from Birds G8 (top), G5 (middle), and G22 (bottom).

The data are presented in this form in Figure 4, with ratios plotted on a logarithmic axis. The plotted points are for blocks of five baseline sessions preceding each resistance test (from Table 2), from individual prefeeding sessions, and from two-session blocks of extinction. As total responding decreases from right to left with various prefeedings or during the course of extinction, an upward trend in this plot implies smaller relative decreases in red than in green. Such trends are evident for Conditions 2 and 3. Note that, in general, the points move from below 1.0 (signifying lower response rate in red than in green, as in baseline) to well above 1.0 (signifying higher response rate in red than in green). The slope is steeper for the data from Condition 3, in which the VT food rate in red components was higher. By contrast, a horizontal relation signifies equal relative changes, and a decreasing relation signifies smaller relative decreases in green than in red, as seen in the data from Conditions 5 and 6. Note that the downward trend as response totals decrease in Conditions

5 and 6 is evident only for G8 and G5 in extinction, and thus is probably due to the color preference identified in Condition 7.

To make summary comparisons across conditions, the extinction data were reexpressed as the weighted average proportion of baseline, $\bar{p}$ (the rationale for calculation of $\bar{p}$ is given by Nevin et al., 1981, 1987). For prefeeding, the unweighted average proportion of baseline was calculated because there was no orderly effect of amount prefed. The ratio of the values of $\bar{p}$ for the red and green components is plotted in Figure 5 as a function of the scheduled ratio of food presentation rates in the red and green components, separately for prefeeding and extinction (note that obtained ratios closely approximated the scheduled values). A $\bar{p}$ ratio of 1.0 signifies that responding is equally resistant to change in the two components, whereas ratios above 1.0 signify that it is more resistant in the red component and ratios below 1.0 signify that it is more resistant in the green component. For all subjects, and for both prefeeding and extinction, the ratio of $\bar{p}$ values is
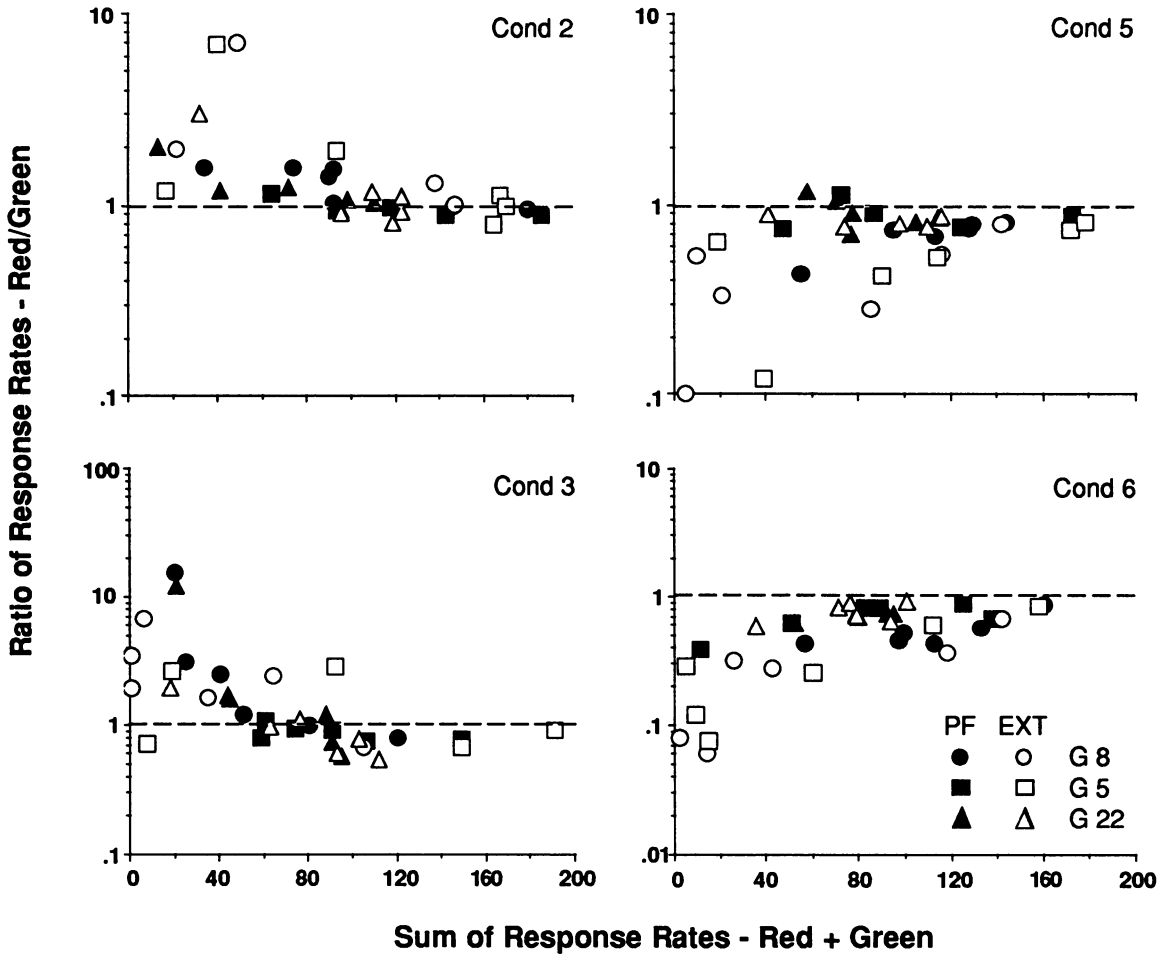
Fig. 4. The ratio of response rates in red and green components in Experiment 1, plotted on a logarithmic $y$ axis, as a function of the sum of the two response rates. The data points represent response rates in all prefeeding sessions, blocks of two extinction sessions, and baseline rates preceding prefeeding and extinction (from Table 2) in Conditions 2, 3, 5, and 6.

a positive function of the ratio of food presentation rates and is above 1.0 when the ratio of food presentation rates exceeds 1.0. Although extinction $p$ ratios are below 1.0 for G8 and G5 when the ratio of food presentation rates is 1.0, there is no consistent difference across the conditions at that ratio (Conditions 5, 6, and 7).

In summary, resistance to prefeeding or extinction in red was greater than in green when the total rate of food presentation was higher in the red component, as in Conditions 2 and 3, and differential resistance to change was positively related to the total rate of food presentation in the red component (relative to the constant green component). Moreover, differ-

ential resistance to prefeeding or extinction was unaffected by the proportion of VT food presentations in the red component when the overall rate of food presentation was constant across components, as in Conditions 5, 6, and 7.

## EXPERIMENT 2

Experiment 1 demonstrated that adding response-independent food to a schedule component decreases the rate and increases the resistance of a target response to change. The rate of a target response decreases also when food is added for an explicit concurrent response (e.g., Catania, 1963). If such a concurrent food schedule functions analogously to
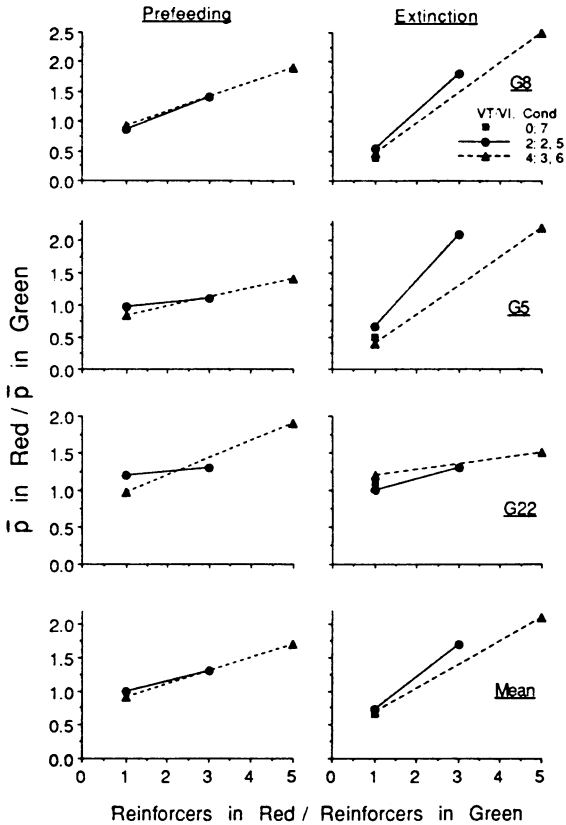
Fig. 5. Resistance to change in the red component relative to that in the green component is expressed as the ratio of average proportions of baseline, $\bar{p}$, in red and green, and related to the ratio of scheduled overall food reinforcement rates in red and green. Data points are coded for scheduled ratios of VT to VI food presentations in the red component, and points with equal ratios are connected to facilitate comparisons between related conditions.

ranged equal VI schedules for key pecking and added VT food presentations in the red-key component.

In the third concurrent schedule pair, food was scheduled only for the target response, but the rate of food presentation was the same as the sum of the two food rates arranged in the first component. Thus, the first and third schedule pairs are analogous to the red-key and green-key components in Experiment 1, Conditions 5 and 6, in which the sum of the food rates arranged by the VI and VT schedules in red was equal to the food rate arranged by the VI schedule in green. If food for an explicit alternative response functions similarly to response-independent food, the target response should be more resistant to change in the first concurrent schedule pair than in the second and should be equally resistant to change in the first and third schedule pairs. Such an outcome would provide further evidence that the overall food rate in the presence of a stimulus determines a response's resistance to change.

The use of an explicit response for alternative food has the advantage that its resistance to change can also be measured. If the total reinforcement arranged in a component by a schedule pair determines the resistance to change of both responses, the target and alternative response should be equally resistant to change because both responses of the concurrent pair occur in the same component stimulus. Response rates, however, should differ according to the relative rate of reinforcement of the two responses.

## METHOD

### Subjects

The subjects were 3 White Carneau pigeons, 2 of which had a history of autoshaping; the 3rd was experimentally naive. They were maintained at about 80% of their free-feeding weights with supplementary feedings following their experimental sessions as needed. Water and grit were continuously available in each bird's home cage.

### Apparatus

The experiment was conducted in a standard two-key pigeon chamber measuring 35 cm across the front panel, 30 cm from front to back, and 35 cm in height. On the front panel were two response keys, a houselight, and an opening giving access to a food hopper. The

response-independent food, as the effects on response rate seem to imply, then perhaps making food contingent upon an alternative response will increase the resistance of a target response to change just as freely delivered food does. Experiment 2 examines this possibility.

Three different pairs of concurrent schedules were arranged, each signaled by different key colors (i.e., a multiple concurrent schedule). Two of the concurrent schedule pairs arranged equal VI food schedules for pecks at the right key (the target response). In the first pair, food was also scheduled for pecks at the left key (the alternative response), whereas in the second, left-key pecks never produced food. Thus, these two components are analogous to the red-key and green-key components of Experiment 1, Conditions 2 and 3, which ar-

two response keys were positioned behind circular openings 2.5 cm in diameter. They were 8 cm apart on centers and 25 cm from the chamber floor, and each could be transilluminated with red, green, or white light. The opening to the hopper measured 6 cm wide by 5 cm high, centered on the front panel. Its bottom was 9.5 cm from the chamber floor. A blower provided ventilation and masking noise. The VI schedules were composed of 13 intervals, the durations of which were obtained by the tables provided by Fleshler and Hoffman (1962). The experiment was controlled and data were recorded by electromechanical equipment in a separate room.

## Procedure

*Preliminary training.* The birds were trained to peck both keys by successive approximations and were then required to make progressively more pecks before food was presented. Concurrent VI VI schedules were then instituted and varied systematically over blocks of days to ensure that responding varied with relative rate of food presentation and that key biases were not developing. The schedules were concurrent VI 120 s VI 120 s, VI 90 s VI 240 s, and VI 240 s VI 90 s, and the birds' relative responding shifted in accordance with the relative food rates.

*Baseline.* Three conditions were arranged and presented quasi-randomly as multiple concurrent schedules. The duration of each component was 60 s, with the keys lighted continuously except during food presentation. Each component was followed by a 20-s timeout with the keys darkened. Components were signaled by the color of both keys: green for Component A, red for Component B, and white for Component C. In Component A, 15 food presentations per hour were available on a VI schedule for pecking the right (target) key; 45 additional food presentations per hour were available on a different VI schedule for pecking the left (alternative) key. In Component B, only 15 food presentations per hour were available on the right key; food was never available for left-key pecks. Thus, Components A and B had equal food rates for the target response, but Component A also arranged alternative food presentations. In Component C, 60 food presentations per hour were available on a VI schedule for pecks on the right (target) key, and, as in Component B, food was never available for left-key pecks.
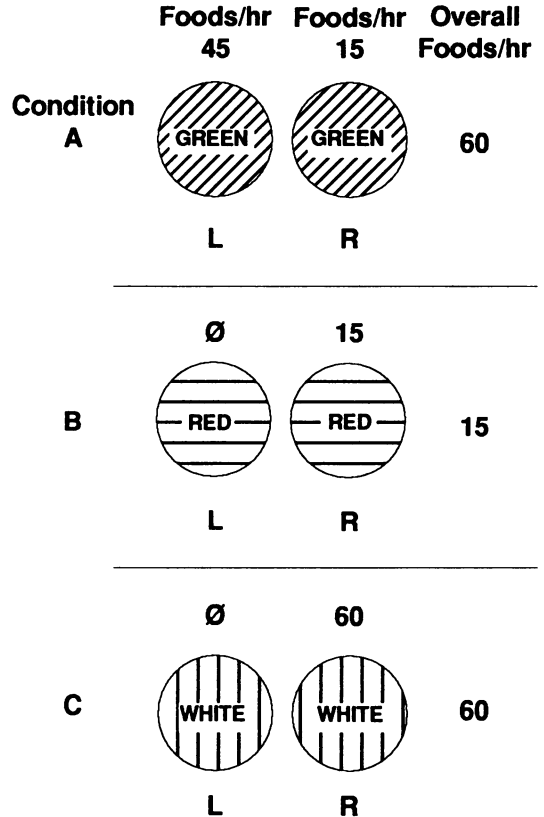


Fig. 6. Schematic of the procedure of Experiment 2. The circles represent the two keys. Components A, B, and C are the three components of the multiple schedule that alternated quasi-randomly every minute (with a 20-s timeout between components) throughout the session. The components consisted of concurrent VI VI schedules (Component A) or concurrent VI extinction (Components B and C). The reinforcers per hour provided by the concurrent schedules are shown above the keys, and the color of the two keys during each component is shown on the key.

Thus, Components A and C had equal overall food rates, distributed over both keys in Component A but concentrated on the right (target) key in Component C. These arrangements are summarized in Figure 6.

The food presentation rates and distributions were arranged by the method described by Stubbs and Pliskoff (1969). A single VI schedule (Fleshler & Hoffman, 1962) operated until a food availability occurred. The VI timer stopped until the assigned food presentation was collected. In Component A, the proportion of food presentations assigned to the left and right keys was .75 and .25, respectively. No changeover delay (COD) was used because the resulting response bursts would

● = A
▲ = B
■ = C



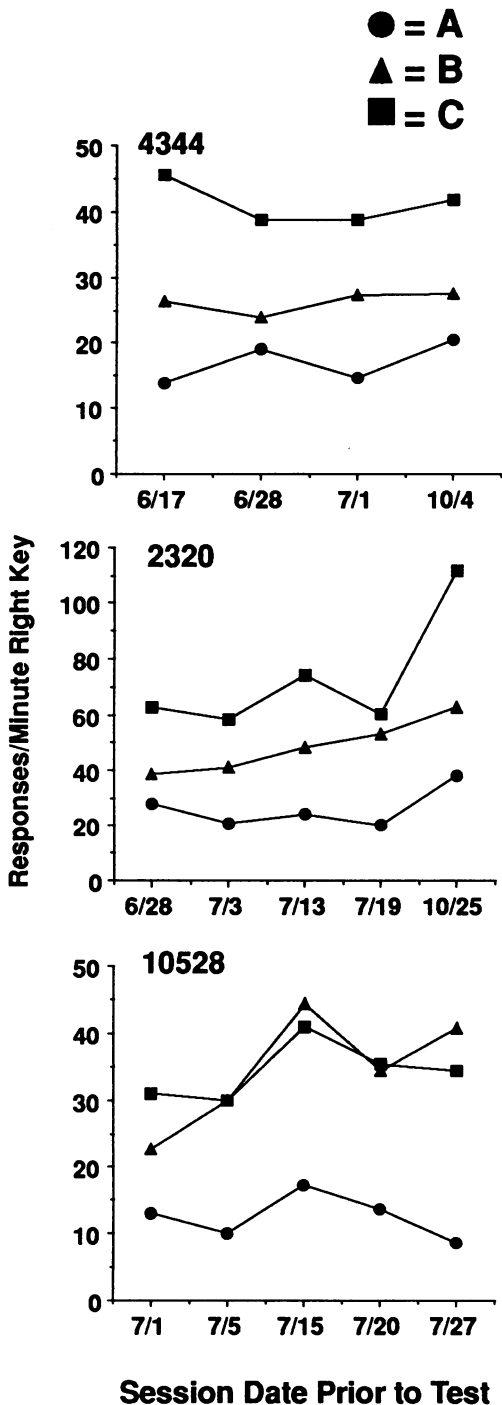**Session Date Prior to Test**

Fig. 7. Right-key response rates (resp/min) from each of the baseline sessions preceding a resistance-to-change test in Experiment 2. Each function in a panel shows the response rate from a different component of the multiple schedule. The *x* axis shows the date of each baseline session preceding a resistance test. The type of resistance test given the next day is indicated in the text.

have complicated interpretation and comparison of response rates (Guilkey, Shull, & Brownstein, 1975; Silberberg & Fantino, 1970).

Each daily session lasted until each of the three components had been presented 18 times (approximately 80 min). After 20 to 32 consecutive sessions of baseline training, tests of resistance to change were begun.

*Extinction.* The extinction condition consisted of a single session that continued until 12 min had elapsed without a key peck. In all other respects, the procedure was the same as in baseline, except that food was never presented.

*Long-session satiation.* The first method of satiation involved feeding the subject in the home cage 30 min to 1 hr before the start of a session. The amount prefed (15 g) was intended to be large enough to speed up the satiation process but not so large as to reduce responding at the start of the session. After prefeeding, the procedure was conducted as in baseline except that the session lasted until 12 min had elapsed without a key peck, as in extinction.

For both long-session satiation and extinction sessions, data were recorded in consecutive half-hour blocks. After a 12-min period without responses, the session continued until the current 30-min block ended, and responses that occurred during this time were recorded.

*Short-session satiation.* For the second method of satiation, sessions were reduced to nine presentations of each component. Immediately before each shortened session the subject was given 0 g, 30 g, 45 g, and sometimes 52.5 g of food in its home cage over 3 or 4 consecutive days.

The order of resistance tests for Birds 2320 and 10528 was long-session satiation, long-session satiation, long-session satiation, extinction, short-session satiation. The order for Bird 4344 was the same except that there were only two long-session satiation tests. Variable numbers of baseline training sessions were conducted between resistance tests; the dates of baseline sessions that preceded each resistance test are given on the *x* axis of Figure 7.

## RESULTS

### Baseline Response Rates

Figure 7 presents for each bird the rate of right-key (target) responding in each of the

Table 3

Average response and reinforcer distributions over 5-day periods of baseline training for each bird in Experiment 2. The top row for each bird shows baseline data from a period immediately before the start of the resistance test series. The bottom row for each bird shows the baseline data from a period near the end of the resistance tests.

| Bird | Response rate | | Reinforcement rate | | Relative measures | |
|---|---|---|---|---|---|---|
| | Left/min | Right/min | Left/hr | Right/hr | Responses | Reinforcers |
| Component A | | | | | | |
| 4344 | 43.01 | 18.79 | 47.00 | 12.08 | .31 | .20 |
| | 31.95 | 20.36 | 43.33 | 16.67 | .39 | .28 |
| 2320 | 66.94 | 36.46 | 46.60 | 14.83 | .35 | .24 |
| | 47.77 | 32.33 | 40.13 | 15.13 | .40 | .27 |
| 10528 | 35.70 | 16.46 | 41.62 | 17.29 | .31 | .29 |
| | 45.05 | 7.30 | 40.67 | 10.62 | .14 | .21 |
| Component B | | | | | | |
| 4344 | 2.93 | 27.30 | 0 | 14.79 | .91 | 1.00 |
| | 0.29 | 30.26 | 0 | 13.42 | .99 | 1.00 |
| 2320 | 7.48 | 49.82 | 0 | 14.11 | .87 | 1.00 |
| | 0.19 | 52.74 | 0 | 13.73 | 1.00 | 1.00 |
| 10528 | 2.58 | 30.79 | 0 | 10.81 | .91 | 1.00 |
| | 0.04 | 46.64 | 0 | 15.33 | 1.00 | 1.00 |
| Component C | | | | | | |
| 4344 | 13.01 | 51.46 | 0 | 58.02 | .80 | 1.00 |
| | 3.20 | 44.13 | 0 | 52.00 | .93 | 1.00 |
| 2320 | 1.50 | 70.77 | 0 | 60.78 | .98 | 1.00 |
| | 0.24 | 90.47 | 0 | 60.93 | 1.00 | 1.00 |
| 10528 | 8.24 | 39.77 | 0 | 57.06 | .82 | 1.00 |
| | 6.52 | 34.06 | 0 | 58.00 | .86 | 1.00 |

three components during each of the baseline sessions before a resistance test, either satiation or extinction. The first and last points, therefore, were separated in time by as much as 3 months. This figure shows how response rates were controlled by the schedules in the different components and indicates the consistency of baseline responding over the course of the experiment.

Baseline response rates were ordered in accordance with expectations based on the absolute and relative food rates. That is, response rates were highest (with two exceptions for Bird 10528) in Condition C, which arranged the highest absolute food rate for the target response (60/hr) and no alternative food; next highest in Component B, which arranged 15 food presentations per hour for the target response and no alternative food; and lowest in Component A, which arranged 15 food presentations per hour for the target response and also arranged alternative food on the left key. The consistent difference between response

rates in Components A and B is a concurrent contrast effect.

Table 3 presents two samples of baseline data, each summed over five consecutive sessions. One sample came from the five sessions immediately preceding the first test of resistance to change; the second sample came from five consecutive sessions near the end of the resistance tests. The table shows the absolute and relative rates of responding and food presentation in each of the three multiple-schedule components. In most cases, relative response rates deviated from relative food rates in the direction of indifference. This deviation was most pronounced for Bird 2320 in Component A; deviations from matching in that component were less extreme for the other birds, and in one case (Bird 10528, second sample), relative response rate was more extreme than relative food rate. Thus, the differences in baseline rates of target-key responding among the multiple-schedule components and between keys are consistent
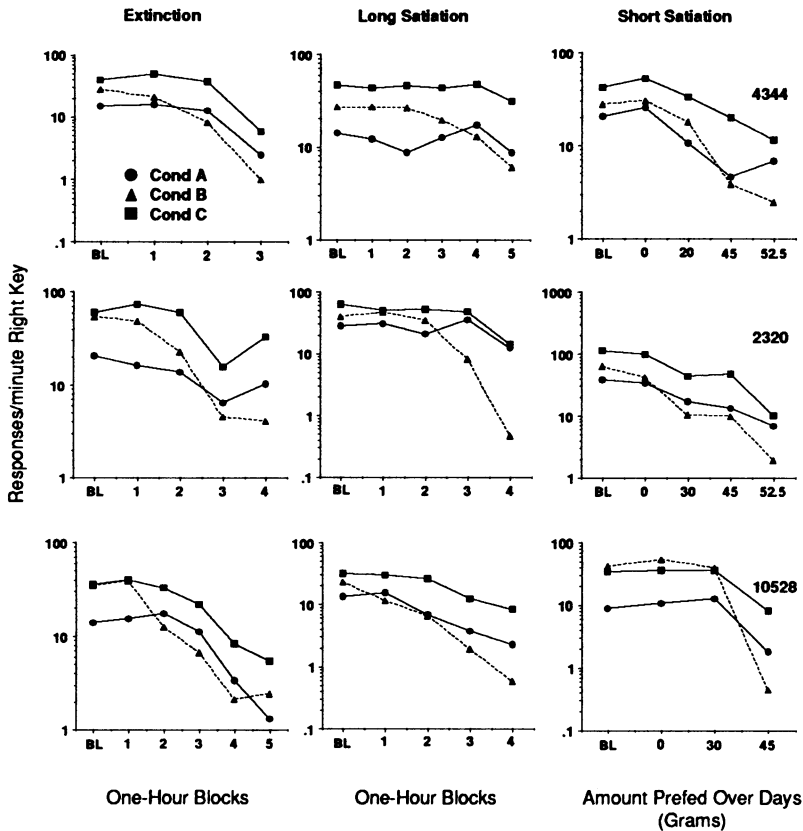
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Fig. 8. Resistance to change of right-key response rates in Experiment 2. Right-key response rates (resp/min) are plotted as a function of increasing values of the change operation, that is, as a function of consecutive hours during the extinction and long-session satiation test and as a function of increasing amounts prefed before a short-satiation test session. Each line in a graph shows the response-rate function from a different component of the multiple schedule. Each row shows the data from a different bird; each column shows the data from a different type of resistance-to-change test. The data are from the only extinction and short-satiation test given and from the first long-session satiation test. The leftmost point for each response-rate function was obtained from the baseline session prior to the resistance test. Note that the *y* axis is scaled logarithmically.

with what is generally known about the effects of absolute and relative food schedules.

### Effects on Resistance to Change

*Target response comparisons.* Figure 8 illustrates for each bird (rows) one set of response-rate functions from each type of resistance test (columns). There are three functions in each panel, one for the target response in each of the multiple-schedule components. The leftmost point for each function shows the response rate during the immediately preceding baseline session. The response-rate axis is logarithmic, so that vertical distance corresponds to relative change. The initial levels of these functions characterize baseline response rates, and their slopes provide direct measures of

relative resistance to the *x*-axis variable, with steeper slopes indicating lesser resistance to change.

Consider first the relation between the functions for Components A and B. Both had the same food rate for the target response (15/hr), but the overall food rate was higher and the relative food rate was lower in Component A than in Component B because of the concurrent food schedule (45/hr) on the left key. During baseline and at the start of the resistance tests, the rate of the target response was higher in Component B than in Component A. However, in all cases, the response rate in Component B dropped below that in Component A so that the function for Component B crossed the function for Component A. This
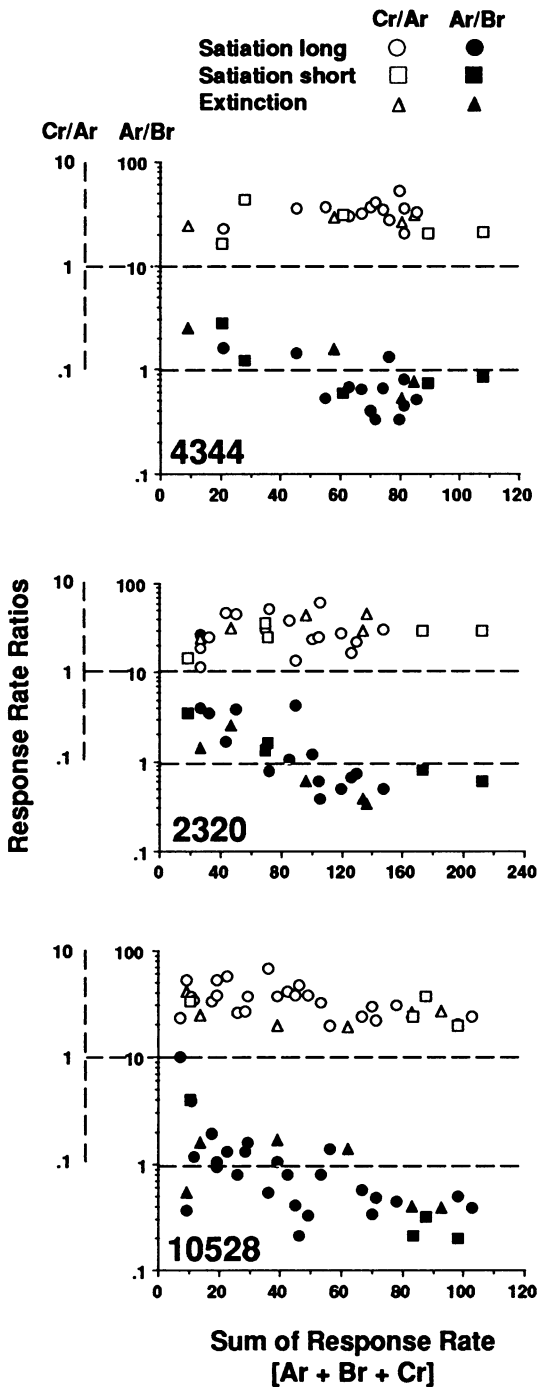
Fig. 9. Ratios of right-key response rates (log scale) plotted as a function of the right-key response rates summed over the three components of the multiple schedule of Experiment 2. Each point shows the response-rate ratio from a different 1-hr block during a resistance test (extinction and long-session satiation) or from the whole short-session satiation test. Solid points show the ratios of right-key responding in Component A (45 rft/hr left; 15 rft/hr

crossover has theoretical implications that will be considered later.

Next, consider the relation between the response rate functions for Components A and C. Both had the same overall food rate (60/hr), but Component A had the lower relative food rate and consequently the lower response rate. Nevertheless, the slopes of the functions are quite similar, indicating that the response rates in both Components A and C were similarly resistant to change.

Another way to examine resistance to change is to plot the ratio of response rates in two components (e.g., A/B) as a function of the rates of responding summed across all components (A + B + C), which indicates the overall level of responding. To the extent that response rates in the two components are equally resistant to change, their ratio should be independent of the overall level of responding; therefore, the data points should scatter about a horizontal line. Conversely, if the performances being compared are differentially resistant to change, the ratio of the more resistant to the less resistant response rate should increase as the overall level of responding declines (see also Figure 4 of Experiment 1 and accompanying text).

Figure 9 presents the data from all three resistance tests in this form for each bird. Each point represents response ratios either from the immediately preceding baseline session, from successive 1-hr blocks of the extinction or long-satiation tests, or from the daily sessions of the short-satiation tests.

The lower panel of each graph shows the comparison between Components A and B, with Component A response rate in the numerator. The points scatter about a line with a rising trend from right to left, indicating that right-key response rate was more resistant to change in Component A than in Component B. The ratio was below 1.0 when the overall level of responding was high and became

←

right) to right-key responding in Component B (0 rft/hr left; 15 rft/hr right). Open points show the ratios of right-key responding in Component C (0 rft/hr left; 60 rft/hr right) to the right-key responding in Component A (45 rft/hr left; 15 rft/hr right). Data from all resistance tests are included as are the data from the baseline sessions preceding the resistance tests. The different symbols indicate the type of resistance test. The Cr/Ar ratio points are displaced upward by one log cycle.
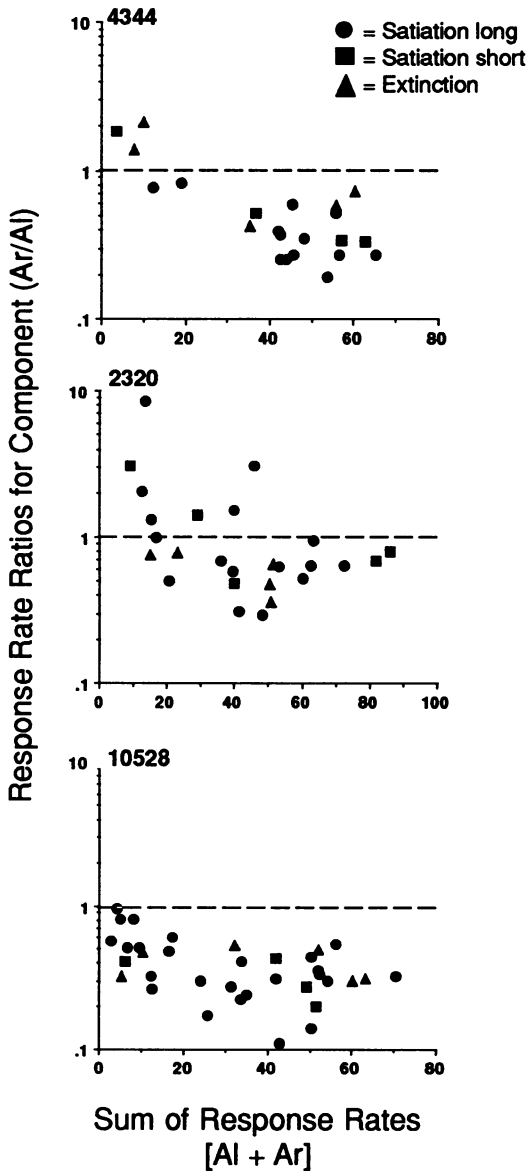
Fig. 10.   Ratios of response rates (right key/left key) plotted over the sum of the response rates (left key plus right key), for Component A of Experiment 2 only (45 rft/hr left; 15 rft/hr right). Each point shows the response-rate ratio from a different 1-hr block during a resistance test (extinction and long-session satiation) or from the whole short-session satiation test. Data from all resistance tests are included as are the data from the baseline sessions preceding the resistance tests. The different symbols indicate the type of resistance test.

greater than 1.0 as overall responding decreased. This is consistent with the crossovers noted in Figure 8. Thus, the additional food presentations on the left key increased the resistance of the target response to change in Component A relative to Component B.

The upper panel in each graph shows the comparison between Components A and C, with Component C response rate in the numerator. The points are consistently above 1.0 and scatter about a horizontal line, indicating that the right-key response occurred at a higher rate but was no more resistant to change in Component C than in Component A. Thus, equal total rates of food presentation (60/hr) in the two components led to similar resistances to change for the target response. There is no evidence that either the A/B relation or the C/A relation differed for the different resistance tests.

*Concurrent resistance to change in Component A.* It is also important to examine relative resistance to change of response rates in relation to the food rates arranged on the two concurrently available keys in Component A. If resistance to change is determined by the overall food rate in a component, as the comparisons above suggest, then left-key and right-key response rates should be equally resistant to change in Component A because the overall food rate in that component is the same for both responses.

Figure 10 presents the ratio of response rates on the right and left keys (Ar/Al) as a function of the sum of response rates (Ar + Al) for Component A only. If response rates on the right and left keys were equally resistant to change, the points should scatter about a horizontal line. For 2 birds (4344 and 2320) the points scatter about a line that rises from right to left, indicating that resistance to change for the right key (15/hr) is greater than that for the left key (45/hr). The scatter of points for the 3rd bird (10528) does not so clearly deviate from a horizontal function.

## GENERAL DISCUSSION

The findings of Experiments 1 and 2 suggest some common conclusions:

1. When a target response is maintained by a given VI food schedule, its baseline rate is lower when alternative food is available either

independently of responding (Experiment 1) or contingent upon a specific concurrent response (Experiment 2) than when there is no alternative food. These results are consistent with many previous findings (e.g., Catania, 1963; Rachlin & Baum, 1972). An exception was reported by Boakes, Halliday, and Poli (1975), who found that VT food presentations in one component of a multiple VI VI schedule increased response rates in that component. The effect was strongest when components were short (20 s; see also Rachlin, 1973). Perhaps the use of relatively long components with timeout between them, as in Experiment 1, is important for the reductions observed in average response rates.

2. When a target response is maintained by a given VI food schedule, its resistance to satiation or extinction is greater when alternative food is (or was) available than when there is (or was) no alternative food (Conditions 2 and 3 of Experiment 1; Components A and B of Experiment 2). These latter results are generally consistent with those of Catania (1969), who examined extinction of a target response established by a VI food schedule with and without concurrent VI food. He found that resistance to extinction was greater when concurrent food was scheduled (as in Component A) than when it was not (as in Component B). His experiment differed in that alternative food was available during extinction of the target response, and thus may be interpreted in terms of adventitious reinforcement for the target response during extinction. The consistency between Catania's and the present results suggests, however, that the effect is more general.

3. When a target response in one component of a multiple schedule is maintained by a given VI food schedule and alternative food is available within that component, its resistance to satiation or extinction does not differ from that in a second component when the response is maintained by a VI schedule arranging food at a rate equal to the sum of the VI and alternative food schedules in the first component (Conditions 5 and 6 of Experiment 1; Components A and C of Experiment 2). These findings confirm those of Nevin et al. (1987), who found no difference in resistance to change for performances based on contingent versus noncontingent schedule transitions. Thus, in general, resistance to change may be unaffected by the fundamental operant contingency.

These results demonstrate the independence of the determiners of maintained response rates and their resistance to change when alternative food schedules are arranged. The results are replicable across laboratories using procedures that vary in their particulars and may therefore be regarded as quite robust. The remainder of this discussion will be devoted to interpretation of these results in more general terms.

*Operant and Pavlovian Contingencies*

One way to approach these results employs the language of contingencies. An operant, response–reinforcer contingency exists when reinforcers are presented only after a specified response. That contingency may be weakened by providing additional reinforcers independently of that response. The strength of the contingency may be characterized by the probability (or rate) of reinforcement given the occurrence of the response relative to the probability (or rate) of reinforcement given the absence of the response (e.g., Gibbon, Berryman, & Thompson, 1974). The general finding is that response rate decreases when the contingency is weakened (e.g., Hammond, 1980). Our results summarized in Paragraph 1 above confirm this finding.

A Pavlovian, stimulus–reinforcer contingency exists when a reinforcer is presented only given the prior presentation of a particular stimulus. The contingency may be weakened by presenting reinforcers in the absence of the stimulus. The strength of the contingency may be characterized by the reinforcer probability (or rate) given the stimulus relative to the reinforcer probability (or rate) in its absence. The general finding is that the effect of the stimulus on behavior decreases when the contingency is weakened (e.g., Rescorla, 1968; cf. Gibbon et al., 1974; Gibbon & Balsam, 1981).

In our experiments, a contingency existed between the stimuli signaling the multiple-schedule components and the reinforcers that occurred during those components. The greater the rate of reinforcement in the presence of a component stimulus relative to the average rate of reinforcement in its absence, the stronger was the stimulus–reinforcer contingency in that

component. As summarized in Paragraphs 2 and 3 above, resistance to change depended on the overall rate of reinforcement in a signaled component: When reinforcement rates differed, resistance to change was greater in the component with the higher overall reinforcement rate. In other words, resistance to change depended directly upon the component-stimulus–reinforcer-rate contingency.

### Interpretations of the Effect of the Stimulus–Reinforcer Contingency

There are several ways of interpreting the effects of the stimulus–reinforcer contingency on the resistance of operant behavior to satiation and extinction. We consider three below. One is based on the possible effects of a Pavlovian process on operant behavior; the second is derived from Herrnstein's (1970) suggestion that the relative rate of reinforcement determines the rate of a response; the third is an interpretation based on local rates of reinforcement.

*Pavlovian processes.* There is considerable precedent for the idea that stimuli can have, as a result of Pavlovian contingencies, nonspecific effects that arouse or modulate operant behavior (e.g., the "central motive state" of Bindra, 1972, and Rescorla & Solomon, 1967; see also Colwill & Rescorla, 1986; Estes, 1943, 1948; Holland, 1983; Killeen, 1979; Morse & Skinner, 1958). Such effects may differ from specific Pavlovian conditioned responses like salivation and elicited key pecking in several ways. First, the nonspecific arousing or modulating effects on operant behavior of a stimulus correlated with a reinforcer may be clearer when assessed by probe tests during extinction by comparison with baseline assessments, which are complicated by ongoing operant reinforcement (e.g., Estes, 1948; Krystal, 1970). By contrast, effects of a specific conditioned response are immediately evident during acquisition or maintenance of the response itself. Second, the nonspecific enhancement of operant behavior is most likely to be observed with a long-duration stimulus (e.g., Edgar, Hall, & Pearce, 1981), whereas specific conditioned responses are generally acquired and maintained most effectively with short-duration stimuli. Nonspecific modulating effects may also be evoked by long-lasting situational or contextual stimuli (e.g., Balsam & Tomie, 1985; Konorski, 1967, chap. VI).

In the present procedures, each of the different colors that signaled the multiple-schedule components may have come to evoke an arousing or modulating effect that contributed to the resistance of key-pecking rates to satiation and extinction. The magnitude of this Pavlovian effect should have varied directly with the rate of food presentation in the presence of each component stimulus. If so, the resistance of operant behavior should likewise have varied directly with the baseline rate of food presentation during each component stimulus, consistent with the data of both experiments. Because we did not attempt to measure such Pavlovian processes, however, this account remains an hypothesis.

*Relative reinforcement account of operant behavior.* As discussed above, the rate of a response is an increasing function of the rate of the reinforcer obtained by that response but a decreasing function of the rate of reinforcement that occurs independently of the response. Herrnstein's (1970) equation is one expression of this principle:

$$B = \frac{kR}{R + Ra + Re} \qquad (1)$$

where $B$ is the rate of the target response, $R$ is the obtained rate of the reinforcer for the target response, $Ra$ is the obtained rate of experimentally arranged alternative reinforcers in the presence of the stimulus where $B$ and $R$ occur, $Re$ is the rate of extraneous, unprogrammed reinforcers obtained during the stimulus (measured in units of the experimentally specified reinforcer), and $k$ is the asymptotic response rate during the stimulus as relative reinforcement [i.e., $R/(R + Ra + Re)$] approaches 1.0. The denominator specifies the total rate of reinforcement during the component stimulus, with $Ra$ and $Re$ occurring independently of the target response. (For simplicity, this discussion ignores the possible effects of reinforcers obtained during other stimulus components. Such effects should be small under the experimental conditions of Experiments 1 and 2. In any case, the basic conclusions would be the same if their effects were considered.)

To apply this equation to our procedures and data, consider first the effect of adding alternative reinforcement on the rate of the target response. That manipulation would be represented as an increase in $Ra$ from zero to some higher value, with all other right-hand

terms constant. An increase in $Ra$ should result in a decrease in $B$, consistent with the data and consistent with the more general contention that degrading the operant contingency should cause the rate of the operant to decrease.

Next consider the effects of the resistance tests. To apply Herrnstein's (1970) equation it is necessary to specify how its right-hand terms might change to represent the effects of increasing satiation or increasing exposure to extinction. One simple assumption is that the values of $R$ and $Ra$ established during baseline training carry over into satiation or extinction tests but are degraded by some function in proportion to their baseline values as satiation or extinction progresses. Such proportional decreases in the value of scheduled reinforcement is indistinguishable in the equation from an increase in $Re$. In other words, increasing satiation or extinction may be represented as an increase in $Re$, and as $Re$ increases, $B$ will decrease.

The size of the effect that $Re$ has on $B$ depends on the total rate of scheduled reinforcement in the presence of a stimulus (i.e., $R + Ra$). More specifically, Equation 1 predicts that a particular-sized increment in $Re$ will result in a smaller decrease in $B$, relative to baseline, when the rate of the scheduled reinforcer is high than when it is low. This is so because the relative decrease in response rate depends on the relative increase in the denominator (e.g., to halve the response rate, $B$, the denominator in Equation 1 must double). And whether a given increment in $Re$ will produce a relatively large or small increase in the denominator will depend on the initial size of the denominator. Thus, the higher the baseline rate of all scheduled reinforcers during a stimulus (i.e., $R + Ra$), the smaller will be the effect of a given increment in $Re$. Significantly, it should not matter whether the scheduled reinforcers in the presence of the stimulus depend on the target response or not. All that matters is the total (i.e., $R + Ra$). The implication, then, is that the relative resistance of a target response to the decremental effects of satiation and extinction should be greater the higher the rate of baseline reinforcement *from all sources* in the presence of the stimulus.

Thus, Equation 1 is consistent with two aspects of our data: (a) Response rate in the presence of a stimulus was a decreasing function of the rate of alternative reinforcement during that stimulus, and (b) the relative resistance of the target response to satiation and extinction depended on the reinforcer rate during the stimulus regardless of their source. The first aspect is a well-known implication of Equation 1; the second implication has not, so far as we know, been described previously.

It is worth emphasizing that it is the denominator of Equation 1 that determines the target response's resistance to satiation and extinction. Because the denominator of Equation 1 specifies the overall rate of reinforcement during a stimulus, it can be construed as specifying a Pavlovian contingency. Thus, an interpretation based on a Pavlovian process and one based on a relative reinforcement principle may be more alike than might first appear.

There are, however, aspects of our data that are inconsistent with Equation 1. Their consideration, though complicated, is necessary for evaluating the relative reinforcement interpretation.

Particularly challenging is the consistent finding that for a given VI schedule, the higher baseline response rate (in Component 1) not only decreased relatively more than the lower response rate (in Component 2) but actually became lower in absolute terms (the crossover effect). According to Equation 1, this can never happen. The numerators are the same for both components (because of the same VI schedule); the denominator is larger for the component providing additional reinforcement. The value of $Re$ is assumed to increase by the same amount in both components during extinction or satiation. Thus, as the denominators increase indefinitely for both components, the predicted response rates converge but do not cross.

Burgess and Wearden (1986) suggested a modification of Herrnstein's (1970) approach that avoids this difficulty for Experiment 1, which employed a VT schedule of alternative reinforcement. They modified Equation 1 as follows to incorporate the effects of VT food:

$$B = \frac{k(R + pRa)}{R + Ra + Re} \qquad (2)$$

Here, the terms are as in Equation 1, except that $p$ is the proportion of VT food presentations ($Ra$) that function as if they were VI food presentations, perhaps because they occur in close temporal contiguity with the response.

Now, assume that Equation 1 (with $Ra = 0$) describes response rate in the green component of Experiment 1, that Equation 2 de-

scribes response rate in the red component, and that there is no interaction between the food schedules in one component and response rate in the other (an empirically reasonable assumption given the constancy of response rate in the green component across experimental conditions with red-component food rates ranging from 60 to 300 per hour). For any value of $p$ less than 1.0, the equations predict that response rate in green will be higher than in red when $Re$ is small, but predict the reverse when both response rates decrease as $Re$ becomes large—the crossover effect that is problematic for Herrnstein's (1970) unmodified equations. (This prediction may be verified by inserting representative numbers into Equations 1 and 2. For example, let $k = 100/min$ and $R = 60/hr$ for both equations, with $Ra = 240/hr$ and $p = .5$ in Equation 2. Then, Equation 1 predicts a response rate of 86/min in Component 1 vs. 58/min in Component 2 when $Re = 10/hr$, and 6/min in Component 1 vs. 13/min in Component 2 when $Re = 1,000/hr$. The ratio of response rate in Component 2 to that in Component 1 increases from .67 when $Re = 10/hr$ to 2.17 when $Re = 1,000/hr$, with a concomitant decrease in the sum of response rates, consistent with the trends for Condition 3 shown in Figure 4.) Thus, the Burgess–Wearden formulation gives a good qualitative account of the data of Experiment 1.

A related formulation by Davison and Jenkins (1985) could also be applied to Experiment 2, in which target (right-key) responding, maintained by 15 reinforcers per hour, was more resistant to change in Component A, with 45 alternative reinforcers per hour arranged on the left key, than in Component B, with no alternative reinforcers. The Davison–Jenkins approach suggests that some left-key reinforcers in Component A may be misallocated to the right key and vice versa. (In effect, the Burgess–Wearden formulation is a one-way misallocation account, and hence a special case of the Davison–Jenkins approach.) This possibility must be taken seriously because no COD was used. In essence, the argument is that the target response had a higher effective rate of reinforcement in Component A and hence was relatively less affected by a given increase in $Re$ than in Component B.

However, this account has difficulty explaining two aspects of the data from Experiment 2. First, if some alternative reinforcers are in fact reinforcing the target response in Component A, then such misallocated reinforcement would result in a higher relative rate of reinforcement for the target response than was scheduled, and deviations from matching in the direction of indifference would be expected. Although such deviations were the rule (see Table 3), the sizes of the deviations do not suggest that accidental strengthening of right-key responding by left-key reinforcers was playing a large role, with the possible exception of Bird 2320. Second, a misallocation account must also explain the similar resistances to change of the target response between Components A and C. If misallocation were the only process responsible for these results, then all (or nearly all) of the 45 left-key reinforcers per hour would have to have been misallocated to the right key in Component A, with few or no right-key reinforcers misallocated in the opposite direction. Yet if that had happened, relative response rates in Component A should have been near 1.0 on the right key, although the proportion of reinforcers was about 0.25—clearly contrary to the data of Table 3.

Thus, our efforts to account for our resistance-to-change data in terms of extensions of Herrnstein's (1970) equation have proven only partly successful. The fact that resistance to change depended on the contingency between component stimuli and reinforcers (a Pavlovian contingency) but not on the proportion of those reinforcers that were contingent on the target response (an operant contingency) was consistent with our extension of Equation 1, but certain details of the data (e.g., the crossover) were dealt with less comfortably.

*Local reinforcer rates.* We now consider an alternative to the idea that the component-stimulus–reinforcer-rate contingency determines resistance to change. This alternative considers the local rates of reinforcement for each response as the determiners of resistance to change in Experiment 2. In Component A, the proportion of time spent engaged in the target response may have approximated .25, as suggested by the literature on concurrent performances (e.g., Baum, 1979; Brownstein & Pliskoff, 1968). If so, the local rate of reinforcement per unit of time spent engaged in the target response would be about 60 per

hour, which is greater than the 15 per hour for target responding in Component B and equal to the 60 per hour in Component C. Thus, if the local rate of reinforcement determined resistance to change of the target response, it should have been more resistant in Component A than in Component B and equally resistant in Components A and C, as found. An account in terms of local reinforcement rate may therefore be appropriate for Experiment 2.

Such an account is more difficult to apply to Experiment 1. To apply the account, one must assume that the time allocated to responding (vs. not responding) follows the same matching principle as suggested above for Experiment 2. Thus, the proportions of time spent responding would be about .39 in Conditions 2 and 5 and about .21 in Conditions 3 and 6, corresponding to the obtained reinforcer proportions (these values may be calculated from Table 2). If this analysis is appropriate, local response rates must have increased from a baseline average of about 73 per minute in Conditions 1, 4, and 7 (where 100% of the time was presumably devoted to responding) to about 169 per minute in Conditions 2 and 5 (an average of 66 per minute with 39% of time allocated to responding) and about 252 per minute in Conditions 3 and 6 (an average of 53 per minute with 21% of time allocated to responding). These calculations suggest that time-allocation matching would require a radical increase in the local rate or tempo of responding, contrary to many analyses of free-operant responding (e.g., Gilbert, 1958; Pear & Rector, 1979). If these implications for local rate of responding are accepted, a local-rate-of-reinforcement account can explain the resistance-to-change data of Experiment 1 as well as those of Experiment 2. An analysis of interresponse-time distributions for the conditions of Experiment 1 might confirm this analysis; however, it strikes us as implausible.

A further reason for skepticism about the role of local reinforcer rates in the determination of resistance to change derives from recent work by Williams and Royalty (1989). They trained pigeons on multiple schedules in which each component consisted of a pair of concurrent schedules that differed in their overall and local reinforcer rates. In probe tests with novel pairs, they found that choice was determined by the overall but not the local rate

of reinforcement in training. This result is relevant to our data on resistance to change, in that there is substantial evidence that the determiners of resistance to change and choice covary (e.g., Mellon & Shull, 1986; for review, see Nevin, 1979). Thus, Williams and Royalty's finding that choice depends on overall rate of reinforcement is consistent with our suggestion that resistance to change depends on the overall rate of reinforcement correlated with a component stimulus. In sum, we doubt that the local-rate-of-reinforcement approach can provide a generally satisfactory account of our data (see also below).

It is interesting, nevertheless, that a local analysis offers a possible explanation for one aspect of the data from Experiment 2 that seems especially troublesome for our view that the contingency between component stimuli and overall reinforcer rates determines resistance to change. The problem is that, in Component A, the relation between the component stimulus and obtained overall reinforcer rate is the same for pecks at both left and right keys; accordingly, responding should have been equally resistant to change on both keys. For at least 2 of the 3 subjects, however, responding to the left key, maintained by the richer schedule, was *less* resistant to both satiation and extinction than was responding on the right key.

In terms of time allocation, at the beginning of extinction the birds would have been spending more time engaged in left-key responding than in right-key responding. As extinction progresses, then, the birds will have had more extinction exposure to the local stimulus correlated with left-key responding than to the local stimulus correlated with right-key responding. Thus, when measured in overall time, left-key responding may extinguish more rapidly.

To extend this logic to the satiation tests, it must be assumed that satiation operates in the same manner as extinction. Perhaps as the bird satiates, it learns that food is no longer reinforcing. Because there is more opportunity for this learning on the key with more responding and more frequent reinforcement, left-key responding may be affected more rapidly by satiation. However, this argument is applied less readily to the short-satiation tests, in which the birds were prefed in their home cages, because it is implausible that learning that food

is less reinforcing is taking place during the short session. Thus, the effects produced by the two types of satiation tests ought to have been different, but in fact they were similar.

The effects of satiation and extinction on the relative resistance of the concurrent operants in Component A were not entirely consistent across subjects, and a similar inconsistency arises in the literature. Myerson and Hale (1988) and Skinner (1950) found that relative responding did not change systematically during extinction from that established during training on concurrent VI VI schedules. However, the extinction data of a discrete-trial concurrent VI VI experiment by Nevin (1969), and of a multiple-schedule study similar to Experiment 2,[2] resembled those reported here in that, during extinction, responding decreased relatively faster on the alternative that previously had the higher reinforcer rate. All in all, the inconsistencies in the literature, coupled with the consistency of our effects across extinction and satiation tests, make us skeptical of any single account of concurrent extinction based on time allocation and local rates of reinforcement.

## Conclusion

Further explorations of the determiners of response rate and resistance to change might employ procedures in which the alternative reinforcers are introduced in a way that does not affect the allocation of time to the target response and that minimizes the chances of reinforcer misallocation. One way to accomplish this is by signaling the alternative reinforcers (e.g., Catania, 1963, 1969). Another approach might involve presentation of alternative reinforcers during successive and distinctive segments of a common signaled situation. This approach has been used by Nevin (1984) and by Nevin et al. (1987), where the common situation was defined by key location; other methods of defining the situation may give even clearer results. Also, these analyses should be extended to other species, responses, and reinforcers because of the well-known effects of keylight–food relations on key pecking by pigeons (Schwartz & Gamzu, 1977). Mace

et al. (in press) have recently replicated Condition 2 of Experiment 1 with human subjects (residents of a group home) engaged in an everyday task; further replication and extension are needed. For the present, however, it appears fruitful to consider the rate of responding maintained under constant conditions and the resistance of responding to change as separable aspects of behavior. The former is determined primarily by response–reinforcer contingencies and the latter by stimulus–reinforcer contingencies.

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