

*PREFERENCE AND RESISTANCE TO CHANGE WITH
CONSTANT-DURATION SCHEDULE COMPONENTS*

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Previous research on preference between variable-interval terminal links in concurrent chains has most often used variable-duration terminal links ending with a single reinforcer. By contrast, most research on resistance to change in multiple schedules has used constant-duration components that include variable numbers of reinforcers in each presentation. Grace and Nevin (1997) examined both preference and resistance in variable-duration components; here, preference and resistance were examined in constant-duration components. Reinforcer rates were varied across eight conditions, and a generalized-matching-law analysis showed that initial-link preference strongly overmatched terminal-link reinforcer ratios. In multiple schedules, baseline response rates were unaffected by reinforcer rates, but resistance to intercomponent food, to extinction, and to intercomponent food plus extinction was greater in the richer component. The between-component difference in resistance to change exhibited additive effects for the three resistance tests, and was systematically related to reinforcer ratios. However, resistance was less sensitive to reinforcer ratios than was preference. Resistance to intercomponent food and to intercomponent food plus extinction was more sensitive to reinforcer ratios in the present study than in Grace and Nevin (1997). Thus, relative to variable-duration components, constant-duration components increased the sensitivity of both preference and relative resistance, supporting the proposition that these are independent and convergent measures of the effects of a history of reinforcement.

Key words: choice, concurrent chains, overmatching, resistance to change, multiple schedules, key peck, pigeons

The study of resistance to change has usually employed multiple variable-interval (VI) schedules of food reinforcement, in which different reinforcer rates are arranged in alternating components presented successively and signaled by distinctive stimuli. In a typical experiment, the components are constant and equal in duration, and are separated by intercomponent intervals (e.g., Nevin, 1974; Nevin, Mandell, & Atak, 1983). After stable baseline performance is established, responding is disrupted for a few sessions in any of several ways (e.g., presenting food during intercomponent intervals, or discontinuing reinforcement altogether). The general finding is that response rate is less disrupted, relative to baseline, in the component with the high-

er reinforcer rate (for review, see Nevin, 1992b).

Resistance to change within each component has been characterized by the slope of the decremental function relating response rate during disruption, expressed as the logarithm of the proportion of baseline, to the value of the disrupter (e.g., rate of intercomponent food, or sessions of extinction). Slope is an inverse measure of resistance: The shallower the slope, the greater the resistance to change. Nevin (1992b) showed that relative resistance to change, expressed as the inverse of the ratio of slopes in two components, approximated a power function of the ratio of reinforcer rates.

Nevin (1979) noted that the terminal links of concurrent-chains schedules, which are produced successively by concurrently available initial-link responses, are analogous to multiple-schedule components. Thus, responding in the initial links of concurrent chains can be construed as measuring preference between multiple-schedule components comprising the terminal links. Across experiments, schedule parameters that affect resistance to change usually have similar effects on preference (for a recent example,

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see Grace, Schwendiman, & Nevin, 1998; for review, see Nevin & Grace, 2000).

The relation between preference and relative reinforcer rate in concurrent chains may be quantified by Grace's (1994) contextual choice model, which is a version of the generalized matching law that accounts for the effects of overall initial- and terminal-link durations on initial-link choice (e.g., Fantino, 1969). The model's core expression is

$$\frac{B_L}{B_R} = b \left[\left(\frac{R_L}{R_R} \right)^a \right]^{(Tt/Ti)}, \quad (1)$$

where B_L and B_R are left and right initial-link responses, R_L and R_R are the reinforcer rates or immediacies in the terminal links produced by left and right initial-link responses, a is the sensitivity of initial-link choice allocation to the terminal-link reinforcer ratio, b characterizes inherent bias between the initial-link responses, and Tt and Ti represent the average times spent in the terminal and initial links per reinforcer, respectively. Equation 1 provides an excellent description of preference in concurrent chains, with a approximately constant across variations in Tt and Ti . Thus, both preference and relative resistance are power functions of reinforcer ratios.

To explore the relation between preference and relative resistance within subjects, Grace and Nevin (1997) arranged conventional concurrent-chains schedules, in which each terminal link ended with a single reinforcer after a variable delay, and multiple schedules, in which the components were identical to those terminal links, in separate phases of each session. Across conditions, they varied relative reinforcer immediacy in the terminal links, with average terminal-link duration constant. In each condition, they measured initial-link preference in the concurrent-chains phase and resistance to response-independent food in the multiple-schedule phase (presented during intercomponent intervals according to a variable-time [VT] schedule). When relative resistance to change in the two components was measured as the difference between log proportions of baseline, it was highly correlated with preference. Grace and Nevin construed this as evidence for convergent measurement of a single construct known as *response strength* in the multiple-schedule liter-

ature and as *conditioned reinforcement value* in the concurrent-chains literature. This construct represents the effects of the history of reinforcement in a distinctive stimulus situation.

Although the terminal-link schedules employed by Grace and Nevin (1997) are standard in research on concurrent chains, the corresponding multiple-schedule components in their study differed from those in previous research on resistance to change in several ways: (a) Components always ended with a single reinforcer, (b) component duration varied from one presentation to the next, and (c) rich and lean components differed in their average duration, as determined by their respective VI schedules. Here, we pursue the evaluation of preference and resistance to change with VI schedules in terminal links of constant and equal duration, corresponding to those usually employed in multiple-schedule research. Under this arrangement, the relative frequency distributions of times to reinforcement from terminal-link entry are the same in rich and lean components if the VI schedules arrange reinforcer availability with constant probability, as approximated by Fleshler-Hoffman (1962) progressions. Unlike the usual variable-delay procedure, the number of reinforcers per component can vary considerably, including zero when the current interval of the VI schedule exceeds the component duration.

The present experiment extends our recent work by using a wide range of reinforcer rates in constant-duration terminal links across eight conditions, and by employing three disrupters in the multiple-schedule phase of each condition: intercomponent VT food, extinction, and intercomponent VT food during extinction. The results provide a comprehensive, parametric evaluation of preference, relative resistance to change, and the relation between these measures using a procedure that makes direct contact with earlier research on resistance to change using multiple VI VI schedules in constant-duration components.

METHOD

Subjects

Four White Carneau pigeons, maintained at 85% of their free-feeding body weights,

served. Birds 022, 031, and 119 had histories of reinforcement on various multiple schedules; Bird 319 had no experimental history. The birds were housed individually in a vivarium with a 12:12 hr light/dark cycle, with lights on at 7:00 a.m.

Apparatus

The experiment was conducted in four similar three-key pigeon chambers, 35 cm deep by 35 cm wide by 35 cm high. The keys were 26 cm above the floor, 2.6 cm in diameter, and separated by 8 cm, center to center. An aperture (6 cm by 5 cm), 13 cm below the center key, gave access to a grain feeder, and a houselight was located 7 cm above the center key. Reinforcement consisted of 2.75-s access to the feeder. The keys could be transilluminated with red, green, or white light, and were operated by pecks with a force of about 0.10 N. A blower provided ventilation and masking noise. The experiment was controlled and data were recorded by a computer running MED-PC[®] located in an adjacent room.

Procedure

Baseline. Sessions consisted of a concurrent-chains procedure in one half and a multiple-schedule procedure in the other half, in random order from day to day. Session halves were separated by a 3-min blackout. Sessions were conducted daily at about the same time of day (3:00 p.m.), with few exceptions. Procedural parameters were selected on the basis of 68 preliminary sessions with Birds 022, 031, and 119; Bird 319 was exposed directly to the final procedure after key pecking was established.

Concurrent-chains procedure. There were 24 initial- and terminal-link cycles of concurrent chains in each session, in which each cycle began with the center key dark and the two side keys lighted white to define the initial links. A terminal-link entry was assigned randomly to either the left or right key, with the restriction that exactly 12 entries to each terminal link were assigned during the session. An initial-link response was reinforced by terminal-link entry provided that (a) it was to the preselected key, (b) an interval selected from an arithmetic VI 25-s schedule had elapsed, and (c) a 1.5-s changeover delay was satisfied. The VI schedule contained 12 inter-

Table 1

Order of conditions and values (in reinforcers per hour) of the VI schedules in the terminal links produced by responses on the left and right keys and in the identical multiple-schedule components, with number of baseline training sessions before the first resistance test.

Con- dition	Left	Right	Ses- sions	Order of tests
1	270	90	35	VT+ext ^a , VI, ext
2	90	270	40	VT+ext, VI, ext
3	240	120	44	VI, VT+ext, ext
4	120	240	39	VI, VT+ext, ext
5	295	65	48	VT+ext, VI, ext
6	65	295	42	VI, VT+ext, ext
7	90	30	39	VT+ext, VT ^a , ext
8	30	90	45	VI, VT+ext, ext

^a These tests were omitted for Bird 319. The first was omitted because the bird entered the experiment late, and the second was omitted because of an intermittent right-key failure that was identified and corrected before the final test.

vals that were sampled randomly with the restriction that each interval preceded left and right terminal-link entries exactly once per session. The VI 25-s schedule did not begin timing until the first peck to either side key in each cycle.

Terminal-link entry was signaled by lighting the center key red or green and extinguishing the side keylights. If the center key was lighted red, one VI schedule was in effect; if it was green, a different VI schedule was in effect. The VI schedules were constructed from Fleshler–Hoffman (1962) progressions containing 12 intervals sampled randomly without replacement. For Birds 031, 119, and 319, pecks in the left and right initial links produced red and green, respectively, on the center key; color assignments were reversed for Bird 022. Terminal links were always 30 s long (excluding reinforcement), after which the next cycle began at once. The VI schedule values in each condition are listed in Table 1.

Multiple-schedule procedure. There were 24 multiple-schedule components, signaled by lighting the center key red or green, presented in random order with the restriction that exactly 12 of each occurred during each session. Key colors signaled VI schedules arranged exactly as in the concurrent chains, and components were always 30 s long excluding reinforcement. Components were separated by a 30-s intercomponent interval

(ICI) to approximate the average time spent in the initial links in the concurrent chains.

Resistance tests. Three different tests of resistance to change were conducted in each condition, separated by a series of baseline sessions.

1. Intercomponent VT food (VT). During the multiple-schedule half of the session, which always occurred second, food was presented during the ICI according to a VT 10-s schedule for five consecutive sessions.

2. Intercomponent VT food plus extinction (VT+ext). During the multiple-schedule half of the session, which always occurred second, food was presented exactly as in the VT food test and, in addition, the VI schedules were discontinued, for five consecutive sessions.

3. Extinction. In the first two conditions, the VI schedules were discontinued for nine consecutive sessions during the multiple-schedule half of the session, which occurred second, while the concurrent-chains procedure remained in effect during the first half. Because responding proved to be quite persistent, the concurrent-chains half of the session was omitted and the VI schedules were discontinued for eight consecutive sessions in all subsequent conditions.

Sequence and duration of conditions. The VI schedules were varied in both relative and absolute reinforcer rate across pairs of conditions, in which the same schedules were reversed in each pair. In each condition, baseline training continued until performance appeared to be stable for all 4 birds. Then, either a VT or VT+ext test was conducted, in an irregular order across conditions. The other test was conducted after at least seven sessions of baseline training intervened. Finally, an extinction test was conducted after at least five more baseline sessions intervened. The full sequence of conditions and tests is summarized in Table 1.

RESULTS

Preference in Concurrent Chains

We begin by considering preference in the initial links of the concurrent chains; terminal-link response rates will be considered below, with multiple-schedule performance. To give an overview of preference over the course of the experiment, the data for all ses-

sions in each condition before the first resistance test were averaged across subjects. Figure 1 shows average initial-link preference, expressed as the log ratio of responses to the left and right keys in the concurrent-chains half of each session. Each panel shows pairs of conditions that reversed the schedules paired with red and green keylights in the terminal links. In each condition, preference changed gradually and approached an asymptote that consistently indicated a strong preference for the richer terminal link. For example, in Condition 1, the log initial-link response ratio was about 0.85, which corresponds to a 7:1 preference for terminal-link schedules with a reinforcer rate ratio of 3:1. Preference followed schedule reversals with each condition change.

Stability of preference was evaluated by fitting regression lines to individual data for the final 10 sessions in each condition. As shown in Figure 2, the regression slopes deviated from 0 by less than ± 0.05 , except for Bird 022 in Condition 6 and Bird 319 in Condition 8. A retrospective examination of their data showed satisfactory stability over the final six to seven sessions in both cases. However, as we show below, preference tended to become more extreme during the resistance test sequence.

Figures 3, 4, and 5 show initial-link preference as a function of terminal-link reinforcer-rate ratios for the block of five baseline sessions immediately preceding each resistance test. The relations were quantified by fitting a logarithmic transformation of Equation 1. The temporal context exponent (Tt/Ti) was omitted because programmed initial- and terminal-link durations were constant across conditions. The parameters of Equation 1 were estimated by least squares regression of log response ratios on log reinforcer ratios:

$$\log(B_L/B_R) = a \log(R_L/R_R) + \log b. \quad (2)$$

If both sensitivity a and bias b equal 1.0, response ratios exactly match reinforcer ratios; values of a greater than 1.0 indicate overmatching.

Values of a for five-session blocks preceding each resistance test are given in Table 2. Equation 2 accounted for an average of 95% of the variance, and the estimated values of a ranged from 1.39 to 2.10, indicating strong

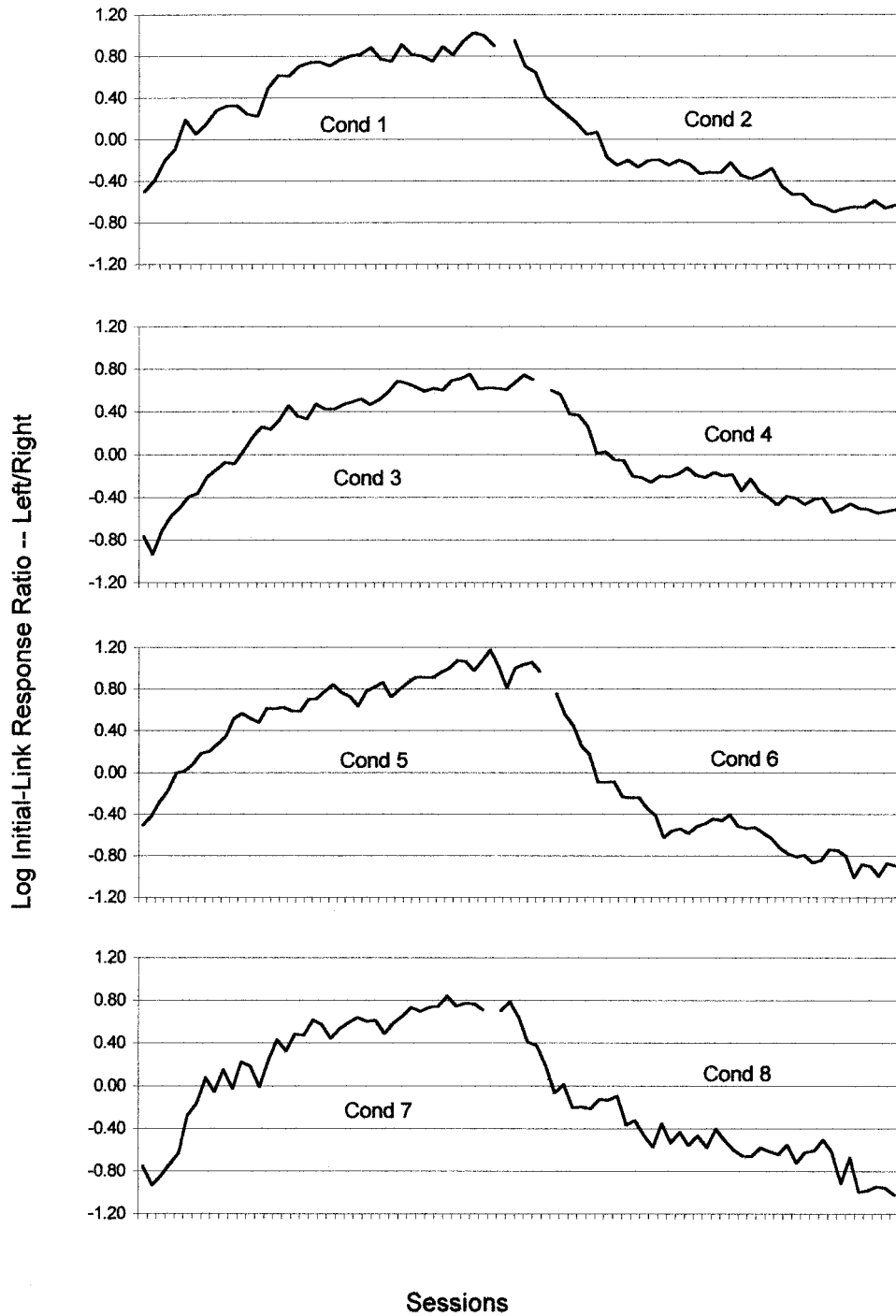


Fig. 1. Preference, expressed as the log ratio of initial-link responses on the left and right keys in concurrent chains and averaged across subjects for all sessions in each condition before the first resistance test, during experimental conditions with different VI schedules in constant-duration terminal links. The VI schedule values in the terminal links were reversed in each successive pair of conditions. Scheduled ratios of terminal-link reinforcer rates were 3:1, 2:1, 4.5:1, and 3:1 across the four pairs of conditions.

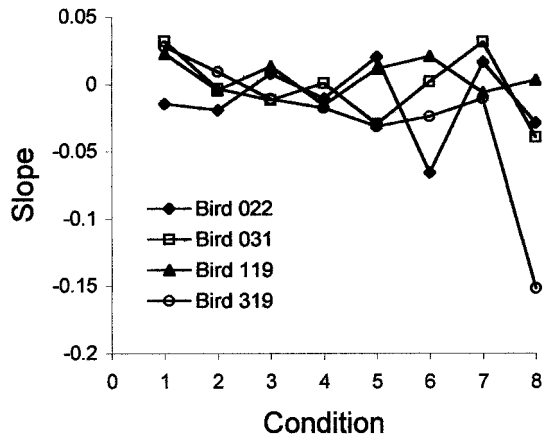


Fig. 2. Stability of preference, measured by the regression slope for the log ratio of initial-link responses over the final 10 sessions of baseline before the first resistance test, across successive experimental conditions for individual subjects.

overmatching. This overmatching cannot be attributed to terminal links that are long relative to initial-link duration (e.g., Fantino, 1969) because the obtained times in the initial links always exceeded 30 s (i.e., with reference to Equation 1, $T_t/T_i < 1.0$).

For the five sessions that immediately preceded the first resistance test, the value of a ranged from 1.55 to 1.71. The value of a was higher for all 4 birds in the five-session block before the second resistance test, but there was no consistent evidence of further increases before the third test. Because preference was reasonably stable before the first test, the increase in sensitivity before the second test probably resulted from the disruptive effects of the first test, but continued exposure to the schedules may also have been a factor.

The effect of overall terminal-link reinforcement rate is given by comparison of Conditions 1 and 2 with Conditions 7 and 8, which had the same reinforcer ratio but differed by a factor of three in absolute reinforcer rate. Figure 1 shows that there was little difference in the average initial-link response ratios between Conditions 1 and 2 and between Conditions 7 and 8. For individual subjects, line estimates of a for Conditions 1 and 2 did not differ consistently from those for Conditions 7 and 8. As noted in Table 1, Bird 319 was not exposed to the VT+ext test in Condition 1. Also, Bird 319 experienced an intermittent right-key failure during Condition 7 that was

identified before the VT test was scheduled, so that test was omitted. As a result, only the line estimates for extinction can be calculated for Bird 319. Complete data for all subjects are given in the Appendix.

Grace and Nevin (1997) found that preference depended on the order of the concurrent-chains and multiple-schedule phases within a session. Specifically, they found that preference was generally more extreme when the concurrent-chains phase occurred second, perhaps because the multiple schedules gave, in effect, preexposure to the terminal-link stimuli and schedules. No such order effect appeared in the present data. Over the final 10 sessions of baseline preceding the first resistance test in each condition, preference was more extreme when the concurrent-chains phase occurred second in four of eight conditions for Bird 022, six of eight for Bird 031, four of eight for Bird 119, and two of eight for Bird 319. On average, log preference ratios differed by less than 0.005 across different orders. Accordingly, order of exposure can be disregarded in the present data.

The value of preference sensitivity, based on all determinations before the three resistance tests in each of the eight conditions and averaged across subjects, was 1.78 (range, 1.39 to 2.10). By contrast, the average value of preference sensitivity reported by Grace and Nevin (1997) was 0.91 (range, 0.83 to 1.05). Their concurrent chains were similar to those arranged here in most particulars, and the ratio of average terminal-link and initial-link durations (T_t/T_i) was approximately the same as in the present procedure (see Equation 1). The major difference is that Grace and Nevin used variable-duration terminal links that always ended with a single reinforcer, whereas the present study used constant-duration terminal links that could include one, many, or no reinforcers at all in each presentation.

Performance in Multiple Schedules

Figure 6 presents average response rates in the multiple-schedule components for the last five sessions of baseline, the five baseline sessions preceding each subsequent resistance test, all five sessions during the VT and VT+ext tests, and the first seven sessions of extinction. Average baseline response rates

Preference and Resistance to VT

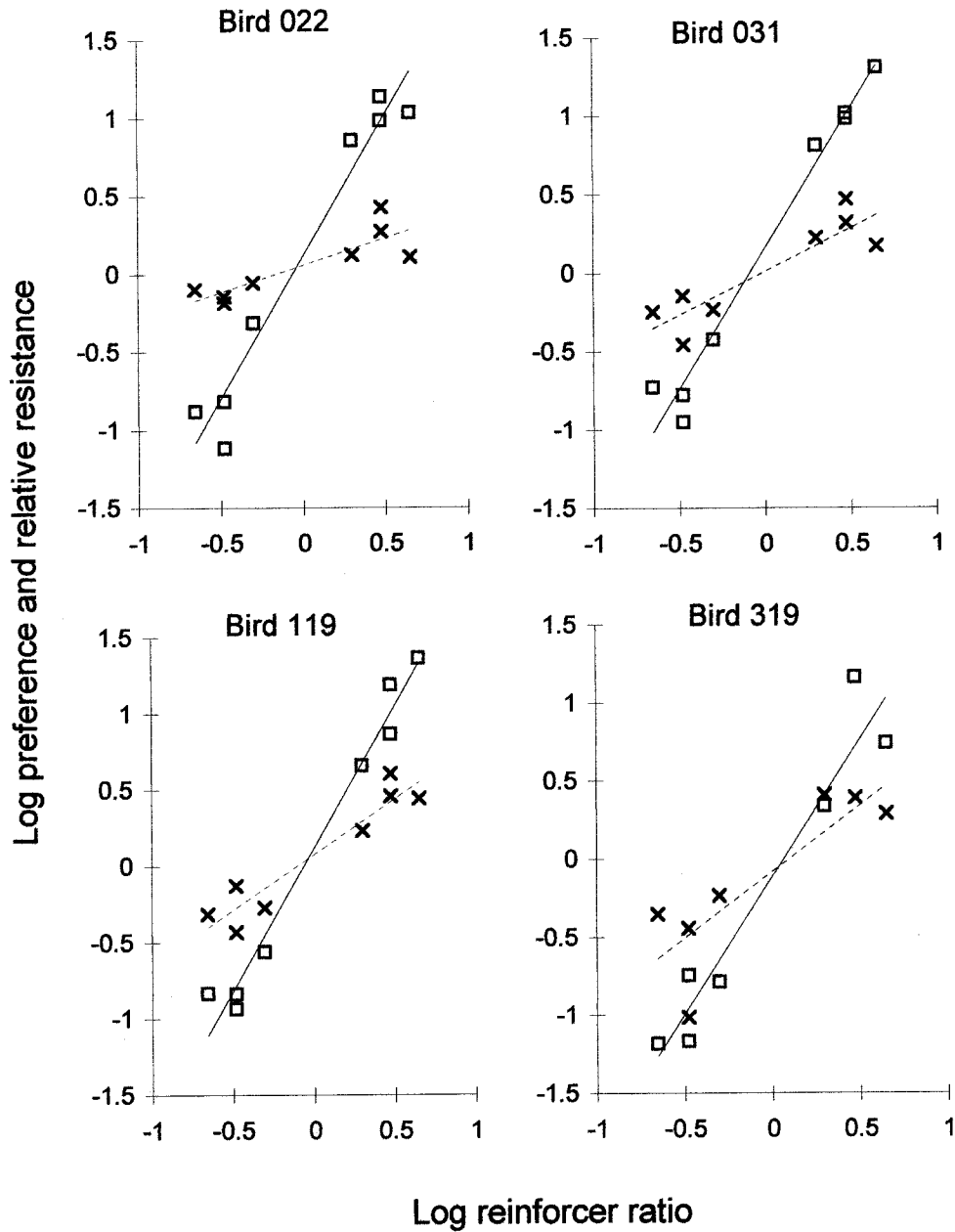


Fig. 3. Preference (open squares) in the initial links of concurrent chains during the five baseline sessions preceding tests of resistance to VT food during intercomponent intervals, and relative resistance (x) in multiple-schedule components during the VT tests, as functions of the reinforcer-rate ratio. The lines through the data are based on fits to Equations 2 and 3; their parameters are given in Table 2.

Preference and Resistance to VT + Ext

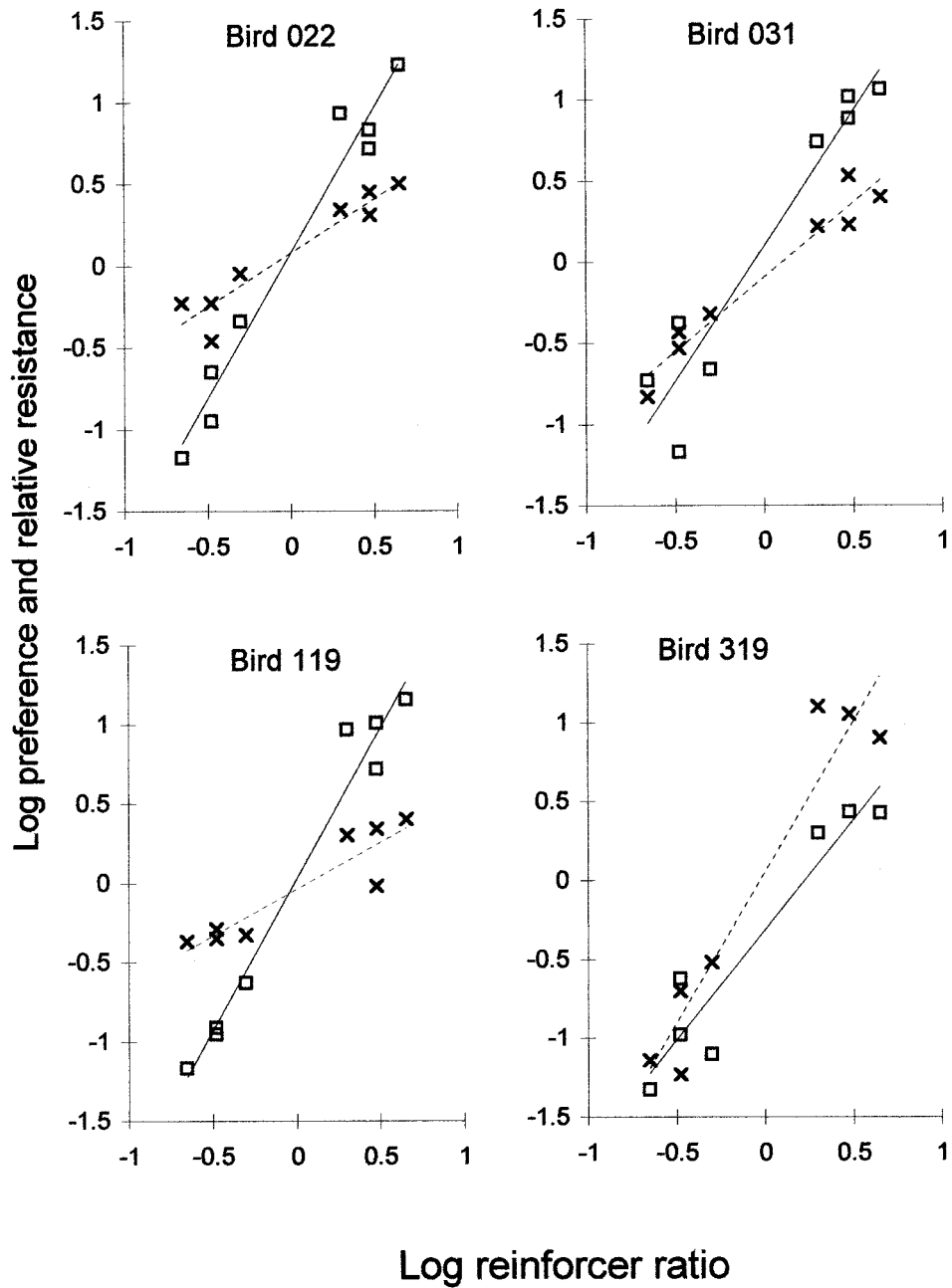


Fig. 4. Preference (open squares) in the initial links of concurrent chains during the five baseline sessions preceding tests of resistance to VT food during intercomponent intervals plus extinction in the schedule components, and relative resistance (x) in multiple-schedule components during the VT+ext tests, as functions of the reinforcer ratio. The lines through the data are based on fits to Equations 2 and 3; their parameters are given in Table 2.

Preference and Resistance to Ext

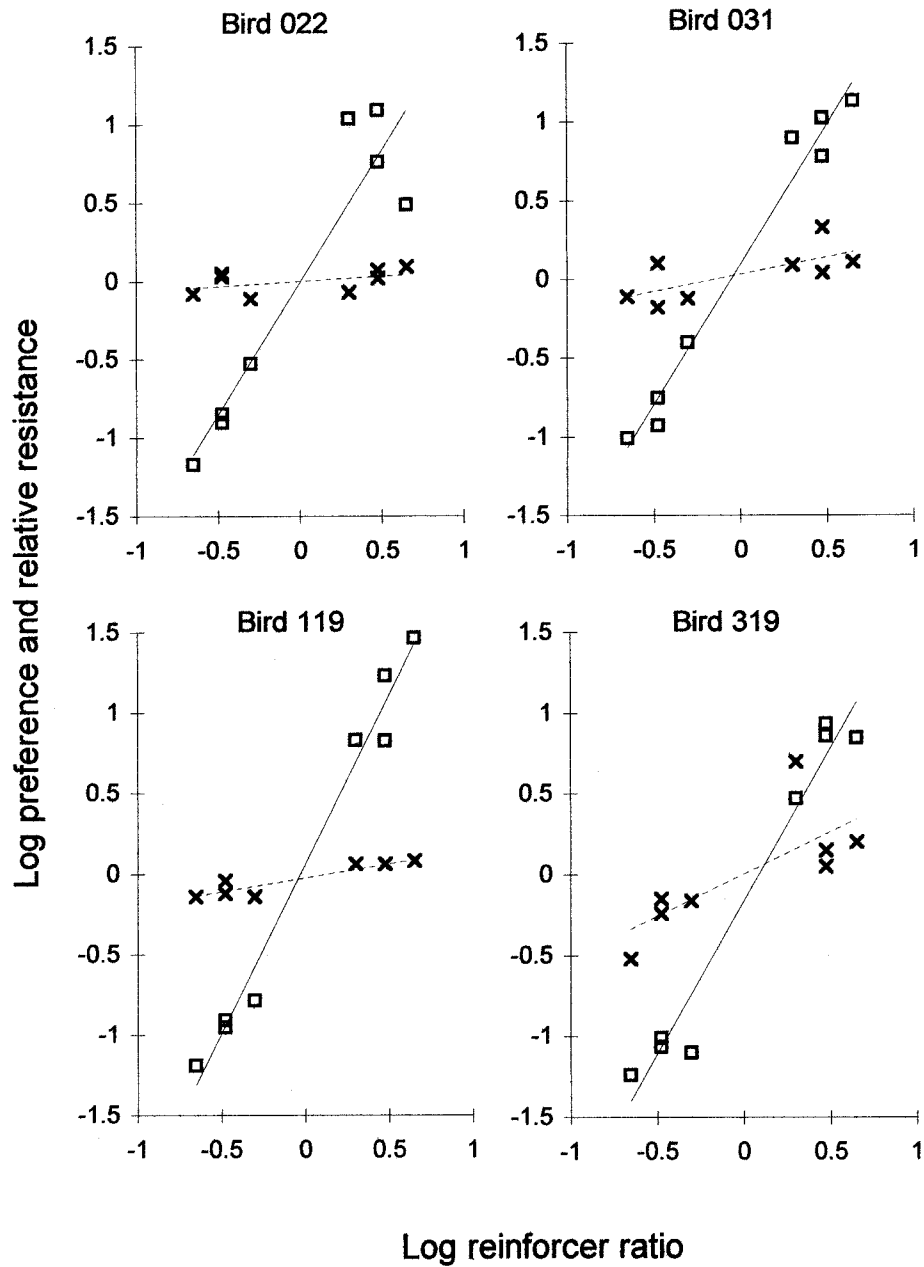


Fig. 5. Preference (open squares) in the initial links of concurrent chains during the five baseline sessions preceding tests of resistance to extinction, and relative resistance (x) in multiple-schedule components for the first five sessions of extinction, as functions of the reinforcer ratio. The lines through the data are based on fits to Equations 2 and 3; their parameters are given in Table 2.

Table 2

Generalized matching law estimates of sensitivity and bias for preference in the five sessions preceding each resistance test, and for relative resistance in each type of test, for the functions shown in Figures 3, 4, and 5. The proportion of variance (VAC) explained by each fitted function is also given. The rightmost column gives the correlation between residuals for preference and relative resistance for each test type.

Bird		Sensitivity	Bias	VAC	Correlation
022	VT preference	1.82	0.11	.95	
	VT resistance	0.35	0.05	.73	0.53
	VT+ext preference	1.77	0.08	.96	
	VT+ext resistance	0.66	0.08	.91	0.36
	Ext preference	1.68	-0.01	.88	
	Ext resistance	0.07	0	.21	-0.56
031	VT preference	1.79	0.15	.97	
	VT resistance	0.55	0.01	.80	0.52
	VT+ext preference	1.67	0.10	.91	
	VT+ext resistance	0.92	-0.09	.95	0.05
	Ext preference	1.77	0.09	.98	
	Ext resistance	0.22	0.03	.48	-0.15
119	VT preference	1.86	0.12	.98	
	VT resistance	0.73	0.07	.90	0.57
	VT+ext preference	1.91	0.03	.97	
	VT+ext resistance	0.59	-0.04	.85	0.69
	Ext preference	2.10	0.06	.98	
	Ext resistance	0.17	-0.02	.86	0.49
319	VT preference	1.75	-0.11	.93	
	VT resistance	0.85	-0.08	.72	0.45
	VT+ext preference	1.39	-0.31	.90	
	VT+ext resistance	1.90	0.05	.92	0.18
	Ext preference	1.89	-0.16	.96	
	Ext resistance	0.52	0	.56	-0.01

were not directly related to the reinforcer rates in the multiple-schedule components; indeed, in some conditions, average response rates were higher in the leaner component. During the VT test, response rates were always greater, both absolutely and relative to baseline, in the richer component. In several conditions, average response rates increased systematically across test sessions in the richer component, but otherwise varied irregularly from session to session. During the VT+ext test, response rates decreased rapidly to low levels, with a relatively slower decrease in the richer component. Finally, during the extinction test, there were occasional increases in response rate in the first session followed by systematic decreases, with response rates generally remaining higher in the richer component throughout. As mentioned above, responding was somewhat more resistant to extinction in Conditions 1 and 2 than in the subsequent conditions, which omitted the concurrent-chains portion of the procedure.

Baseline response rates. The sensitivity of re-

sponse-rate ratios to reinforcer-rate ratios was estimated by fitting the data for the five-session blocks preceding each resistance test to a version of Equation 2, with B_L and B_R identified with response rates in multiple-schedule components corresponding to the terminal links produced by left- and right-key initial links. Estimated sensitivity values ranged from 0.1 to -0.1 for Birds 022, 031, and 119, indicating little sensitivity to the reinforcer ratio; sensitivity was consistently but not strongly negative for Bird 319. Although multiple-schedule sensitivity is usually reported to be between 0.3 and 0.5 (Davison & McCarthy, 1988; McSweeney, Farmer, Dougan, & Whipple, 1986), our results are not unprecedented when timeout periods are arranged between components. For example, Nevin et al. (1983) found essentially no relation between component response rates and reinforcer rates when 30-s timeouts intervened between 1-min components, and on average response rates were lower in the richer component in one of their conditions.

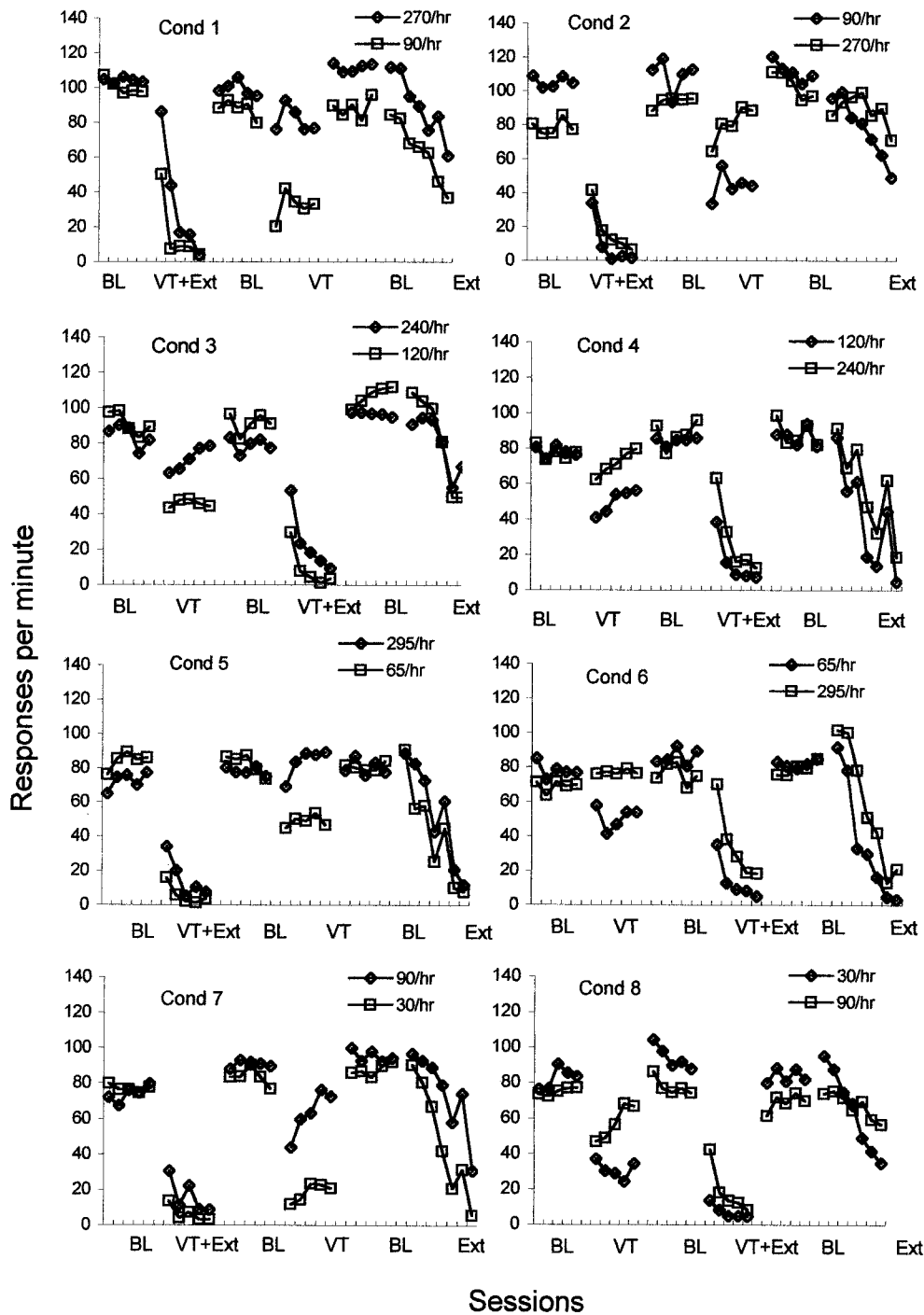


Fig. 6. Response rates in multiple VI VI schedule components during five sessions of baseline preceding each resistance test, and response rates during successive sessions examining resistance to VT food during intercomponent intervals, VT food plus extinction, and extinction. Data are averages across subjects for each experimental condition. The order of VT and VT+ext tests varied between conditions as indicated on the x axis. Scheduled reinforcer rates in the two components are indicated in each panel.

We performed similar analyses on response-rate ratios in the terminal links of the concurrent chains, and again found small and inconsistent values of sensitivity to reinforcer-rate ratios. This result also has precedent: Over a range of reinforcer rates similar to that used here, Herrnstein (1964) reported that response rates in VI terminal links were not directly related to reinforcer rate. All in all, baseline response rates in concurrent-chains terminal links and multiple-schedule components were not systematically related to reinforcer rates. Complete data are given in the Appendix.

Resistance to change. In previous research, resistance to change in a schedule component has been measured by expressing response rate during disruption as the logarithm of the proportion of the predisruption baseline. Relative resistance in two components has been measured in two ways. The first measure is the difference between components in response rates averaged over sessions of the resistance test (B_x) relative to response rates averaged over the preceding sessions of baseline (B_o), transformed to logarithms: $\log (B_{xL}/B_{oL}) - \log (B_{xR}/B_{oR})$, where the terms are subscripted for multiple-schedule components corresponding to terminal links produced by responding on the left and right keys during the initial links. This measure was used by Grace and Nevin (1997).

The second measure is the inverse of the ratio of slopes of functions relating log response rate to the value of the disrupter arranged during test sessions. The inverse is used because shallower slopes signify greater resistance to change. The logarithm of this measure, called the log resistance ratio, was used in Nevin's (1992b) review for all data with disrupters that varied systematically between or within successive resistance tests (e.g., rate of VT food or sessions of extinction), and thus produced orderly variation in response rates during disruption. For studies that used a single value of the disrupter, line estimates of slope were based on the average response rate during disruption relative to baseline.

Each of these measures has advantages and drawbacks. The difference measure permits direct comparison with the results of Grace and Nevin (1997), who used this measure for

VT+ext as well as VT tests of resistance. However, the difference can be shown to increase with the severity of the disrupter (e.g., successive sessions; see the appendix in Grace & Nevin). The slope ratio measure is independent of the severity of the disrupter; however, its sign is negative if responding increases relative to baseline in one component, so its logarithm cannot be computed. For consistency with the analyses of Grace and Nevin, we will use the difference measure for all resistance tests conducted here. Moreover, as will be shown below, the difference measure exhibits additive effects of the VT, extinction, and VT+ext tests. Finally, the difference measure is closely related to a measure of psychological distance proposed by Luce (1963) and to a measure of discrimination proposed by Davison and Tustin (1978). These relations will be considered further in the Discussion. For computation, B_x is defined as the average response rate in the first five sessions of each resistance test, including extinction, and B_o is defined as the average response rate in the immediately preceding five sessions of baseline. Complete data are given in the Appendix. The Appendix also includes the slopes of extinction curves over seven sessions, calculated as in Nevin's (1992b) review, to facilitate comparison with previous analyses.

In addition to preference, Figure 3 shows that relative resistance to VT food was positively related to the reinforcer ratio for all birds. The sensitivity of relative resistance to the reinforcer ratio was estimated by Equation 3, an analogue to the generalized matching law with the parameters subscripted m :

$$\log \frac{B_{xL}}{B_{oL}} - \log \frac{B_{xR}}{B_{oR}} = a_m \log \frac{R_L}{R_R} + \log b_m, \quad (3)$$

where a_m is the sensitivity of relative resistance to the reinforcer ratio and b_m represents inherent bias in resistance. The fitted values of a_m ranged from 0.35 to 0.85, with a mean of 0.62 (Table 2). For all birds, relative resistance was less sensitive to the reinforcer ratio than was preference. Equation 3 accounted for an average of 79% of the variance.

Figure 4 shows the relation between relative resistance to VT+ext and the reinforcer ratio. When the sensitivity of relative resistance to the reinforcer ratio was estimated by

Equation 3, values of a_m ranged from 0.59 to 1.90, with a mean of 1.02 (Table 2). For all but Bird 319, relative resistance was less sensitive to the reinforcer ratio than was preference. Equation 3 accounted for an average of 90% of the variance.

Figure 5 shows that relative resistance to extinction was positively related to the reinforcer ratio for all birds, but for some the functions were fairly shallow and variable. Again, the sensitivity of relative resistance to the reinforcer ratio was estimated by Equation 3. The fitted values of a_m ranged from 0.07 to 0.52, with a mean of 0.24 (Table 2). Equation 3 accounted for an average of 53% of the variance. All sensitivity values were substantially lower than for preference, and were also lower than for resistance to VT or VT+ext. Nevin et al. (1983) also found that relative resistance to extinction was less sensitive to the reinforcer ratio than was relative resistance to VT.

There were no consistent differences in line estimates of sensitivity of relative resistance in any of the three resistance tests for Conditions 1 and 2 and for Conditions 7 and 8, which had the same reinforcer ratio but differed by a factor of three in overall reinforcer rate. Thus, neither relative resistance nor preference sensitivities were affected by overall reinforcer rate over the range examined here.

An analysis of successive resistance determinations within each condition did not reveal any consistent effects of test order. However, the first resistance test was VT in four conditions and VT+ext in the other four, whereas extinction was always third. Thus, test type and order were confounded, and we cannot determine whether the sensitivity of relative resistance increased over successive tests, as for preference.

Relative resistance to VT in the present constant-duration components may be compared directly with the results for variable-duration components ending with a single reinforcer in the study by Grace and Nevin (1997), which evaluated resistance to VT in the same way. In the present study, values of a_m for VT averaged 0.62 (range, 0.35 to 0.85), which is greater than the average of 0.20 (range, 0.09 to 0.39) reported by Grace and Nevin. This difference is statistically significant according to a t test for independent

groups, $t(6) = 3.31$, $p < .02$, two-tailed. Grace and Nevin (1997, Figure 2) also examined resistance to VT+ext in the two conditions with the most extreme reinforcer ratios. Line estimates of slopes (not previously published) were 0.06, 0.23, 0.27, and 0.28. This may be compared with line estimates for resistance to VT+ext in the two conditions with the most extreme reinforcer rates in the present study: 0.56, 0.59, 0.94, and 1.56. The line estimates are substantially greater in the present study. Although these experiments employed different ranges of reinforcer rates, the component durations and the intercomponent intervals were similar, and the VT and VT+ext test procedures were the same. Accordingly, we conclude that the constant-duration procedure enhanced sensitivity to reinforcer-rate ratios for relative resistance as well as for preference.

Relations among resistance tests. Examination of Figure 6 shows that response rates were more sharply reduced in the first five sessions of VT+ext tests than in either VT or extinction tests. The disruptive effects of VT+ext tests may reflect the additive combination of the separate effects of VT and extinction. To evaluate this possibility, we compared relative resistance to VT+ext within each condition with the sum of relative resistance to VT and relative resistance to extinction, all measured as $\log(B_{xL}/B_{oL}) - \log(B_{xR}/B_{oR})$, the difference measure employed in our analyses of sensitivity to relative reinforcement above. For each subject, relative resistance for VT+ext was highly correlated with the sum of relative resistance for VT and for extinction (Bird 022, $r = .79$, $n = 8$; Bird 031, $r = .79$, $n = 8$; Bird 119, $r = .81$, $n = 8$; Bird 319, $r = .98$, $n = 6$). All correlations are statistically significant. Figure 7 shows that relative resistance for VT+ext predicted by summing the independently measured relative resistances for VT and for extinction does not deviate consistently from the line indicating exact prediction.

We also examined within-component measures of resistance to change that have been employed in previous research, such as the untransformed proportion of baseline (e.g., Nevin, 1974), the weighted mean proportion of baseline (e.g., Cohen, Riley, & Weigle, 1993; Nevin, Mandell, & Yarensky, 1981), and the logarithm of proportion of baseline (e.g.,

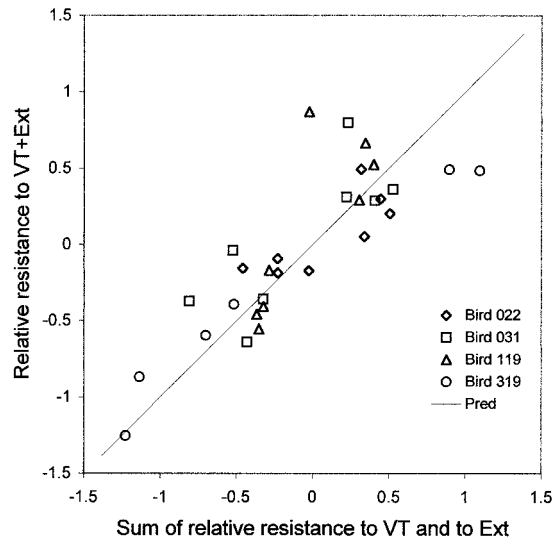


Fig. 7. Relative resistance to change, measured as the difference between log proportions of baseline in the two multiple-schedule components, for the VT+ext test plotted in relation to the sum of relative resistance for the VT test and for the extinction test. Each data point represents the results for a single condition. The diagonal line represents exact agreement between predicted and obtained relative resistance to change.

Grace & Nevin, 1997). Interestingly, within-component resistance to VT+ext was not well predicted by summing those same measures for VT and for extinction. We conclude that the between-component difference in log proportions of baseline in the components of a multiple schedule is a valid measure of relative resistance in that it is additive with respect to testing method within conditions as well as being sensitive to variations in the reinforcer ratio between conditions.

Relations Between Preference and Resistance

Grace and Nevin (1997) argued that preference and relative resistance provided convergent measurement of a single construct reflecting learning based on the conditions of reinforcement correlated with the discriminative stimuli defining the concurrent-chains terminal links and the multiple-schedule components. Their argument was based in part on the fact that both preference and relative resistance were power functions of reinforcer ratios, as confirmed by Figures 3, 4, and 5 here, and also on the correlation of the deviations of preference and relative resis-

tance to VT from the regression analyses. Pooled across subjects, Grace and Nevin obtained a significant correlation between residuals for preference and resistance to VT food ($r = .52, p < .003$), suggesting that some unspecified variable in addition to the reinforcer-rate ratio affected learning in each condition, and was expressed similarly in both aspects of behavior. The present study replicated Grace and Nevin's result: Residuals for preference taken from the baselines immediately preceding the VT tests and residuals for relative resistance to VT were positively (but not significantly) correlated for all 4 birds (see Table 2), and the pooled data were significantly correlated ($r = .48, p < .005$). Similar analyses found that residuals for preference and relative resistance to VT+ext were positive for all 4 birds, but failed to achieve statistical significance when pooled ($r = .17, p > .10$). There was no consistent evidence of correlations between residuals for extinction; indeed, correlations were negative for 3 of the 4 birds, and the pooled value of r was $-.10$. Grace and Nevin suggested that the effects of systematic variance between conditions arising from variables other than reinforcer ratios will be detectable only when nonsystematic variance is relatively small, and it may be that extinction, alone or together with VT food, increased the proportion of nonsystematic variance in the data for these tests.

DISCUSSION

This study was designed as a systematic replication and extension of the experiment by Grace and Nevin (1997), which obtained measures of preference and resistance to change within subjects and sessions. In the concurrent-chains phase of each session, conventional variable-duration terminal links ended with a single reinforcer. In the multiple-schedule phase, components were identical to the variable-duration terminal links, although this arrangement is rare in the multiple-schedule literature. The present experiment extends our analyses to concurrent-chains schedules with constant-duration terminal links, which are rare in research on schedule preference, and corresponding constant-duration multiple-schedule components, which are standard in multiple-sched-

ule research and have been used extensively in the study of resistance to change. It also extends our earlier study by employing three resistance tests in each condition. We consider the effects of different scheduling arrangements on preference before discussing resistance to change.

Preference

In the present study, preference was substantially more sensitive to the reinforcer ratio than in Grace and Nevin (1997). This between-experiment difference in preference sensitivity has been replicated within subjects by Grace and Nevin (in press). They compared constant-duration and variable-duration terminal links using identical VI schedules across conditions, and found greater sensitivity to reinforcer-rate ratios and reliable overmatching in the former. Their procedure did not include a phase with multiple-schedule components. Therefore, overmatching with constant-duration terminal links is not unique to our two-phase procedure.

The strong and reliable overmatching obtained with constant-duration terminal links is especially striking by comparison with previous research on concurrent chains with variable-duration terminal links ending with a single reinforcer. In seven archival studies of concurrent chains with this standard procedure, sensitivity exponents averaged 0.90 in Grace's (1994) reanalysis. Grace and Nevin (1997) obtained exponents averaging 0.91 when the standard concurrent-chains procedure alternated with multiple VI components ending with reinforcement. Thus, preference sensitivity is similar across experiments with and without a multiple-schedule phase.

Resistance to Change in Multiple Schedules

As described above, baseline response rates in the multiple-schedule components were largely independent of the reinforcer rates in those components. However, it is important to distinguish between the insensitivity of steady-state response rates to parametric variation in schedule values and the effects of short-term disruption of those response rates. When responding was disrupted for a few sessions by VT, VT+ext, or extinction, the log proportion of baseline responding was greater in the richer component than in the leaner component in almost every case. Thus, the

effect of reinforcer rate on resistance to change is independent of its effect (or lack of effect) on baseline performance (for similar conclusions, see Nevin, Tota, Torquato, & Shull, 1990).

The differences between log proportions of baseline response rates depended systematically on the reinforcer-rate ratio. The data presented in Figures 3, 4, and 5 show that relative resistance to change is well described by power functions of reinforcer-rate ratios, in which the exponents vary between subjects and resistance tests. Comparison with the exponents for relative resistance to VT and to VT+ext in Grace and Nevin (1997) suggests that sensitivity was significantly greater in the present data.

Previous research with constant-duration multiple-schedule components was summarized by Nevin (1992b). Aggregating across experiments, he suggested that the sensitivity of resistance ratios to reinforcer ratios was similar for diverse disrupters. However, some within-experiment comparisons have shown that resistance to extinction is less differentiated between components than resistance to VT (e.g., Nevin et al., 1983, and the present data) or resistance to prefeeding (e.g., Nevin & Grace, 1999), especially when the baseline schedules are rich.

Our within-experiment comparisons employed a measure—the difference between log proportions of baseline for five-session averages—that has not previously been used to estimate differences in resistance to extinction. To compare our extinction data with earlier results in standard two-component multiple schedules, we calculated the slopes of extinction curves over seven sessions with response rates transformed to logarithms, exactly as in earlier studies (e.g., Nevin, 1992a); these slopes are given in the Appendix. The average value of a_m in Equation 3, based on line estimates for slopes in our Conditions 5 and 6 with 295 and 65 reinforcers per hour, is 0.27. The average line estimate of a_m for conditions with 300 and 60 reinforcers per hour in Nevin (1992a), calculated from his Tables 1 and 2 assuming no color bias, is also 0.27. Thus, when baseline reinforcer rates are comparable between experiments, the sensitivities of resistance ratios for extinction are the same. Accordingly, we conclude that just as the sensitivity of preference in concurrent

	Resistance to change		Discrimination								
	B_0 B_x		B_1 B_2								
S_1	<table style="border-collapse: collapse; margin: auto;"> <tr><td style="padding: 5px;">w</td><td style="padding: 5px;">x</td></tr> <tr><td style="padding: 5px;">y</td><td style="padding: 5px;">z</td></tr> </table>	w	x	y	z	S_1	<table style="border-collapse: collapse; margin: auto;"> <tr><td style="padding: 5px;">w</td><td style="padding: 5px;">x</td></tr> <tr><td style="padding: 5px;">y</td><td style="padding: 5px;">z</td></tr> </table>	w	x	y	z
w	x										
y	z										
w	x										
y	z										
S_2	<table style="border-collapse: collapse; margin: auto;"> <tr><td style="padding: 5px;">w</td><td style="padding: 5px;">x</td></tr> <tr><td style="padding: 5px;">y</td><td style="padding: 5px;">z</td></tr> </table>	w	x	y	z	S_2	<table style="border-collapse: collapse; margin: auto;"> <tr><td style="padding: 5px;">w</td><td style="padding: 5px;">x</td></tr> <tr><td style="padding: 5px;">y</td><td style="padding: 5px;">z</td></tr> </table>	w	x	y	z
w	x										
y	z										
w	x										
y	z										

Fig. 8. For free-operant multiple schedules, the left matrix designates response rates during baseline (B_0) or resistance tests (B_x) in components signaled by S_1 or S_2 . For discrete-trial signal-detection or conditional discrimination paradigms, the right matrix designates the probabilities of responses B_1 or B_2 on trials signaled by S_1 or S_2 .

chains is unaffected by exposure to multiple schedules within a session (see above), relative resistance to extinction in constant-duration multiple-schedule components is unaffected by exposure to concurrent chains. Therefore, our measures of preference and resistance to change are truly independent.

On Measures

The measure of relative resistance to change employed here and by Grace and Nevin (1997, in press) is closely related to a measure of psychological distance proposed by Luce (1963) for signal-detection experiments, and to a measure of discrimination proposed by Davison and Tustin (1978) for conditional discriminations. The relations among these measures are evident when the data are arranged in matrix form as shown in Figure 8. In these matrices, w , x , y , and z represent response rates in research on resistance to change of free-operant behavior and response probabilities in discrete-trial discrimination research. In the present study and in Grace and Nevin (1997), relative resistance to change in components signaled by S_1 and S_2 is measured as $\log(x/w) - \log(z/y)$. For signal-detection experiments, Luce (1963) derived $\eta = [(x/w)*(y/z)]^{0.5}$ from choice theory to measure confusion between stimuli S_1 and S_2 (the inverse of discrimination). In logarithmic form, $2 \log \eta = \log(x/w) - \log(z/y)$, which is equivalent to our measure of relative resistance. Relatedly, Davison and Tustin (1978) derived $d = [(w/x)*(z/y)]^{0.5}$ from the generalized matching law to measure stimulus control in conditional discrimination experiments. Thus, $-2 \log$

$d = \log(x/w) - \log(z/y)$, again equivalent to our measure of relative resistance. The use of a single measure should facilitate integrative analyses of conditional discriminations and resistance to change (cf. Davison & Nevin, 1999).

It should be noted that in the discrimination paradigm, B_1 and B_2 designate different, concurrently available responses, whereas in the resistance-to-change paradigm, B_0 and B_x designate the same response under different successive conditions (baseline and resistance test). Davison and Nevin (1999) argued that stimulus control by S_1 and S_2 , as measured by $\log d$, depends on the extent to which B_1 and B_2 are effectively discriminated. Likewise, relative resistance between schedules signaled by S_1 and S_2 depends on the extent to which resistance test conditions are effectively different from baseline. In our study, it is reasonable to suggest that VT+ext is more different from baseline than either VT or extinction alone. Within the set of three resistance tests employed in each condition of our study, we have shown that relative resistance to VT+ext is well predicted by relative resistance to VT plus relative resistance to extinction. Thus, the difference measure of relative resistance captures the expected ordinal relation among the resistance tests and meets the requirement of additivity that has long been invoked as the sine qua non of measurement in the physical sciences (e.g., Campbell, 1920). Indeed, additivity is consistent with the identification of disrupters as forces in the metaphor of behavioral momentum (Nevin et al., 1983). Our data (see Figure 7) imply that the effective force of

VT+ext was equal to the sum of forces of the VT and extinction disrupters.

Traditional research on multiple-schedule performance considered only the rates of responding maintained under baseline conditions of reinforcement in components signaled by S_1 and S_2 (i.e., w and y in the left matrix). Similarly, classical psychophysics considered only the probability of a single response to different stimuli (i.e., w and y in the right matrix). Psychophysics made important advances when an alternative response (B_2) was introduced so that the discriminability of the stimuli could be estimated independently of response bias. Likewise, research on operant behavior advanced when disrupters were introduced to determine B_x so that relative response strength could be estimated independently of baseline response rate. Davison and Nevin (1999) argued that the discriminability of different stimuli was additive; that is, a measure of discriminability between stimuli S_1 and S_3 was roughly equal to the sum of discriminabilities measured separately for S_1 and S_2 and for S_2 and S_3 . Analogously, we have shown that a measure of relative response strength is additive with respect to differences between baseline and resistance tests. Further implications of these analogies remain to be explored.

Preference, Resistance, and Convergent Measurement

Grace and Nevin (1997) argued that because preference and relative resistance covaried with changes in immediacy of reinforcement between conditions according to power functions, and because deviations from generalized-matching-law fits were correlated within conditions, these aspects of behavior provided independent and convergent measurement of a construct identified with the value or strength of discriminated operant behavior. The present results replicate those of Grace and Nevin in that power functions explained substantial percentages of the variance in the data for both preference and relative resistance, and deviations were positively correlated for the pooled results when inter-component VT food served as the disrupter.

At its most general, the argument for convergent measurement requires that any variable that affects preference should have similar effects on relative resistance and vice

versa. Therefore, the increased sensitivity of preference to reinforcer ratios with constant-duration terminal links, relative to that reported by Grace and Nevin (1997) for variable-duration terminal links, should be accompanied by increased sensitivity of relative resistance in the corresponding multiple-schedule components. Our data show that relative resistance to VT and to VT+ext was significantly more sensitive to reinforcer ratios with constant-duration components than with Grace and Nevin's variable-duration components. This covariation of preference and relative resistance across experiments with different scheduling arrangements supports our approach to convergent measurement of value and strength as independent expressions of a single aspect of learned behavior.

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APPENDIX

Baseline data for the last five sessions preceding each test of resistance to change for initial links and multiple-schedule components. Baseline data are presented in order of determination. Resistance data are five-session means. L and R refer to the initial-link side key and to the terminal-link schedule produced by that side key or its equivalent multiple-schedule component. Also given are slopes of extinction curves over seven sessions. Scheduled reinforcer rates, in reinforcers per hour, are given in the first column for each condition as L/R. Response rates over 100 per minute are rounded to the nearest whole number.

Bird	Condition	Before test type	Baseline performance										
			Total initial-link responses		terminal link				Multiple schedule				
			L	R	Resp/min		Rft/hr		Resp/min		Rft/hr		
022	1 270/90	VT+ext	6,258	918	120.0	105.0	260	82	142.0	130.0	264	78	
		VT	8,411	615	119.0	110.0	268	110	144.0	122.0	260	78	
		Ext	7,329	597	141.0	126.0	278	82	151.0	116.0	236	80	
	2 90/270	VT+ext	1,332	5,923	130.0	116.0	92	250	144.0	118.0	84	260	
		VT	1,079	7,039	135.0	120.0	102	260	142.0	124.0	66	260	
		Ext	935	6,573	131.0	139.0	92	256	147.0	139.0	74	260	
	3 240/120	VT	6,894	960	132.0	125.0	228	112	144.0	129.0	222	108	
		VT+ext	6,831	794	125.0	127.0	232	114	134.0	129.0	228	106	
		Ext	7,750	712	145.0	142.0	228	112	160.0	141.0	228	108	
	4 120/240	VT	2,190	4,511	141.0	155.0	108	224	127.0	135.0	108	234	
		VT+ext	2,170	4,727	116.0	143.0	110	224	112.0	136.0	108	232	
		Ext	1,680	5,647	96.1	113.0	110	230	110.0	128.0	104	226	
	5 295/65	VT+ext	8,824	552	104.0	92.2	298	52	110.0	92.6	278	80	
		VT	8,965	835	95.0	92.6	296	42	105.0	87.3	266	86	
		Ext	5,796	1,892	103.0	101.0	284	56	109.0	94.6	282	80	
	6 65/295	VT	1,193	9,079	105.0	94.1	56	292	97.4	98.9	74	268	
		VT+ext	821	12,215	109.0	104.0	58	288	109.0	111.0	68	278	
		Ext	681	10,071	108.0	98.3	78	274	99.1	104.0	64	288	
	7 90/30	VT+ext	6,312	1,214	119.0	107.0	76	24	138.0	119.0	92	40	
		VT	6,178	640	141.0	107.0	86	28	150.0	112.0	90	28	
		Ext	6,993	1,214	138.0	111.0	66	30	159.0	110.0	96	36	
	8 30/90	VT	640	8,326	125.0	104.0	22	74	122.0	101.0	28	96	
		VT+ext	996	8,848	137.0	114.0	28	74	132.0	107.0	32	100	
		Ext	963	7,684	134.0	102.0	36	72	128.0	109.0	20	80	
	031	1 270/90	VT+ext	4,110	392	57.5	52.0	258	76	57.1	57.0	258	98
			VT	4,190	438	56.1	52.2	256	74	53.8	49.9	256	92
			Ext	4,004	380	58.6	55.4	260	92	63.2	51.5	264	86
		2 90/270	VT+ext	670	1,595	37.8	36.6	78	246	43.7	44.6	80	248
VT			497	4,449	52.1	43.0	74	260	46.4	44.1	100	250	
Ext			516	4,361	57.5	57.4	84	258	52.2	56.1	98	246	
3 240/120		VT	3,368	521	43.3	40.0	224	108	49.2	50.3	222	106	
		VT+ext	3,110	564	44.2	32.3	220	104	47.3	37.6	214	106	
		Ext	4,958	632	54.0	49.4	228	108	54.9	50.1	224	102	
4 120/240		VT	1,028	2,736	39.6	39.8	108	224	45.0	41.6	110	212	
		VT+ext	814	3,713	49.9	44.6	106	218	47.2	47.5	112	228	
		Ext	1,022	2,569	47.2	45.1	104	216	50.4	46.6	106	220	
5 295/65		VT+ext	5,841	502	50.7	48.3	290	80	51.5	51.0	262	50	
		VT	6,723	332	50.1	50.3	288	74	43.9	41.8	256	58	
		Ext	4,675	345	53.4	50.1	278	68	53.9	48.4	272	56	
6 65/295		VT	659	3,535	48.0	45.5	70	274	39.5	44.7	52	250	
		VT+ext	655	3,506	48.0	45.4	78	270	48.1	48.1	50	278	
		Ext	371	3,785	47.3	48.4	58	274	38.3	47.9	68	268	
7 90/30		VT+ext	4,407	573	48.2	44.6	88	26	48.7	35.5	92	30	
		VT	4,964	454	37.9	35.1	86	30	40.7	39.6	82	16	
		Ext	4,178	697	42.3	40.3	72	22	39.6	35.4	104	24	
8 30/90		VT	439	2,639	31.6	30.0	26	80	26.8	20.8	20	96	
		VT+ext	250	3,680	40.2	27.7	28	100	34.7	22.9	30	70	
		Ext	253	2,010	40.6	25.7	16	64	32.2	13.9	26	88	

APPENDIX

(Extended)

Bird	Condition	Resistance to change				
		Test type	Resp/min		Ext slopes	
			L	R	L	R
022	1 270/90	VT+ext	66.1	21.7		
		VT	118.0	53.7		
		Ext	161.0	116.0	-0.004	-0.016
	2 90/270	VT+ext	13.3	18.5		
		VT	77.7	95.1		
		Ext	136.0	114.0	-0.012	-0.002
	3 240/120	VT	107.0	72.8		
		VT+ext	42.8	18.9		
		Ext	121.0	125.0	-0.114	-0.117
	4 120/240	VT	107.0	131.0		
		VT+ext	34.6	44.7		
		Ext	43.3	65.2	-0.132	-0.090
	5 295/65	VT+ext	29.6	7.8		
		VT	125.0	81.0		
		Ext	67.1	46.9	-0.070	-0.056
	6 65/295	VT	81.7	105.0		
		VT+ext	28.0	48.6		
		Ext	66.2	84.3	-0.210	-0.065
	7 90/30	VT+ext	30.8	12.8		
		VT	103.0	29.0		
Ext		139.0	81.9	-0.076	-0.158	
8 30/90	VT	66.8	85.0			
	VT+ext	18.3	42.6			
	Ext	127.0	101.0	-0.061	-0.008	
031	1 270/90	VT+ext	12.8	3.8		
		VT	41.0	18.4		
		Ext	48.7	36.0	-0.058	-0.050
	2 90/270	VT+ext	4.4	12.1		
		VT	16.2	44.4		
		Ext	29.9	49.0	-0.042	-0.015
	3 240/120	VT	35.3	21.8		
		VT+ext	10.0	4.8		
		Ext	49.2	36.4	-0.120	-0.200
	4 120/240	VT	21.2	33.9		
		VT+ext	4.9	10.4		
		Ext	36.2	44.3	-0.067	-0.019
	5 295/65	VT+ext	9.0	3.5		
		VT	33.1	21.3		
		Ext	53.1	36.6	-0.160	-0.290
	6 65/295	VT	23.1	46.9		
		VT+ext	3.1	20.0		
		Ext	17.0	28.1	-0.290	-0.250
	7 90/30	VT+ext	4.2	1.8		
		VT	29.9	9.9		
Ext		42.2	17.7	-0.058	-0.130	
8 30/90	VT	14.4	15.6			
	VT+ext	2.1	4.6			
	Ext	33.2	11.3	-0.170	-0.110	

APPENDIX

(Continued)

Bird	Condition	Before test type	Total initial-link responses		Baseline performance terminal link				Multiple schedule			
					Resp/min		Rft/hr		Resp/min		Rft/hr	
			L	R	L	R	L	R	L	R	L	R
119	1 270/90	VT+ext	6,366	1,211	106.0	109.0	282	70	114.0	114.0	258	104
		VT	6,356	863	101.0	104.0	246	82	101.0	117.0	260	98
		Ext	6,455	961	99.2	94.4	246	78	93.6	90.2	272	88
	2 90/270	VT+ext	909	7,355	107.0	121.0	86	244	103.0	124.0	86	270
		VT	832	7,124	124.0	120.0	76	276	106.0	124.0	96	268
		Ext	761	6,855	117.0	113.0	94	252	106.0	123.0	90	256
	3 240/120	VT	6,198	1,356	80.5	117.0	224	110	83.6	115.0	226	110
		VT+ext	8,038	868	88.1	133.0	218	110	99.1	123.0	226	108
		Ext	6,708	995	90.0	124.0	230	108	89.3	121.0	220	110
	4 120/240	VT	1,637	5,934	99.8	101.0	106	228	92.6	95.4	114	226
		VT+ext	1,346	5,703	109.0	113.0	112	224	98.8	108.0	106	234
		Ext	914	5,606	98.0	89.8	112	226	92.4	106.0	106	228
	5 295/65	VT+ext	9,335	648	93.4	118.0	288	66	80.2	117.0	256	60
		VT	11,442	496	98.4	135.0	276	68	91.7	127.0	288	62
		Ext	10,633	366	95.7	123.0	288	76	103.0	123.0	278	60
	6 65/295	VT	912	6,167	120.0	91.0	58	270	108.0	92.9	64	284
		VT+ext	555	8,105	119.0	96.8	56	274	103.0	97.8	70	276
		Ext	526	8,175	131.0	101.0	84	280	121.0	116.0	48	272
	7 90/30	VT+ext	8,447	829	89.4	110.0	94	28	80.4	111.0	92	38
		VT	7,103	459	88.3	113.0	90	36	81.3	99.8	84	20
		Ext	7,849	460	102.0	118.0	68	46	91.0	110.0	114	24
	8 30/90	VT	854	5,840	92.6	87.3	20	80	86.7	101.0	40	78
		VT+ext	803	7,166	105.0	86.7	26	76	90.0	89.9	32	100
		Ext	687	5,563	93.4	79.4	28	90	92.5	86.1	34	78
319	1 270/90	VT+ext	not run									
		VT	7,028	482	119.0	99.5	252	88	99.5	63.4	276	72
		Ext	7,166	996	154.0	121.0	264	86	139.0	95.7	254	86
	2 90/270	VT+ext	1,818	7,618	144.0	35.2	82	222	131.0	28.2	90	230
		VT	1,236	6,883	146.0	96.9	88	242	144.0	82.6	86	262
		Ext	721	8,367	142.0	102.0	76	256	141.0	97.9	82	254
	3 240/120	VT	5,364	2,471	79.8	105.0	214	110	60.0	70.6	216	110
		VT+ext	5,490	2,762	50.5	99.0	226	106	35.9	75.5	206	108
		Ext	6,623	2,255	82.9	127.0	230	112	81.8	116.0	216	108
	4 120/240	VT	1,206	7,387	65.1	35.4	110	218	47.1	36.9	104	200
		VT+ext	756	9,474	99.2	63.9	110	224	79.2	61.0	108	222
		Ext	806	10,139	90.7	65.5	106	214	93.7	72.1	112	220
	5 295/65	VT+ext	4,908	1,836	44.6	80.6	256	84	47.9	76.6	258	54
		VT	7,547	1,374	65.7	93.0	268	56	71.5	72.6	252	66
		Ext	7,321	1,047	62.9	70.4	248	72	55.3	56.6	266	58
	6 65/295	VT	697	10,543	82.3	41.0	64	238	67.9	39.2	66	250
		VT+ext	599	12,592	96.2	45.0	60	266	83.8	47.7	66	260
		Ext	551	9,575	80.6	42.2	74	238	69.7	47.0	68	274
	7 90/30	VT+ext	2,902	1,064	43.7	49.4	90	22	28.7	43.0	78	38
		VT	not run									
		Ext	4,443	518	101.0	103.0	76	40	92.0	96.1	82	24
	8 30/90	VT	970	14,191	100.0	71.6	6	84	94.3	77.3	34	88
		VT+ext	779	7,366	117.0	85.4	34	78	121.0	91.9	20	80
		Ext	819	8,379	95.5	67.4	24	72	83.0	68.0	28	94

APPENDIX

(Extended)

Bird	Condition	Test type	Resistance to change		Ext slopes	
			Resp/min		L	R
			L	R		
119	1 270/90	VT+ext	20.7	21.9		
		VT	89.4	36.2		
		Ext	89.2	74.1	-0.068	-0.141
	2 90/270	VT+ext	10.9	29.6		
		VT	31.4	99.3		
		Ext	71.2	110.0	-0.085	-0.022
	3 240/120	VT	71.3	57.0		
		VT+ext	14.4	8.9		
		Ext	91.4	109.0	-0.071	-0.115
	4 120/240	VT	44.2	84.8		
		VT+ext	15.5	35.7		
		Ext	52.4	82.7	-0.122	-0.115
	5 295/65	VT+ext	17.0	9.9		
		VT	117.0	58.7		
		Ext	101.0	100.0	-0.107	-0.187
	6 65/295	VT	60.1	107.0		
		VT+ext	23.1	50.9		
		Ext	80.9	108.0	-0.195	-0.171
	7 90/30	VT+ext	13.4	8.4		
		VT	56.2	17.1		
Ext		90.2	95.4	-0.014	-0.177	
8 30/90	VT	34.3	53.5			
	VT+ext	7.8	15.1			
	Ext	67.6	69.6	-0.122	-0.076	
319	1 270/90	VT+ext	not run			
		VT	77.5	20.2		
		Ext	63.7	39.6	-0.105	-0.185
	2 90/270	VT+ext	8.7	9.4		
		VT	52.2	84.1		
		Ext	74.1	72.6	-0.155	-0.085
	3 240/120	VT	70.4	32.2		
		VT+ext	27.1	4.6		
		Ext	70.0	83.8	-0.149	-0.238
	4 120/240	VT	27.2	36.6		
		VT+ext	7.7	19.5		
		Ext	56.7	63.0	-0.289	-0.280
	5 295/65	VT+ext	6.4	1.3		
		VT	68.1	35.5		
		Ext	56.8	36.6	-0.244	-0.203
	6 65/295	VT	37.9	49.3		
		VT+ext	2.3	17.9		
		Ext	35.0	77.7	-0.553	-0.195
	7 90/30	VT+ext	17.2	2.3		
		VT	not run			
Ext		62.0	46.0	-0.099	-0.171	
8 30/90	VT	8.9	75.8			
	VT+ext	1.1	13.7			
	Ext	72.6	103.0	-0.083	-0.007	