JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 2002, **77,** 233–255 NUMBER 3 (MAY)

PREFERENCE AND RESISTANCE TO CHANGE WITH CONSTANT- AND VARIABLE-DURATION TERMINAL LINKS: INDEPENDENCE OF REINFORCEMENT RATE AND MAGNITUDE

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Pigeons responded in a three-component multiple concurrent-chains procedure in which the variable-interval reinforcement schedules were the same across components but magnitudes differed across components. The terminal links were arranged either as a variable delay followed by presentation of a reinforcer (''variable duration'') or as a fixed period of access to the schedule during which a variable number of reinforcers could be earned (''constant duration''). Relative reinforcement rate was varied parametrically across both types of conditions. After baseline training in each condition, resistance to change of terminal-link responding was assessed by delivering food during the initial links according to a variable-time schedule. Both preference and resistance to change were more sensitive to reinforcement-rate differences in the constant-duration conditions. Sensitivities of preference and resistance to change to relative reinforcement rate did not change depending on relative reinforcement magnitude. Taken together, these results confirm and extend those of prior studies, and suggest that reinforcement rate and magnitude combine additively to determine preference and resistance to change. A single structural relation linking preference and resistance to change describes all the data from this and several related studies.

Key words: concurrent chains, resistance to change, behavioral momentum, reinforcement rate, reinforcement magnitude, key peck, pigeons

Many studies of choice in concurrent variable-interval (VI) schedules have explored the effects of varying the rate and magnitude of reinforcement for the alternatives. The most recent example, by McLean and Blampied (2001), showed that sensitivity of choice to reinforcer-rate ratios was independent of relative and absolute reinforcer magnitude, as required by the concatenated generalized matching law proposed by Baum and Rachlin (1969):

$$\frac{B_1}{B_2} = b\left(\frac{R_1}{R_2}\right)^{a_r}\left(\frac{M_1}{M_2}\right)^{a_m}, \qquad (1)$$

where B represents response rate, R represents reinforcer rate, and M represents reinforcer magnitude, each subscripted for Alternatives 1 and 2. The parameters a_r and a_m represent sensitivity of choice to reinforcer rate and magnitude ratios, respectively, and b represents bias toward one alternative or the other that is independent of the conditions of reinforcement. A number of studies, however, have found interactions between absolute and relative reinforcer rates and magnitudes in concurrent schedules, and the overall pattern of results is not easy to interpret (see review by McLean & Blampied, and discussion by Davison & Nevin, 1999).

Clearer and more consistent data may be available in an ostensibly more complex paradigm: concurrent chains. The reason is that concurrent chains separate the measurement of preference in concurrent initial links from the conditions of reinforcement in the terminal links, which occur successively. Thus, direct effects of reinforcers on the responses that produce them—for example, longer pauses after larger reinforcers—do not enter into initial-link choice responding. Grace (1994) showed that preference in concurrent chains is well described by an expanded version of Equation 1, known as the contextual choice model:

$$\frac{B_1}{B_2} = b\left(\frac{N_1}{N_2}\right)^{a_n}\left[\left(\frac{R_1}{R_2}\right)^{a_r}\left(\frac{M_1}{M_2}\right)^{a_m}\right]^{Tt/Ti}, \qquad (2)$$

This research was supported by NSF Grant IBN-9507584 to the University of New Hampshire (J. A. Nevin, Principal Investigator). Some of these data were included in an undergraduate honors' thesis by the second author and were presented at the annual meeting of the Association for Behavior Analysis, Chicago, May 1997.

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where B represents initial-link response rate, N represents the terminal-link entry rate, R represents terminal-link reinforcer rate (or the reciprocal of delay), and M represents terminal-link reinforcer magnitude, all subscripted for the terminal links produced by responses in one or the other initial link. The parameters a_n, a_r, and a_m represent sensitivity to terminal-link entry rate, reinforcer rate, and reinforcer magnitude; Tt and Ti represent the average times spent per reinforcer in the terminal and initial links; and b represents initial-link bias. Thus, Equation 2 has four parameters to be estimated from initial-link response ratios, but they may be reduced to three (as in Equation 1) by arranging initial-link schedules that lead to equal frequencies of terminal-link entry. If the average initial-link and terminal-link durations are held constant across variations in reinforcer rate and magnitude, Tt/Ti becomes a constant multiplier on a_r and a_m. When Tt/Ti is about 1.0, estimates of a_r are usually close to 1.0 (matching; Grace, 1994).

Ten Eyck (1970) varied reinforcer rate and duration by 2:1 ratios separately in the terminal links of concurrent chains, and found that initial-link response proportions roughly matched the product of reinforcer rate and duration, which he termed *rate of reinforcement time*. His results were consistent with the independence of reinforcer rate and magnitude assumed by Equations 1 and 2. Ten Eyck arranged independent initial-link VI schedules, with terminal-link schedules such that Tt/Ti approximated 1.0, and although he did not provide terminal-link entry rates, the range of preferences he observed was not so extreme as to produce large differences in N_1 and N_2. Therefore, in terms of Equation 2, a_r and a_m were about equal.

Grace (1995) conducted a parametric evaluation of Equation 2 with N_1 and N_2 held equal by interdependent initial-link schedules and with programmed Tt/Ti constant across conditions. In the terminal links, reinforcer rates varied by 4:1 ratios between conditions, and reinforcer magnitudes varied by 3:1 ratios within conditions. In additional conditions with reinforcer-rate ratios of 1:1, magnitude ratios varied by 2:1 and 5:1. Grace found that a_r was greater when reinforcer magnitudes were the same than when they differed, suggesting interaction rather than independence of these reinforcer dimensions. Ti increased substantially, however, as preference departed increasingly from indifference. When obtained rather than arranged values of Tt/Ti were used in Equation 2, there was no consistent evidence of interaction. Estimates of a_m were greater than estimates of a_r, regardless of whether programmed or obtained Tt/Ti values were used in fitting Equation 2 to the data.

In summary, the data from concurrent chains support the independence of reinforcer rate and magnitude in the determination of preference, but Ten Eyck (1970) explored a limited range of the independent variables, and Grace (1995) evaluated a theoretical parameter post hoc to reach this conclusion. Accordingly, we conducted a systematic, parametric replication of Grace's study, but with independent initial-link schedules as used by Ten Eyck to avoid the problem of large increases in Ti when preference becomes extreme that is observed with interdependent schedules.

Both Ten Eyck (1970) and Grace (1995) arranged VI terminal links that ended with the first reinforcer and therefore varied in duration (VD), as in the majority of concurrent-chains research. Grace and Nevin (2000, Experiment 1) found that when VI schedules were arranged in constant-duration (CD) terminal links, and hence could include one, several, or no reinforcers at all, preference was more sensitive to reinforcer-rate ratios than in VD conditions. The effect was large: On average, a_r was 1.26 in VD and 2.13 in CD conditions. These within-subject results confirmed the difference in sensitivity between otherwise similar studies reported by Grace and Nevin (1997; VD, mean $a_r = 0.91$) and Nevin and Grace (2000b; CD, mean $a_r = 1.78$). The VD versus CD difference remains to be explained, although Grace and Nevin (2000, Experiment 2) found that CD terminal links with varied numbers of reinforcers (including zero) were preferred to CD terminal links that always included exactly one reinforcer occurring randomly in time. These results suggested that variability in the number of reinforcers per terminal link contributes to preference.

Research on resistance to change in multiple chains confirmed Ten Eyck's (1970) result. Nevin, Mandell, and Yarensky (1981) found that resistance in both initial and terminal links depended on both rate and magnitude of reinforcement in the terminal links, and was similar when the product of rate and magnitude was the same. This and many subsequent results suggested that resistance to change in multiple schedules depends on the same reinforcer variables as preference in concurrent chains (for review, see Nevin & Grace, 2000a). Recent results show that resistance, like preference, is more sensitive to reinforcer rate with CD than with VD schedule components (Nevin & Grace, 2000b). However, because Nevin et al. (1981, Experiment 2) arranged only three values of reinforcer rates and magnitudes in VD terminal links, additional data are needed. Accordingly, after determining preferences in each condition, we examined resistance to change in VD and CD terminal links by giving response-independent food according to a variable-time (VT) schedule in the initial links and presenting the terminal links independently of initial-link responding, a method used by Grace and Nevin (2000) to facilitate the acquisition of preference and resistance data within subjects and conditions.

To summarize, in order to evaluate the independence and additivity of reinforcer-rate and magnitude ratios with respect to preference in concurrent chains under two different terminal-link scheduling arrangements that strongly affect the sensitivity of preference, and to provide further data on the relations between resistance to change and preference, we systematically replicated Grace's (1995) study with independent initial-link VI schedules. Pigeons responded in a three-component multiple concurrent-chains procedure. Within each condition, terminal-link reinforcer rates were the same in all components but magnitudes differed between components. Terminal-link schedules varied between conditions. After baseline training in each condition, response-independent food was given during the initial links. In the first set of five conditions, VI schedules were arranged in VD terminal links, and in the second set VI schedules were arranged in CD terminal links. The last two conditions were VD replications. With this design, we could explore preference and resistance to change parametrically as functions of reinforcer rate and magnitude with both VD and CD terminal links.

METHOD

Subjects

Four White Carneau pigeons, numbered 955, 956, 005, and 961, participated as subjects, and were maintained at 85% of free-feeding weights (±15 g) by immediate postsession feedings. They were housed individually in a vivarium with a 12:12 hr light/dark cycle (lights on at 7:00 a.m.), with free access to water and grit. All pigeons had experience with a variety of experimental procedures.

Apparatus

Four standard three-key operant chambers (35 cm deep by 35 cm wide by 35 cm high) were used. The keys were 26 cm above the floor and arranged in a row. Each chamber was equipped with a houselight located 7 cm above the center key and a grain magazine with an aperture (6 cm by 5 cm) 13 cm below the center key. The magazine was illuminated when wheat was made available. Keys required a force of about 0.10 N for closure, which resulted in a feedback click. They could be lighted red, green, or white, and only the side keys were used. Each chamber was enclosed in a sound-attenuating box, and a fan provided ventilation and masking noise. Experimental events were controlled and data recorded with a microcomputer located in an adjacent room running MED-PC™ software.

Procedure

Because subjects were experienced, training began immediately in a three-component multiple concurrent-chains procedure. With few exceptions, sessions were conducted 7 days per week at approximately the same time. Each session consisted of three components, which were defined by the color used for all keylight stimuli in that component (red, green, or white). Components occurred in a random order (except as described below) and were separated by a 3-min blackout. The houselight provided general illumination at all times in the components except during reinforcement delivery.

Each component consisted of 24 initial- and terminal-link cycles. At the start of a cycle, the side keys were illuminated red, green, or white (depending on the component) to signal the initial links. Concurrent independent VI 40-s VI 40-s schedules operated during the initial links. Each schedule contained 12 intervals constructed from an arithmetic progression, a, $a + d$, $a + 2d$, . . ., in which a equals one 12th and d equals one 6th of the schedule value, and intervals were sampled without replacement. In each cycle, the initial links did not begin timing until the first response; then both VIs were started (i.e., the VIs were response initiated). After an initial-link schedule timed out, the next response to that key was reinforced by entry into a terminal link. There was no changeover delay. Terminal-link entry was signaled by a change from constant to blinking illumination of that key (0.25 s off, 0.25 s on), coupled with darkening of the other key.

Terminal-link responses were reinforced according to either VI or random-interval (RI) schedules. The VI schedules contained 12 intervals and were constructed according to the progression of Fleshler and Hoffman (1962), so that the distributions of interreinforcer intervals were approximately exponential (and thus similar to the RI schedules). Within each condition, the same pair of terminal-link schedules was used in all three components. The component schedules differed in the reinforcement magnitudes for the terminal links. In the red component, the magnitudes (seconds of access to grain) were 3.33 s and 1.67 s for the left and right terminal links, respectively; in the green component the magnitudes were reversed; and in the white component the magnitudes were 2.5 s for both terminal links. During reinforcement, the grain feeder was raised and illuminated for the specified duration while all other lights in the chamber were darkened.

The terminal links were arranged in two ways depending on the condition. The VD conditions used VI schedules. An interval was sampled from the appropriate schedule upon entry; the first response after that interval had timed out was reinforced; and the next initial-link cycle began immediately after reinforcement delivery.

The CD conditions used RI schedules. The terminal links consisted of a 20-s period of access to an RI schedule during which as many reinforcers as were made available by the schedule could be earned. The RI schedule was implemented by sampling a probability generator every 0.5 s. After a reinforcer had been set up, the next response produced access to food. Reinforcement time was excluded from the 20-s terminal-link duration. The side key was extinguished and the initial links were reinstated after the 20 s had elapsed. If a reinforcer had been arranged but not collected at the end of the 20 s, it remained available at the beginning of the next presentation of that terminal link.

Table 1

Terminal-link schedules and order of conditions for all pigeons.

		Pigeon			
		955	956	005	961
Variable duration					
VI 8 s	VI 32 s	2	3	1	4
VI 32 s	VI 8 s	1	4	2	3
VI 13.33 s	VI 26.67 s	4	1	3	2
VI 26.67 s	VI 13.33 s	3	2	4	1
VI 20 s	VI 20 s	5	5	5	5
Constant duration					
RI 13.55 s	RI 38.17 s	7	8	6	9
RI 38.17 s	RI 13.55 s	6	9	7	8
RI 17.06 s	RI 24.15 s	9	6	8	7
RI 24.15 s	RI 17.06 s	8	7	9	6
RI 20 s	RI 20 s	10	10	10	10
Variable duration					
VI 13.33 s	VI 26.67 s	11	11	11	11
VI 26.67 s	VI 13.33 s	12	12	12	12

The experiment consisted of a set of VD conditions followed by a set of CD conditions and a VD replication. The order of conditions within the first two sets was counterbalanced across subjects and is listed in Table 1. In the VD conditions (VI schedules) the terminal-link reinforcement-rate ratios were 4:1, 1:4, 2:1, 1:2, and 1:1. In the CD conditions (RI schedules), the reinforcement-rate ratios were 2.83:1, 1:2.83, 1.41:1, 1:1.41, and 1:1. These were reduced compared with the VD ratios to decrease the likelihood of exclusive preference (which is possible with independent initial links), because sensitivity to relative reinforcement rate was expected to be greater with CD terminal links (Grace & Nevin, 2000). The VD replication consisted of the conditions with 2:1 and 1:2 reinforcement-rate ratios.

The average durations of the VI schedules in a particular condition always summed to 40 s, so that the programmed average time in the terminal links was 20 s in both the VD and CD conditions. The RI schedules were chosen so that the overall programmed terminal-link reinforcement rate would be 180 reinforcers per hour in each condition (i.e., equal to the VD conditions). The average programmed initial-link duration was also 20 s. Because the average initial- and terminal-link times are equal, Equation 2 predicts that preference in the VD conditions should match relative terminal-link reinforcement rate (assuming that $a_r = 1$, which is approximately true for VI schedules; Grace, 1994).

Training continued for 36 sessions in each condition. A fixed number of sessions rather than a stability criterion was used to equate exposure to the terminal links before the resistance-to-change tests; this rationale was also based on the authors' past experience that 36 sessions is sufficient for preference to reach stability in this procedure.

After baseline training, six test sessions were conducted to determine the resistance to change of responding in the terminal links. Response-independent food delivery during the initial links was used as the disrupter. A variable-time (VT) 10-s schedule operated during the initial links, and the duration of each food presentation was 1.67 s. Because initial-link response rate was expected to drop substantially in these sessions, terminal-link entry was made response independent (i.e., the initial links were changed to concurrent VT 40-s schedules).

Grace (1995) reported effects of component order on preference within sessions (specifically, induction in the following component from the location of the previous large-magnitude terminal link). Thus, the order of components in the test sessions was counterbalanced both within and across conditions, so components appeared in each ordinal position twice during the six test sessions. Different orders were used across conditions for each subject. In addition, the same sequence of component orders during a test was also used for the last six baseline sessions in each condition to control for any potential effects of component order on terminal-link response rates. Baseline responding in the next condition began immediately after the pigeons recovered their 85% body weights.

RESULTS

The primary data were the initial- and terminal-link response rates. Data were aggregated over the last six sessions of baseline and the six resistance-to-change test sessions in each condition. Selected raw data are listed in the Appendix.

To determine whether 36 sessions of baseline per condition were sufficient to produce stable initial-link preference, we computed regressions over the last 10 baseline sessions in each condition (log relative initial-link response rate by session number). A slope near zero indicates lack of trend. For all subjects, the average slopes (with 95% confidence intervals) were as follows: Pigeon 955, 0.004 (CI: −0.003, 0.011); Pigeon 956, 0.003 (−0.006, 0.012); Pigeon 005, −0.005 (−0.016, 0.006); Pigeon 961, 0.006 (−0.0003, 0.011). All confidence intervals included zero, and the average slopes were close to zero. Note that the largest slope (Pigeon 961) implies a change in preference of only 0.06 log units over the course of the 10 sessions, to be compared with the changes in preference across conditions that were often one log unit or more. As expected, therefore, preferences typically stabilized by the end of 36 sessions.

Relative initial-link response rates were analyzed with a logarithmic version of the contextual choice model (Equation 2; Grace, 1994), omitting the temporal context exponent because the arranged initial- and terminal-link durations were equal:

$$\log\left(\frac{B_1}{B_2}\right) = \log b + a_n \log\left(\frac{N_1}{N_2}\right) + a_r \log\left(\frac{R_1}{R_2}\right) + a_m \log\left(\frac{M_1}{M_2}\right). \quad (3)$$

Log relative initial-link response rate as a function of the log terminal-link reinforcement-rate ratio is shown in Figure 1, for all subjects in both the VD and CD conditions. The straight lines represent regressions on the data from the red (2:1 magnitude ratio),

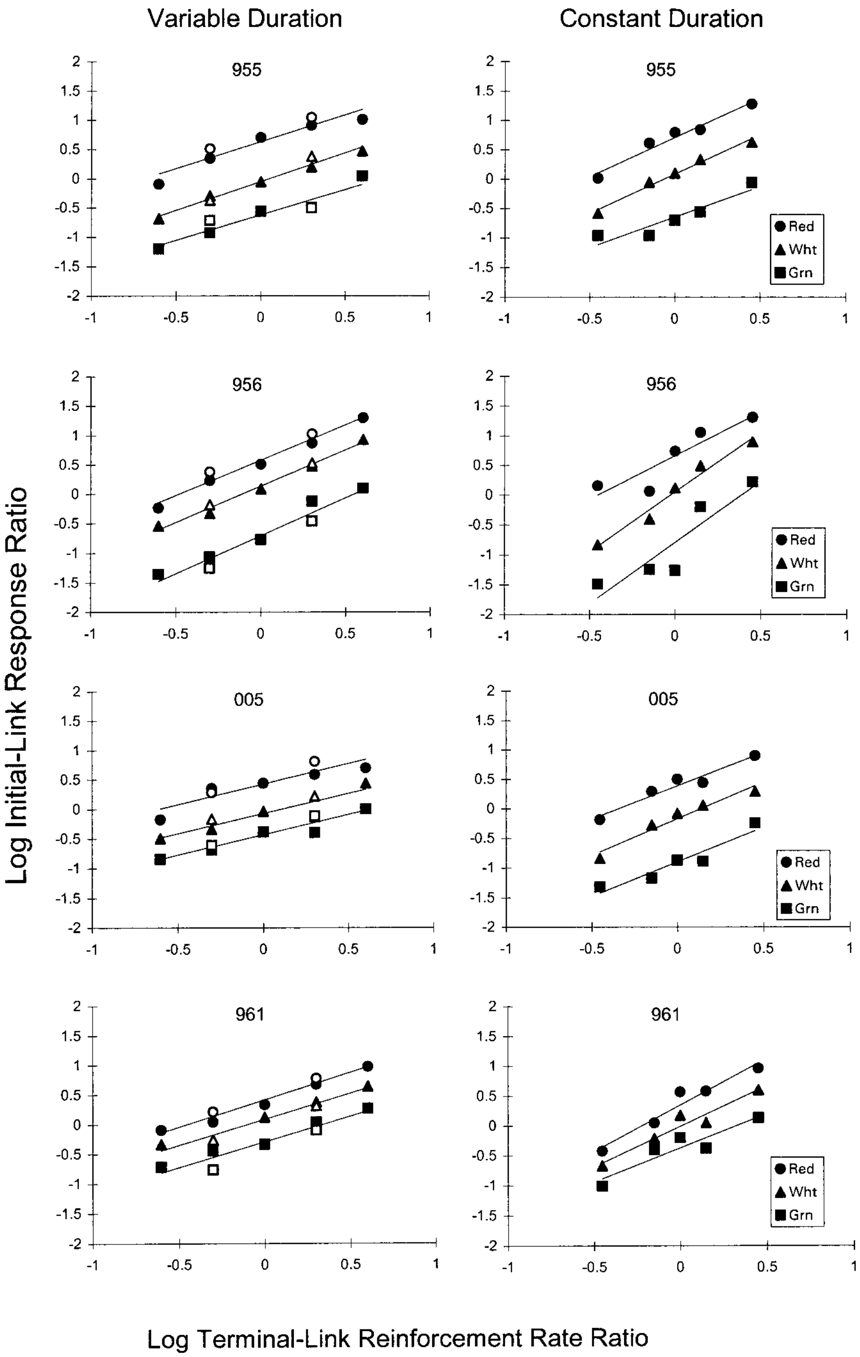

Fig. 1. Log relative initial-link response ratio as a function of log terminal-link reinforcement rate ratio, for both the VD (left panels) and CD (right panels) conditions. Circles represent data from the red component (2:1 magnitude ratio), triangles represent data from the white component (1:1 magnitude ratio), and squares represent data from the green component (1:2 magnitude ratio). Replication data are indicated with open symbols. Best fitting regression functions are shown for each component.

Table 2

Parameter estimates for the regressions performed on the preference data in Figure 1. Data are listed for both VD and CD conditions and the VD replication.

Pigeon		Variable duration			Constant duration		
		log b	a_r	VAC	log b	a_r	VAC
955	Red	0.63	0.92	.89	0.71	1.34	.96
	White	−0.05	0.99	.97	0.08	1.34	.98
	Green	−0.62	0.87	.90	−0.65	1.03	.87
	Estimated a_m	2.09			2.25		
956	Red	0.58	1.21	.97	0.66	1.48	.83
	White	0.14	1.24	.99	0.05	2.02	.97
	Green	−0.71	1.28	.95	−0.80	2.05	.83
	Estimated a_m	2.14			2.42		
005	Red	0.43	0.70	.83	0.39	1.13	.94
	White	−0.07	0.68	.83	−0.17	1.24	.95
	Green	−0.43	0.69	.92	−0.90	1.16	.91
	Estimated a_m	1.43			2.14		
961	Red	0.42	0.92	.97	0.34	1.56	.94
	White	0.09	0.88	.97	−0.01	1.35	.94
	Green	−0.30	0.87	.91	−0.37	1.14	.86
	Estimated a_m	1.18			1.19		

white (1:1 magnitude ratio), and green (1:2 magnitude ratio) components (including replications for the VD conditions). The slopes and intercepts of these lines give estimates of a_r and log b, respectively, for each component.

The other parameters in Equation 3 (a_n and a_m) were determined as follows. Rather than estimate a_n (sensitivity to terminal-link entry ratio) from the data as a fitted parameter, it was set a priori to 1 (see also Grace, 1999). Because the initial-link schedules were constant and equal, the programmed entry ratio was always 1:1, and deviated systematically in favor of the richer schedule only as preference became extreme. Thus, because the entry ratio is not a true independent variable (but in fact is a function of the dependent variable), best fitting estimates of a_n can sometimes be large (i.e., > 2), but it is unlikely that this represents true sensitivity to the entry ratio. In effect, setting a_n equal to 1 means that the log entry ratio is subtracted from the log initial-link response ratio before values of log b and a_r are estimated. The value of a_m is obtained by comparing bias estimates across components because magnitudes were constant across conditions within each component: Bias for the red component is log b + a_m log(2); bias for the green component is log b + a_m log(1/2). Thus, subtracting green bias from red bias and dividing by 2 log(2) gives a_m.

As Figure 1 shows, sensitivity to relative reinforcement rate (a_r) increased in the CD conditions for all subjects, as evidenced by the greater slopes in the right panels. There was also a clear effect of reinforcement magnitude, demonstrated by the separation and order of the regression lines (red, white, and green components). The data points for the VD replication conditions were close to the original values. Finally, the regression lines in both conditions are approximately parallel, suggesting no interaction between reinforcement rate and magnitude (Grace, 1995).

The estimated slopes (a_r) and intercepts (log b) from the regressions in Figure 1 are listed in Table 2 and confirm the visual impression from Figure 1. The regressions described the data well; the average variance accounted for (VAC) in both the VD and CD conditions was .92. In 12 of 12 comparisons, the estimate of a_r was greater in the CD conditions. In the VD conditions, preference for Pigeon 956 overmatched, for Pigeons 005 and 961 undermatched, and for Pigeon 955 approximately matched relative terminal-link reinforcement rate. The average value of a_r in the VD conditions was 0.94. By contrast, all slopes were greater than 1 for the CD conditions, demonstrating clear overmatching.

Table 3

Variance accounted for by Equation 3 when the preference data from the VD conditions were analyzed with either one, two (red-green and white), or three parameters of sensitivity to terminal-link reinforcement rate (a_r). None of the increases in variance accounted for by the models with two and three a_r values were statistically significant.

	Number of a_r parameters (VD)			Number of a_r parameters (CD)		
Pigeon	1	2	3	1	2	3
955	.970	.970	.970	.977	.978	.981
956	.967	.967	.967	.927	.929	.936
005	.935	.936	.936	.973	.974	.974
961	.968	.968	.969	.936	.936	.945
Average	.960	.960	.961	.953	.954	.959

The mean value of a_r for the CD conditions was 1.40.

Table 2 also shows that sensitivity to magnitude was consistently greater than sensitivity to rate. In seven of eight cases (the exception being Pigeon 961, CD conditions), a_m exceeded all three determinations of a_r. The average value of a_m was 1.71 for the VD condition and 2.00 for the CD condition.

Independence of reinforcement rate and magnitude requires that the regression lines in Figure 1 be parallel, implying that sensitivity to reinforcement rate (slope) does not depend on relative magnitude. To test this assumption, we computed the VAC by Equation 3 when a_r was constrained to be equal for all three components, and compared it with the VAC when either two (one for red-green and one for white) or three values of a_r were estimated. Table 3 gives the results. All of the F ratios calculated to compare the VAC by the two- and three-valued a_r models against the single-valued model failed to reach significance ($p > .05$). Overall, the increase in VAC between the one- and three-valued a_r models was very small: .001 and .006 for the VD and CD conditions, respectively. This is strong evidence for the independence of rate and magnitude as determiners of initial-link preference.

As noted in the introduction, one of our goals was to replicate Grace's (1995) study with independent initial links. With this procedure, obtained initial-link duration should vary less as a function of preference than it does with interdependent scheduling. An important question is the extent to which obtained initial-link duration did vary, and whether the results from the analyses of preference reported above would change in any meaningful way if obtained initial-link time is included in the model. Figure 2 shows average obtained initial-link time (Ti) as a function of preference for both VD and CD conditions. For comparison, the average data from Grace (1995) are also depicted. For all subjects, there was a tendency for obtained Ti values to increase as preference became more extreme, although the increases were less than those reported by Grace. We conducted a series of analyses to determine whether the inclusion of obtained Ti values would affect the results. The major results reported above (i.e., increased sensitivity to reinforcement rate in the CD conditions; independence of rate and magnitude) remained unchanged. Thus, use of independent initial links effectively reduces the amount of systematic variation in obtained Ti compared with interdependent scheduling.

The increased sensitivity to reinforcement rate in the CD conditions may have resulted from differences between programmed and obtained delays to reinforcement. The programmed distributions of reinforcement delays from terminal-link onset were homogeneous because the probability of reinforcement per unit time arranged by the RI schedules was constant. One implication is that although the probabilities differed for the rich and lean schedules, the normalized distributions of delays (i.e., the proportion of total reinforcers arranged per unit time) were always equal. Depending on the actual pattern of responding, however, it is possible that the obtained delay distributions might have been different. If reinforcers were relatively more likely to be earned after short delays in the rich terminal link, increased bias towards that alternative could result, producing overmatching. Thus, we conducted an analysis of the obtained reinforcement distributions for the CD conditions.

First we examined whether the obtained relative reinforcement rates corresponded to those that were programmed. The upper left panel of Figure 3 shows the obtained log reinforcement-rate ratio plotted against the programmed log reinforcement-rate ratio. To provide more reliable sampling, data for in-

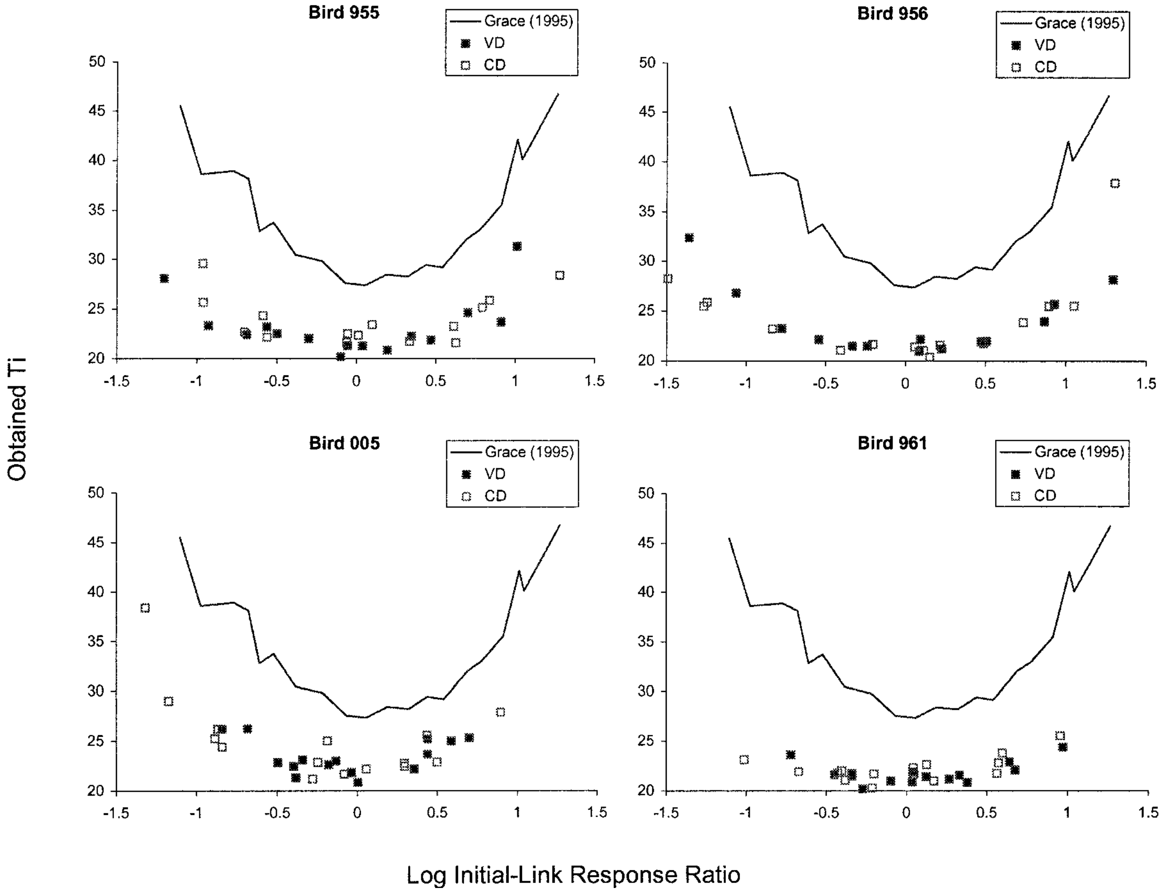

Fig. 2. Obtained average time in the initial links per terminal-link entry (*Ti*) in seconds for all pigeons and conditions. Data from the VD conditions are shown with filled symbols; data from the CD conditions are shown with open symbols. For comparison, group-mean data from Grace's (1995) study with interdependent initial links are indicated by the solid line.

dividual pigeons are based on data from all baseline sessions (36) in each condition. Although there appears to be a tendency for obtained ratios to be slightly less than programmed for the most extreme conditions (2.83:1 and 1:2.83), overall the obtained relative reinforcement rates closely approximated the programmed values.

Next we determined whether the obtained delay distributions might have induced a bias towards either the richer or the leaner alternative. For this analysis we computed the values of the terminal links, with value determined by the delay distribution. Although value may be quantified in various ways, one method that has proved successful in previous research is to assume that the effects of multiple reinforcers delivered during a terminal link are additive and are scaled as a function of the reciprocal of the delay from terminal-link onset (e.g., Shull, Spear, & Bryson, 1981). If the obtained delay distributions are equal to the programmed distributions and if value is calculated according to the sum-of-reciprocals rule, then the log value ratio should equal the log obtained reinforcement-rate ratio. However, the upper right panel of Figure 3 shows that the obtained log value ratios deviated systematically from the obtained log reinforcement-rate ratios. Specifically, value ratios were less extreme, and this effect was especially pronounced for the more extreme relative reinforcement-rate ratios.

To isolate this effect more clearly, we calculated value based on the normalized rein-

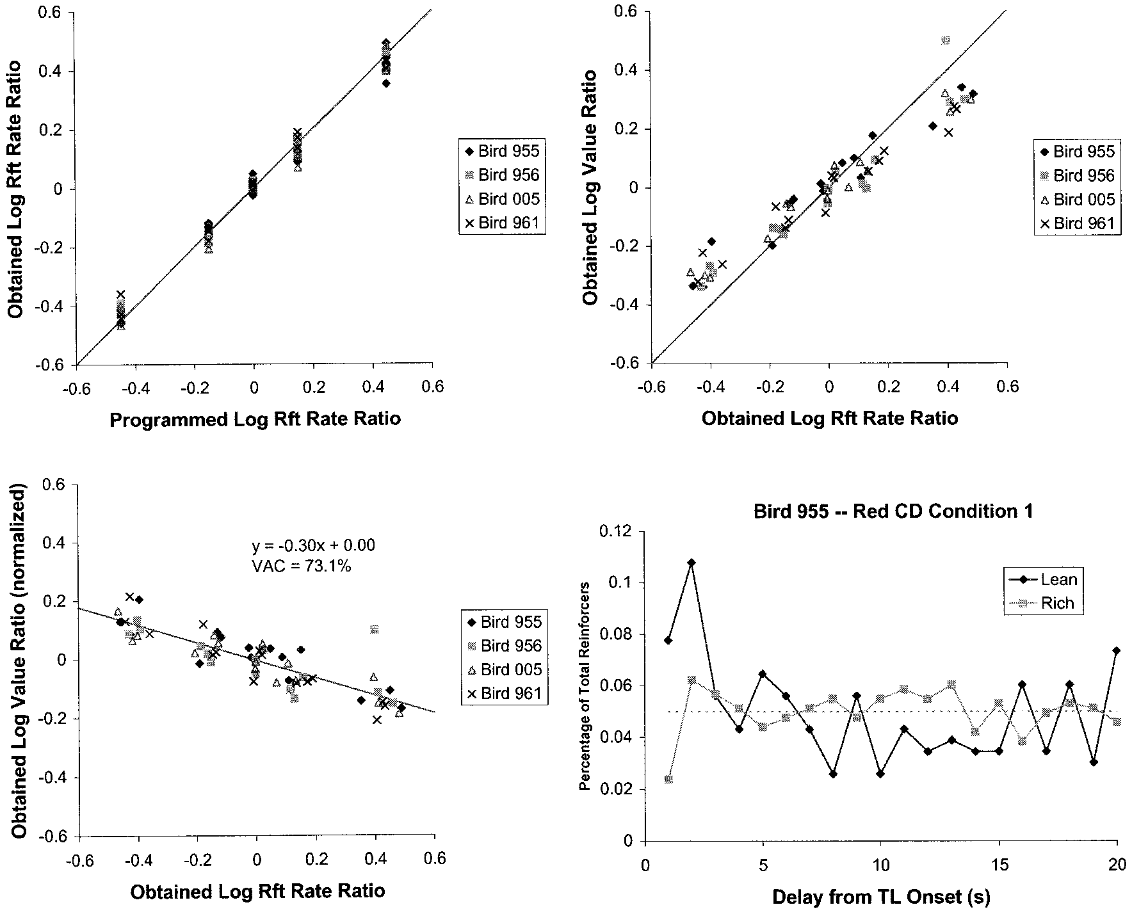

Fig. 3. Analysis of obtained reinforcement delay distributions for the CD conditions. The upper left panel plots programmed versus obtained log reinforcement-rate ratios for all subjects as indicated in the legend. The diagonal line indicates equality. The upper right panel shows the obtained log value ratio (where value is calculated according to the sums-of-reciprocals rule) as a function of the obtained log reinforcement-rate ratio. The diagonal line indicates equality, but log value ratios are systematically less extreme. The lower left panel shows the obtained log value ratio using normalized distributions, including a regression line. The lower right panel displays the obtained normalized reinforcement delay distributions for a representative subject in one condition. The dashed line indicates the programmed distribution (which is equal for both the rich and lean alternatives). See text for more explanation.

forcement delay distributions. Specifically, the obtained distributions were normalized by dividing the number of reinforcers obtained in each 1-s interval by the total number of reinforcers received for that terminal link. The log value ratios were then obtained using the sum-of-reciprocals rule and were plotted against the log reinforcement-rate ratio in the lower left panel of Figure 3. If the normalized delay distributions are equal (as they are programmed to be), then the slope of the best fitting regression line should be zero. The slope is clearly negative, however, thus demonstrating a bias against the richer terminal link.

This effect implies that short-delay reinforcers were relatively more likely in the lean alternative. The lower right panel of Figure 3 shows representative normalized delay distributions for 1 pigeon in one condition. The programmed distribution is indicated by the dashed line (5% of total reinforcers should be obtained in each 1-s interval). Note that the obtained reinforcement probability is elevated for the lean terminal link for the first 2 s; conversely, the reinforcement probability during the first 1 s is reduced for the rich terminal link. This general pattern was repeated across most conditions, producing the negative relation seen in the lower left panel of Figure 3. This result suggests that reinforcers were more likely to be scheduled but not earned at the end of a lean terminal link, and thus were held over for the next presentation. In any event, the implication is that the obtained delay distributions are not able to account for the strong overmatching observed in the CD conditions.

Relative resistance to change was modeled with a generalized matching model similar to Equation 3:

$$\log\left(\frac{B_{x1}}{B_{o1}}\right) - \log\left(\frac{B_{x2}}{B_{o2}}\right) = \log b' + a_{r'}\log\left(\frac{R_1}{R_2}\right) + a_{m'}\log\left(\frac{M_1}{M_2}\right). \quad (4)$$

In Equation 4, B_o and B_x are the terminal-link response rates in baseline and during the disrupter test, respectively (subscripted for Alternatives 1 and 2). Thus, relative resistance to change is measured as the difference between the log proportion of baseline response rates during the test. According to Equation 4, relative resistance is determined by the additive combination of bias and terms for relative reinforcement rate and magnitude. The parameters log b', $a_{r'}$, and $a_{m'}$ correspond to those in Equation 3. A ratio corresponding to terminal-link entry frequency has been omitted (effectively setting its exponent to zero) because terminal-link entry was arranged by identical VT schedules during resistance tests, and there is no theoretical basis to expect relative frequency to influence resistance to change (Nevin, Mandell, & Atak, 1983). Moreover, Nevin and Grace (1998)[1] varied component frequency in a standard multiple schedule and found that it did not affect resistance to change.

Figure 4 shows that resistance to change was an increasing function of reinforcement rate in nearly all cases (the only exception being Pigeon 005, red component). It is also clear that resistance to change is less sensitive than preference is to relative reinforcement rate (note the reduced range of the ordinates in Figure 4). The data are also more variable than the corresponding data for preference in Figure 1.

The regression lines in Figure 4 represent the fits of Equation 4. Parameters are listed for individual subjects in Table 4. The greater variability of the data is indicated by an average VAC of .62 and .77 for the VD and CD conditions, respectively. In 10 of 12 cases, sensitivity to relative reinforcement rate ($a_{r'}$) was greater in CD than in VD conditions. The average value of $a_{r'}$ for the VD conditions was 0.28; the corresponding CD average was 0.42. Thus, as for the preference data, sensitivity to relative reinforcement rate was overall greater in the CD conditions. Sensitivity to magnitude was also greater in the CD conditions. However, overall sensitivity values were reduced compared to those obtained with preference.

An analysis was conducted to determine whether reinforcement rate and magnitude were independent determiners of resistance to change. Table 5 lists the VAC when $a_{r'}$ was constrained to be equal for all three components, and when two (one for red-green and one for white) or three different values of $a_{r'pr}$ were estimated. Every F ratio calculated to compare the VAC by the two- and three-valued a_r models against the single-valued model failed to reach significance ($p > .05$). The increase in VAC between the one- and three-valued $a_{r'}$ models, although larger than that for preference (see Table 3), was still small: .030 and .026 for the VD and CD conditions, respectively. This suggests that as for preference, rate and magnitude have additive and independent effects on resistance to change.

Because the CD conditions were completed after the VD conditions, it is possible that differential sensitivity to reinforcement rate and magnitude might have been confounded by order effects. In particular, sensitivity to magnitude (a_m and $a_{m'}$) might have been expected to increase across conditions because the reinforcement durations remained constant across the experiment. Therefore, we conducted an analysis to determine whether the order of conditions (which differed for each subject) had any effect on sensitivity. For the

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[1] Nevin, J. A., & Grace, R. C. (1998, April). *Rate versus number of reinforcers and resistance to change.* Paper presented at the annual meeting of the Eastern Psychological Association, Philadelphia.

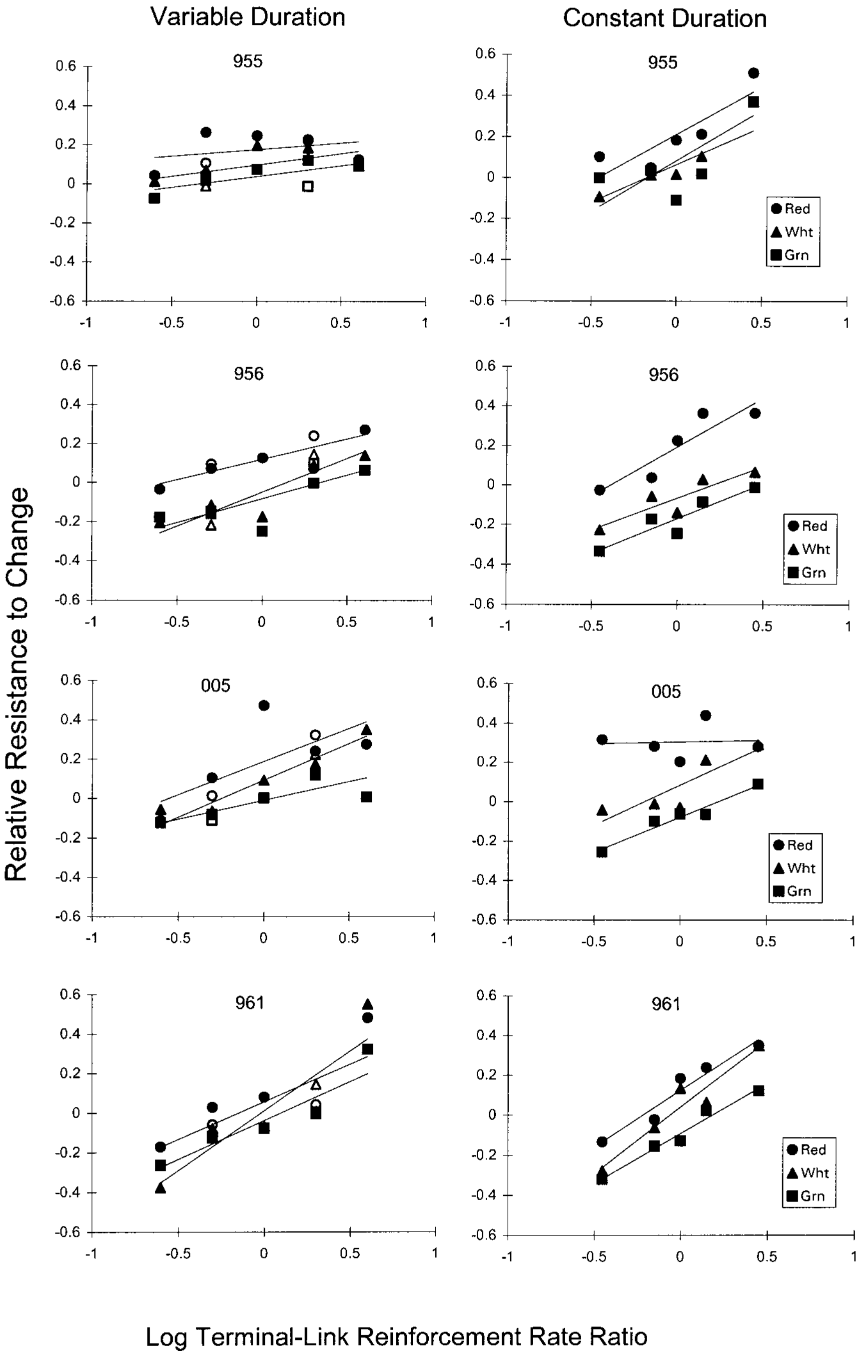

Fig. 4. Relative resistance to change as a function of log terminal-link reinforcement-rate ratio, for both the VD (left panels) and CD (right panels) conditions. Circles represent data from the red component (2:1 magnitude ratio), triangles represent data from the white component (1:1 magnitude ratio), and squares represent data from the green component (1:2 magnitude ratio). Replication data are indicated with open symbols. Best fitting regression functions are shown for each component.

Table 4

Parameter estimates for the regressions performed on the resistance-to-change data in Figure 2. Data are listed for both VD and CD conditions and the VD replication.

		Variable duration			Constant duration		
Pigeon		log b'	$a_{r'}$	VAC	log b'	$a_{r'}$	VAC
955	Red	0.18	0.07	.12	0.21	0.46	.75
	White	0.10	0.12	.38	0.08	0.49	.89
	Green	0.04	0.11	.49	0.06	0.37	.46
	Estimated a_m	0.23			0.25		
956	Red	0.12	0.21	.72	0.19	0.50	.85
	White	−0.05	0.35	.80	−0.07	0.32	.81
	Green	−0.08	0.24	.61	−0.17	0.35	.86
	Estimated a_m	0.34			0.60		
005	Red	0.19	0.34	.52	0.30	0.02	.00
	White	0.09	0.37	.92	0.08	0.41	.77
	Green	−0.01	0.19	.64	−0.08	0.36	.95
	Estimated a_m	0.33			0.64		
961	Red	0.06	0.38	.63	0.12	0.57	.94
	White	0.01	0.60	.82	0.04	0.67	.93
	Green	−0.04	0.39	.84	−0.09	0.50	.97
	Estimated a_m	0.16			0.36		

first four VD and CD conditions, we computed point estimates of sensitivity to reinforcement rate and magnitude for both preference and resistance to change. For sensitivity to reinforcement rate, point estimates were computed as the average of the log initial-link response rate (corrected for unequal terminal-link entries) or relative resistance to change, divided by the log reinforcement-rate ratio. For sensitivity to magnitude, the difference between corrected log initial-link response ratios (or log relative resistances) for the red and green components divided by 2 log(2) served as the point estimate. The fifth condition in each set had a reinforcement-rate ratio of 1:1, and so was excluded from the analysis for rate (a_r, $a_{r'}$). The average data are shown in Figure 5. Point estimates from the VD replication conditions are shown for comparison. The data (excluding the VD replication) were entered into a series of 2 × 4 (for rate) or 2 × 5 (for magnitude) repeated measures analyses of variance (ANOVA) with type (VD or CD) and order of condition as factors. For a_m (preference sensitivity to magnitude), there was a significant effect of order, $F(4, 12) = 4.62$, $p < .02$. The main effect of type approached significance, $F(1, 3) = 9.56$, $p = .05$. A planned linear contrast reached significance, $F(1, 3) = 33.73$, $p < .02$, indicating that point estimates of a_m increased across successive conditions within each set. The trend is also evident in Figure 5. Results for sensitivity to magnitude for resistance to change ($a_{m'}$) were similar. There were significant effects of order, $F(4, 12) = 11.88$, $p < .001$, and type, $F(1, 3) = 10.23$, $p < .05$. A planned linear contrast was significant, $F(1, 3) = 332.87$, $p < .001$, showing that $a_{m'}$ increased across successive conditions for both VD and CD sets. There were no significant effects of order on sensitivity to reinforcement rate for both measures (a_r and $a_{r'}$). Thus, these results suggest that the increased sensitivity of preference and resistance to change to magnitude in the CD conditions might have been the result of extended training.

Table 5

Variance accounted for by Equation 4 when the resistant-to-change data from the VD conditions were analyzed with either one, two (red-green and white), or three parameters of sensitivity to terminal-link reinforcement rate ($a_{r'}$). None of the increases in variance accounted for by the models with two and three $a_{r'}$ values were statistically significant.

	Number of $a_{r'}$ parameters (VD)			Number of $a_{r'}$ parameters (CD)		
Pigeon	1	2	3	1	2	3
955	.558	.559	.590	.709	.713	.718
956	.748	.779	.779	.886	.891	.899
005	.718	.755	.772	.823	.849	.896
961	.741	.745	.745	.941	.950	.952
Average	.691	.709	.721	.840	.851	.866

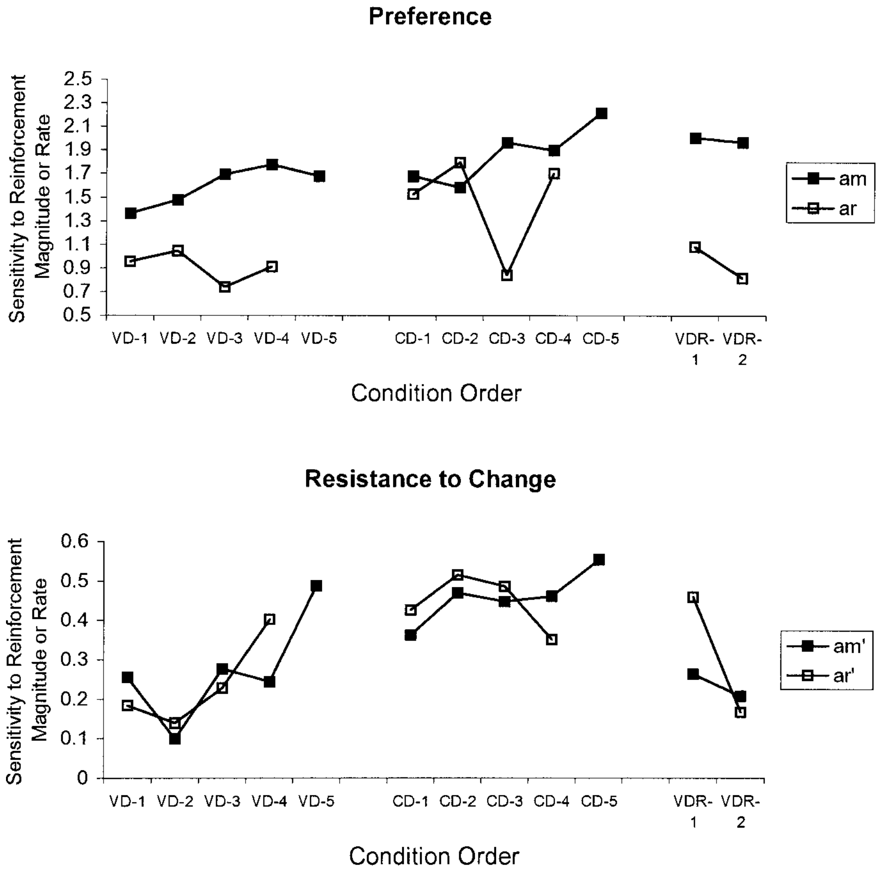

Fig. 5. Point estimates of sensitivity to reinforcement rate (open squares) and magnitude (filled squares) for the VD and CD conditions and the VD replication (VD-R) conditions. Preference data are shown in the upper panel; resistance-to-change data are shown in the lower panel. The fifth condition in the VD and CD sets was omitted for sensitivity to rate, as point estimates could not be obtained because the relative reinforcement rate was 1:1. Data are averaged across pigeons. Note that because order of conditions was counterbalanced, data points from each pigeon that contributed to the average values shown were obtained with different terminal-link reinforcement-rate ratios.

DISCUSSION

Pigeons responded in a three-component multiple concurrent-chains procedure in which the terminal-link VI schedules were the same in each condition but the reinforcement-magnitude ratios differed across components. The terminal-link reinforcement-rate ratio was varied in two sets of conditions while the independent initial links and overall terminal-link reinforcement rate were held constant. In the VD conditions, the terminal links ended after a single reinforcer, and in the CD conditions the terminal links consisted of a 20-s period of access to the schedule during which a variable number of reinforcers could be earned. After baseline training in each condition, terminal-link responding was disrupted by delivering free food in the initial links. Thus, we obtained parametric measures of preference and resistance to change by varying both reinforcement rate and magnitude in VD and CD procedures.

An important goal of our study was to test whether the effects of reinforcement rate and magnitude on preference and resistance to change were additive. Part of our experiment constituted a replication of Grace (1995) with independent initial-link schedules. Grace tested whether equal versus unequal reinforcement magnitudes would affect sensitivity of preference to reinforcement immediacy (or, equivalently in this case, rate). He used a three-component concurrent-chains procedure similar to the one in the present study, except that the initial links were interdependent and guaranteed equal exposure to the terminal links. In that procedure, the average time spent in the initial links can increase without limit when preference becomes extreme. The initial analysis suggested that sensitivity was greater in the equal-magnitude component; however, sensitivities were not systematically different when obtained initial-link time was included in the model (Grace, 1994). Grace therefore concluded that reinforcement magnitude and immediacy were independent, as required by the matching law (Baum & Rachlin, 1969).

We replicated Grace's (1995) basic design, except using independent initial links. Although independent initial links do not guarantee that the terminal-link access rates remain constant, the obtained initial-link time will not deviate as much from the programmed value. The preference data in Figure 1 provide strong support for the independence of reinforcement magnitude and rate: In the VD conditions, the regression lines in Figure 1 are approximately parallel. The CD data were more variable, but there were still no systematic deviations from parallelism. To test the parallelism requirement more rigorously, we computed the increment in VAC when sensitivity to reinforcement rate (a_r) was allowed to differ across components. All of the increments were small and fell far short of statistical significance. Results for resistance to change, although more variable, supported the same conclusion (see Figure 4). We therefore conclude that for pigeons responding in concurrent chains, relative reinforcement magnitude does not affect the control of preference and resistance to change by reinforcement rate. The data are consistent with simple additivity, as required by the matching law (Baum & Rachlin, 1969; Logue, Rodriguez, Peña-Correal, & Mauro, 1984).

Previous research (Grace & Nevin, 2000) has found that preference was more sensitive to relative reinforcement rate with CD terminal links, but results for resistance to change were mixed. That prior study, however, obtained only point estimates of sensitivity, and one of our goals was to determine if resistance to change would be more sensitive to reinforcement rate in the CD procedure if reinforcement rate was varied parametrically. Such a result would extend the general covariation of preference and resistance to change (Nevin & Grace, 2000a).

Our data replicated Grace and Nevin's (2000) results for preference: For all subjects and components (12 of 12 cases), sensitivity to reinforcement rate (a_r in Equation 3) was greater in the CD conditions than in the VD conditions (see Table 2 and Figure 5). Moreover, point estimates of sensitivity from the VD replication conditions decreased in all 12 cases compared with the CD conditions. For the resistance-to-change data, sensitivity to reinforcement rate also increased for all subjects in the CD conditions (10 of 12 cases). Although the resistance data were overall more variable, results suggest that CD versus VD scheduling has similar effects on sensitivity to reinforcement rate for both preference and resistance to change.

Sensitivity values were consistent with prior experiments. In the present experiment, average sensitivity to reinforcement rate (including replications) in the VD conditions was 0.94 for preference and 0.28 for resistance to change. These are comparable to the corresponding values of 0.91 and 0.20 reported by Grace and Nevin (1997). For the CD conditions, the average sensitivities were 1.40 and 0.42. These are somewhat lower than the 1.78 and 0.62 that Nevin and Grace (2000b) obtained, but were greater than the VD sensitivities.

Exactly why sensitivity to reinforcement rate should be greater in the CD conditions is still unclear. We examined the possibility that differences in the obtained delay-to-reinforcement distributions might have favored the richer terminal link. If the latency to the first response per terminal link was shorter for the rich alternative, then relatively more short-delay reinforcers might be obtained for that alternative, which could produce an increased preference for the richer schedule (i.e., overmatching). We found the opposite result, however: Short-delay reinforcers were relatively more likely for the lean alternative (see Figure 3). If anything, this might have been expected to encourage undermatching. That strong overmatching was still obtained underscores the reliability of the increased sensitivity under CD scheduling. Grace and Nevin (2000) suggested that different vari-

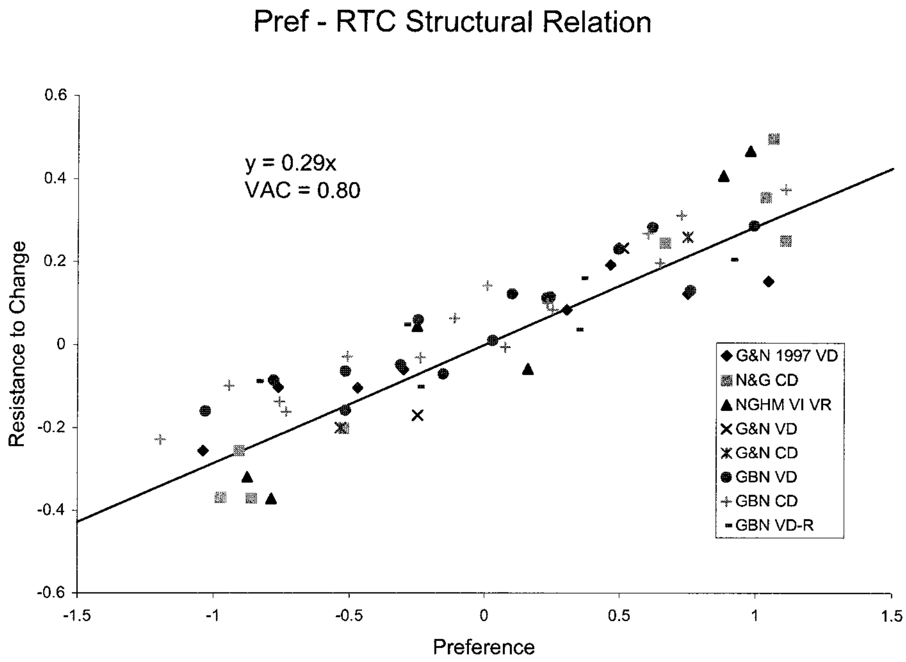

Fig. 6. The structural relation between preference and relative resistance to change. Shown are average data obtained from five experiments conducted by Nevin, Grace, and colleagues: G&N 1997 VD (Grace & Nevin, 1997, VD VI schedules); N&G CD (Nevin & Grace, 2000b, CD VI schedules); G&N VD (Grace & Nevin, 2000, VD VI schedules); G&N CD (Grace & Nevin, 2000, CD VI schedules); GBN VD (present data, VD VI schedules); GBN CD (present data, CD RI schedules); GBN VD-R (present data, VD replication); NGHM VI VR (Nevin, Grace, Holland, & McLean, 2001, VI vs. VR schedules).

ables might control preference in VD and CD procedures; specifically, immediacy for VD and rate or numerosity for CD scheduling. Our data are consistent with this view.

There was one additional difference between the CD and VD conditions: The range of relative reinforcement rates was reduced for the CD conditions (from 4:1 to 2.83:1). The reason for this was to avoid exclusive preference, which is possible with independent initial-link schedules. This reduction, however, is unlikely to have caused the increased sensitivity to reinforcement rate. Using interdependent scheduling, Nevin and Grace (2000b) found increased sensitivity with ratios up to 4.54:1.

The sensitivity of preference to magnitude increased for all subjects in the CD conditions. Point estimates, however, showed an effect of sustained training: Sensitivity to magnitude increased across successive conditions in both phases of the experiment (see Figure 5). Order effects were not obtained with sensitivity to reinforcement rate. Because the magnitudes remained constant within each component across conditions, the increased sensitivity resembles the effect of length of training in simple concurrent schedules (Todorov, Oliveira Castro, Hanna, Bittencourt de Sa, & Barreto, 1983). Thus, it is premature to conclude that CD versus VD scheduling has any effects on sensitivity to magnitude for preference. By contrast, however, for resistance to change, sensitivity to magnitude ($a_{m'}$) was greater in the CD conditions. All subjects showed an increase in $a_{m'}$ between the VD and CD conditions, and point estimates of $a_{m'}$ decreased in the replication for 3 of 4 pigeons (for Pigeon 955 it remained virtually the same).

The present results fit well with the data on resistance to VT food in relation to preference that we have obtained in other studies that permit within-subject, within-condition comparisons of these measures. Figure 6 plots resistance to change against preference in every condition of every study that has measured both variables. The y axis gives the value of $\log (B_{x1}/B_{o1}) - \log (B_{x2}/B_{o2})$ for the VT food resistance tests, and the x axis gives the corresponding value of log (B_{i1}/B_{i2}) for initial-link preference, where each measure is averaged within each condition over 4 pigeons. A relation of simple proportionality (the regression line was constrained to pass through the origin) provides an excellent description of the data, regardless of whether the components were variable or constant in duration, whether they had the same or different reinforcer magnitudes, and whether they employed VI versus VI or VI versus variable-ratio schedules of food reinforcement. Note that although both preference and relative resistance are related to reinforcement-rate ratios by power functions, the structural relation between them is not forced because the sensitivity exponents need not covary within or between experiments. This is strong evidence for the proposition that a single construct sometimes termed *strength* or *value* is expressed similarly in preference and in resistance to change (Nevin & Grace, 2000a).

Thus, our results extend the general covariation of preference and resistance to change to include VI schedules that vary in both reinforcement rate and magnitude in both VD and CD scheduling arrangements. For both measures of behavior, a model that assumes additive effects of rate and magnitude works well. Finally, the fact that our data were at least as orderly as those from prior studies that arranged only a single pair of schedules per condition (Grace & Nevin, 1997; Nevin & Grace, 2000b) demonstrates the efficiency of the three-component procedure.

REFERENCES

Baum, W. M., & Rachlin, H. C. (1969). Choice as time allocation. *Journal of the Experimental Analysis of Behavior, 12,* 861–874.

Davison, M., & Nevin, J. A. (1999). Stimuli, reinforcers, and behavior: An integration. *Journal of the Experimental Analysis of Behavior, 71,* 439–482.

Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior, 5,* 529–530.

Grace, R. C. (1994). A contextual model of concurrent-chains choice. *Journal of the Experimental Analysis of Behavior, 61,* 113–129.

Grace, R. C. (1995). Independence of reinforcement delay and magnitude in concurrent chains. *Journal of the Experimental Analysis of Behavior, 63,* 255–276.

Grace, R. C. (1999). The matching law and amount-dependent exponential discounting as accounts of self-control choice. *Journal of the Experimental Analysis of Behavior, 71,* 27–44.

Grace, R. C., & Nevin, J. A. (1997). On the relation between preference and resistance to change. *Journal of the Experimental Analysis of Behavior, 67,* 43–65.

Grace, R. C., & Nevin, J. A. (2000). Comparing preference and resistance to change in constant- and variable-duration schedule components. *Journal of the Experimental Analysis of Behavior, 74,* 165–188.

Logue, A. W., Rodriguez, M. L., Peña-Correal, T. E., & Mauro, B. C. (1984). Choice in a self-control paradigm: Quantification of experience-based differences. *Journal of the Experimental Analysis of Behavior, 41,* 53–67.

McLean, A. P., & Blampied, N. M. (2001). Sensitivity to relative reinforcer rate in concurrent schedules: Independence from relative and absolute reinforcer duration. *Journal of the Experimental Analysis of Behavior, 75,* 25–42.

Nevin, J. A., & Grace, R. C. (2000a). Behavioral momentum and the law of effect. *Behavioral and Brain Sciences, 23,* 73–130. (includes commentary)

Nevin, J. A., & Grace, R. C. (2000b). Preference and resistance to change with constant-duration schedule components. *Journal of the Experimental Analysis of Behavior, 74,* 79–100.

Nevin, J. A., Grace, R. C., Holland, S., & McLean, A. P. (2001). Variable-ratio versus variable-interval schedules: Response rate, resistance to change, and preference. *Journal of the Experimental Analysis of Behavior, 76,* 43–74.

Nevin, J. A., Mandell, C., & Atak, J. R. (1983). The analysis of behavioral momentum. *Journal of the Experimental Analysis of Behavior, 39,* 49–59.

Nevin, J. A., Mandell, C., & Yarensky, P. (1981). Response rate and resistance to change in chained schedules. *Journal of Experimental Psychology: Animal Behavior Processes, 7,* 278–294.

Shull, R. L., Spear, D. J., & Bryson, A. E. (1981). Delay or rate of food delivery as a determiner of response rate. *Journal of the Experimental Analysis of Behavior, 35,* 129–143.

Ten Eyck, R. L., Jr. (1970). Effects of rate of reinforcement-time upon concurrent operant performance. *Journal of the Experimental Analysis of Behavior, 14,* 269–274.

Todorov, J. C., Oliveira Castro, J. M., Hanna, E. S., Bittencourt de Sa, M. C. N., & Barreto, M. Q. (1983). Choice, experience, and the generalized matching law. *Journal of the Experimental Analysis of Behavior, 40,* 99–111.

Received March 14, 2000
Final acceptance January 29, 2002

APPENDIX

Selected raw data from the experiment. Data are shown separately for the red (R), green (G), and white (W) components in each of the 12 conditions. Listed are the terminal-link schedules, the reinforcement magnitudes, the number of responses to each initial link (BL, BR), time allocated (in seconds) to responding in each initial link (TL, TR), number of entries into each terminal link (eL, eR), and terminal-link response rates (responses per minute) during baseline (tlL, tlR) and the VT food resistance test (tlxL, tlxR). All data are summed over the last six sessions of baseline training in each condition (and over the six sessions of the VT food resistance test).

Pigeon	Condition	Schedules	Reinforcement	BL	BR
955	1 (R)	VI 32 VI 8	3.33 s 1.67 s	969	1,183
	1 (G)		1.67 s 3.33 s	86	2,578
	1 (W)		2.5 s 2.5 s	416	2,602
	2 (R)	VI 8 VI 32	3.33 s 1.67 s	4,205	137
	2 (G)		1.67 s 3.33 s	1,178	1,136
	2 (W)		2.5 s 2.5 s	1,984	673
	3 (R)	VI 26.67 VI 13.33	3.33 s 1.67 s	1,871	693
	3 (G)		1.67 s 3.33 s	177	2,491
	3 (W)		2.5 s 2.5 s	824	1,689
	4 (R)	VI 13.33 VI 26.67	3.33 s 1.67 s	3,220	290
	4 (G)		1.67 s 3.33 s	668	2,349
	4 (W)		2.5 s 2.5 s	1,713	1,062
	5 (R)	VI 20 VI 20	3.33 s 1.67 s	3,034	373
	5 (G)		1.67 s 3.33 s	446	2,216
	5 (W)		2.5 s 2.5 s	1,278	1,453
	6 (R)	RI 38.17 RI 13.55	3.33 s 1.67 s	1,124	1,090
	6 (G)		1.67 s 3.33 s	144	2,999
	6 (W)		2.5 s 2.5 s	582	2,184
	7 (R)	RI 13.35 RI 38.17	3.33 s 1.67 s	4,541	95
	7 (G)		1.67 s 3.33 s	1,258	1,482
	7 (W)		2.5 s 2.5 s	2,602	507
	8 (R)	RI 17.06 RI 24.15	3.33 s 1.67 s	2,661	465
	8 (G)		1.67 s 3.33 s	240	3,247
	8 (W)		2.5 s 2.5 s	1,319	1,629
	9 (R)	RI 24.15 RI 17.06	3.33 s 1.67 s	3,234	307
	9 (G)		1.67 s 3.33 s	469	2,009
	9 (W)		2.5 s 2.5 s	1,754	749
	10 (R)	RI 20 RI 20	3.33 s 1.67 s	2,785	303
	10 (G)		1.67 s 3.33 s	319	2,180
	10 (W)		2.5 s 2.5 s	1,467	1,102
	11 (R)	VI 13.33 VI 26.67	3.33 s 1.67 s	4,094	209
	11 (G)		1.67 s 3.33 s	656	2,411
	11 (W)		2.5 s 2.5 s	2,210	823
	12 (R)	VI 26.67 VI 13.33	3.33 s 1.67 s	1,919	529
	12 (G)		1.67 s 3.33 s	219	2,299
	12 (W)		2.5 s 2.5 s	731	1,766
956	1 (R)	VI 13.33 VI 26.67	3.33 s 1.67 s	4,381	462
	1 (G)		1.67 s 3.33 s	1,766	2,368
	1 (W)		2.5 s 2.5 s	3,127	960
	2 (R)	VI 26.67 VI 13.33	3.33 s 1.67 s	2,332	1,586
	2 (G)		1.67 s 3.33 s	245	5,313
	2 (W)		2.5 s 2.5 s	1,287	2,759
	3 (R)	VI 8 VI 32	3.33 s 1.67 s	5,304	118
	3 (G)		1.67 s 3.33 s	2,589	1,806
	3 (W)		2.5 s 2.5 s	3,874	281
	4 (R)	VI 32 VI 8	3.33 s 1.67 s	1,448	2,244
	4 (G)		1.67 s 3.33 s	77	5,671
	4 (W)		2.5 s 2.5 s	830	3,057
	5 (R)	VI 20 VI 20	3.33 s 1.67 s	2,934	794
	5 (G)		1.67 s 3.33 s	541	3,898
	5 (W)		2.5 s 2.5 s	2,028	1,567
	6 (R)	RI 17.06 RI 24.15	3.33 s 1.67 s	3,786	195
	6 (G)		1.67 s 3.33 s	1,300	2,248
	6 (W)		2.5 s 2.5 s	2,399	656

APPENDIX

(*Extended*)

TL	TR	eL	eR	tlL	tlR	tlxL	tlxR
1,316.55	1,585.65	73	71	77.18	72.57	47.05	40.24
51.25	3,983.50	50	94	63.01	58.69	33.95	37.57
559.73	2,665.47	63	81	70.05	68.31	51.01	48.57
4,334.98	164.93	108	36	92.35	65.67	58.96	31.53
1,321.36	1,740.70	70	74	81.67	56.18	45.17	24.60
2,209.44	935.33	72	72	81.87	61.65	62.52	38.16
2,261.04	940.37	79	65	89.89	93.13	56.72	32.11
135.40	3,220.90	54	90	79.73	78.83	36.31	34.55
981.18	2,186.84	71	73	90.98	80.39	52.17	39.28
3,057.45	350.30	83	61	107.37	89.18	75.58	37.68
701.29	2,535.94	68	76	88.14	84.48	55.72	40.52
1,627.13	1,376.04	73	71	89.34	93.71	66.72	45.69
3,147.52	389.00	89	55	106.39	94.51	81.05	40.90
409.95	2,924.79	61	83	105.90	98.89	65.34	51.59
1,337.04	1,729.79	72	72	104.79	112.85	70.80	48.55
1,763.16	1,453.57	72	72	101.77	78.91	55.89	34.33
226.30	4,028.68	44	100	53.22	73.68	29.41	40.84
975.53	2,524.34	73	71	95.81	73.39	44.26	42.15
3,979.17	98.08	103	41	86.53	82.05	69.10	20.22
1,241.61	1,870.15	71	73	84.33	98.78	60.58	30.08
2,651.08	452.99	79	65	84.02	86.33	70.92	31.02
2,791.23	551.73	84	60	99.74	101.86	61.40	56.18
232.17	3,457.01	58	86	77.19	110.40	58.79	77.73
1,378.37	1,859.18	69	75	87.16	105.06	58.52	68.57
3,403.22	311.54	87	57	89.92	99.75	78.84	53.65
560.95	2,626.14	66	78	74.26	89.03	59.46	68.45
2,191.03	935.54	75	69	83.57	91.51	56.90	49.00
3,223.62	387.95	86	58	86.62	88.58	84.09	56.55
281.64	2,981.10	61	83	87.46	89.62	51.95	68.48
1,932.61	1,436.78	74	70	87.57	84.82	53.95	50.41
3,652.12	130.06	92	52	104.81	113.00	90.78	58.11
516.79	2,631.83	67	77	108.72	112.75	78.02	83.50
2,294.40	787.59	76	68	95.19	94.65	82.85	60.78
2,624.11	734.17	76	68	83.16	98.08	61.42	56.74
218.60	3,704.21	48	96	67.51	100.31	54.81	74.71
897.83	2,368.94	71	73	77.73	87.82	45.02	52.15
3,237.75	210.16	81	63	176.30	111.63	184.49	99.23
1,016.62	7,795.62	72	72	126.71	130.24	116.42	120.55
2,732.89	423.27	75	69	148.20	138.62	159.36	121.63
1,937.72	1,113.18	67	77	165.30	135.48	154.34	107.54
98.09	3,754.27	50	94	116.61	125.09	82.92	125.09
1,058.31	2,035.24	72	72	147.75	128.13	112.48	127.65
3,998.07	48.76	100	44	171.95	105.55	182.93	60.21
1,905.60	1,284.40	77	67	128.77	135.70	131.34	120.13
3,505.04	187.64	89	55	168.68	134.90	173.10	100.49
1,237.73	1,856.90	76	68	172.40	152.48	142.48	136.88
58.83	4,600.11	34	110	99.78	123.81	82.64	154.44
700.90	2,483.95	70	74	134.30	121.74	83.51	121.66
2,575.40	586.47	77	67	142.25	129.35	57.87	39.35
567.48	2,778.37	65	79	84.17	130.19	15.83	43.61
1,988.24	1,031.04	74	70	100.57	123.98	30.62	56.71
3,535.01	134.22	91	53	155.77	103.47	139.01	40.06
1,030.23	2,085.37	69	75	90.14	121.84	55.85	92.18
2,628.54	503.85	78	66	120.48	110.31	83.10	71.36

APPENDIX

(*Continued*)

Pigeon	Condition	Schedules	Reinforcement	BL	BR
	7 (R)	RI 24.15 RI 17.06	3.33 s 1.67 s	2,251	1,908
	7 (G)		1.67 s 3.33 s	181	5,804
	7 (W)		2.5 s 2.5 s	1,157	2,941
	8 (R)	RI 13.55 RI 38.17	3.33 s 1.67 s	5,934	15
	8 (G)		1.67 s 3.33 s	2,085	1,193
	8 (W)		2.5 s 2.5 s	3,376	273
	9 (R)	RI 38.17 RI 13.55	3.33 s 1.67 s	1,854	1,376
	9 (G)		1.67 s 3.33 s	106	5,656
	9 (W)		2.5 s 2.5 s	409	3,586
	10 (R)	RI 20 RI 20	3.33 s 1.67 s	2,827	359
	10 (G)		1.67 s 3.33 s	174	5,180
	10 (W)		2.5 s 2.5 s	1,679	1,254
	11 (R)	VI 13.33 VI 26.67	3.33 s 1.67 s	4,096	200
	11 (G)		1.67 s 3.33 s	983	2,999
	11 (W)		2.5 s 2.5 s	2,956	591
	12 (R)	VI 26.67 VI 13.33	3.33 s 1.67 s	2,499	968
	12 (G)		1.67 s 3.33 s	158	5,505
	12 (W)		2.5 s 2.5 s	1,473	2,178
005	1 (R)	VI 8 VI 32	3.33 s 1.67 s	2,173	238
	1 (G)		1.67 s 3.33 s	1,241	1,163
	1 (W)		2.5 s 2.5 s	1,627	608
	2 (R)	VI 32 VI 8	3.33 s 1.67 s	763	1,182
	2 (G)		1.67 s 3.33 s	275	3,187
	2 (W)		2.5 s 2.5 s	540	1,992
	3 (R)	VI 13.33 VI 26.67	3.33 s 1.67 s	1,544	270
	3 (G)		1.67 s 3.33 s	651	1,583
	3 (W)		2.5 s 2.5 s	621	966
	4 (R)	VI 26.67 VI 13.33	3.33 s 1.67 s	1,286	536
	4 (G)		1.67 s 3.33 s	284	2,430
	4 (W)		2.5 s 2.5 s	439	1,205
	5 (R)	VI 20 VI 20	3.33 s 1.67 s	1,540	473
	5 (G)		1.67 s 3.33 s	612	1,800
	5 (W)		2.5 s 2.5 s	913	967
	6 (R)	RI 13.55 RI 38.17	3.33 s 1.67 s	2,366	150
	6 (G)		1.67 s 3.33 s	1,066	1,682
	6 (W)		2.5 s 2.5 s	1,245	521
	7 (R)	RI 38.17 RI 13.55	3.33 s 1.67 s	567	1,256
	7 (G)		1.67 s 3.33 s	17	4,283
	7 (W)		2.5 s 2.5 s	205	2,114
	8 (R)	RI 17.06 RI 24.15	3.33 s 1.67 s	1,836	428
	8 (G)		1.67 s 3.33 s	255	3,090
	8 (W)		2.5 s 2.5 s	1,135	1,024
	9 (R)	RI 24.15 RI 17.06	3.33 s 1.67 s	1,564	752
	9 (G)		1.67 s 3.33 s	86	3,109
	9 (W)		2.5 s 2.5 s	821	1,561
	10 (R)	RI 20 RI 20	3.33 s 1.67 s	1,590	417
	10 (G)		1.67 s 3.33 s	197	2,225
	10 (W)		2.5 s 2.5 s	875	1,088
	11 (R)	VI 13.33 VI 26.67	3.33 s 1.67 s	2,089	206
	11 (G)		1.67 s 3.33 s	974	1,307
	11 (W)		2.5 s 2.5 s	1,387	811
	12 (R)	VI 26.67 VI 13.33	3.33 s 1.67 s	1,661	718
	12 (G)		1.67 s 3.33 s	330	2,132
	12 (W)		2.5 s 2.5 s	893	1,275
961	1 (R)	VI 26.67 VI 13.33	3.33 s 1.67 s	2,156	1,966
	1 (G)		1.67 s 3.33 s	1,186	3,412
	1 (W)		2.5 s 2.5 s	1,539	2,956
	2 (R)	VI 13.33 VI 26.67	3.33 s 1.67 s	3,481	605
	2 (G)		1.67 s 3.33 s	2,241	2,055
	2 (W)		2.5 s 2.5 s	3,035	1,198

APPENDIX

(*Extended. Continued*)

TL	TR	eL	eR	tlL	tlR	tlxL	tlxR
1,909.61	1,170.13	73	71	149.75	116.00	117.58	83.96
163.35	3,555.23	51	93	85.83	127.76	61.00	135.04
1,141.91	1,890.14	72	72	116.24	113.98	81.51	91.55
5,444.73	6.68	137	7	148.88	99.60	142.88	41.38
2249.71	858.46	74	70	100.61	123.10	75.17	94.56
3479.61	186.00	88	56	123.94	90.72	107.49	67.86
1,826.43	1,110.27	70	74	140.70	128.18	73.14	70.93
66.15	3,990.71	53	91	67.45	106.70	21.46	73.54
417.16	2,923.17	63	81	94.93	96.93	46.67	80.61
3,103.15	329.61	85	59	125.81	114.46	87.09	47.29
301.15	3,364.48	55	89	85.83	115.20	31.14	73.61
1,931.01	1,101.12	73	71	108.87	110.96	57.54	81.13
3,722.83	142.71	95	49	108.49	102.97	95.57	52.36
893.73	2,221.36	70	74	84.13	105.06	61.43	61.54
3,145.01	341.62	86	58	92.81	97.17	76.98	57.86
2,499.45	711.22	75	69	102.38	98.22	87.40	67.75
83.40	3,868.83	49	95	67.96	87.86	51.82	96.84
1,615.01	1,413.60	73	71	77.36	69.34	54.53	80.85
3,358.02	284.53	93	51	58.43	66.82	44.75	27.15
1,834.85	1,166.36	74	70	82.81	118.92	50.77	71.78
2,537.03	868.82	71	73	37.28	96.32	40.55	46.66
1,227.48	2,031.73	71	73	80.98	44.09	71.62	50.61
254.53	3,514.12	54	90	76.85	116.45	46.62	93.73
670.52	2,615.57	66	78	84.25	72.07	64.43	62.63
3,107.24	490.12	86	58	73.35	61.09	58.88	28.19
1,101.45	2,129.44	73	71	95.07	108.92	60.39	52.66
1,287.85	2,022.63	67	77	61.84	77.76	50.07	42.13
2,168.26	1,026.21	74	70	75.05	73.50	61.01	47.01
329.62	3,445.77	52	92	81.42	113.24	45.68	76.75
937.18	2,383.91	64	80	71.05	83.20	45.59	62.07
2,898.54	725.44	78	66	96.02	90.25	82.06	25.99
740.13	2329.64	65	79	98.79	127.49	57.98	74.43
1,509.52	1,634.89	73	71	97.74	108.82	60.56	54.50
3,825.99	185.61	96	48	81.49	63.48	78.03	31.88
1,584.11	1,707.32	76	68	95.98	137.98	61.63	72.13
2,335.88	936.39	79	65	70.91	108.65	69.30	54.45
819.33	2,781.95	59	85	94.20	128.80	73.69	48.82
6.69	5,522.73	11	133	78.25	177.90	33.11	135.96
228.04	3,283.33	58	86	70.40	139.09	39.90	86.94
3,162.82	516.77	88	56	96.81	128.87	91.20	44.08
245.72	3,387.71	56	88	88.10	174.46	55.89	128.45
1,677.85	1,515.49	71	73	81.11	132.26	74.49	74.61
2,157.67	1,072.66	74	70	112.45	133.16	77.77	48.13
65.95	4,104.66	42	102	70.17	198.74	39.55	140.72
948.91	2,101.14	72	72	100.25	144.72	58.10	86.23
2,636.20	656.81	79	65	96.73	86.60	84.06	47.12
198.61	3,570.46	57	87	74.28	149.12	47.47	109.77
1,331.63	1,787.44	71	73	88.39	106.96	63.88	82.70
3,402.32	217.75	88	56	94.19	67.21	60.63	20.59
1,359.34	1,774.69	71	73	95.99	116.26	52.83	48.67
2,169.09	1,074.13	73	71	91.07	99.57	69.25	45.12
2,340.67	837.00	79	65	91.13	99.24	67.24	71.27
357.38	3,237.88	56	88	89.20	157.81	45.46	103.52
1,271.26	1,814.57	73	71	82.56	113.29	52.27	85.41
1,658.84	1,495.17	72	72	114.25	109.67	107.80	97.24
795.43	2,318.45	71	73	115.05	121.80	79.49	112.97
1,069.07	1,838.47	71	73	97.99	116.86	66.64	95.58
2,856.97	324.61	79	65	123.08	96.32	111.43	88.37
1,550.09	1,460.45	72	72	111.49	111.33	97.67	96.56
2,289.97	710.26	74	70	103.06	94.15	84.71	76.37

APPENDIX

(*Continued*)

Pigeon	Condition	Schedules	Reinforcement	BL	BR
	3 (R)	VI 32 VI 8	3.33 s 1.67 s	1,757	2,259
	3 (G)		1.67 s 3.33 s	619	4,060
	3 (W)		2.5 s 2.5 s	1,308	2,919
	4 (R)	VI 8 VI 32	3.33 s 1.67 s	4,762	374
	4 (G)		1.67 s 3.33 s	2,630	1,271
	4 (W)		2.5 s 2.5 s	3,356	686
	5 (R)	VI 20 VI 20	3.33 s 1.67 s	3,130	1,304
	5 (G)		1.67 s 3.33 s	1,461	3,560
	5 (W)		2.5 s 2.5 s	2,541	1,910
	6 (R)	RI 24.15 RI 17.06	3.33 s 1.67 s	2,353	2,134
	6 (G)		1.67 s 3.33 s	1,323	3,420
	6 (W)		2.5 s 2.5 s	1,653	2,698
	7 (R)	RI 17.06 RI 24.15	3.33 s 1.67 s	3,543	756
	7 (G)		1.67 s 3.33 s	1,402	3,565
	7 (W)		2.5 s 2.5 s	2,402	2,144
	8 (R)	RI 38.17 RI 13.55	3.33 s 1.67 s	1,070	3,283
	8 (G)		1.67 s 3.33 s	359	4,356
	8 (W)		2.5 s 2.5 s	691	3,727
	9 (R)	RI 13.55 RI 38.17	3.33 s 1.67 s	4,488	289
	9 (G)		1.67 s 3.33 s	2,175	1,534
	9 (W)		2.5 s 2.5 s	3,359	678
	10 (R)	RI 20 RI 20	3.33 s 1.67 s	3,241	728
	10 (G)		1.67 s 3.33 s	1,403	2,225
	10 (W)		2.5 s 2.5 s	2,168	1,384
	11 (R)	VI 13.33 VI 26.67	3.33 s 1.67 s	4,342	452
	11 (G)		1.67 s 3.33 s	1,695	2,313
	11 (W)		2.5 s 2.5 s	2,460	1,264
	12 (R)	VI 26.67 VI 13.33	3.33 s 1.67 s	2,759	1,605
	12 (G)		1.67 s 3.33 s	518	3,680
	12 (W)		2.5 s 2.5 s	1,650	3,155

APPENDIX

(*Extended. Continued*)

TL	TR	eL	eR	tlL	tlR	tlxL	tlxR
1,497.70	1,526.66	71	73	95.77	71.03	70.61	77.88
370.47	3,029.28	64	80	93.03	82.50	50.49	82.16
842.83	2,286.37	71	73	85.31	58.91	47.17	77.77
3,279.50	229.35	83	61	76.87	105.47	103.90	47.07
2,086.49	963.59	76	68	99.65	121.33	101.25	58.80
2,834.13	460.33	76	68	78.17	101.14	84.62	30.75
2,276.76	831.81	76	68	108.22	115.36	83.09	73.91
852.47	2,240.46	68	76	123.31	113.79	73.30	80.99
1,821.44	1,264.07	72	72	105.36	102.98	63.54	72.66
1,853.60	1,357.16	72	72	111.46	110.83	74.00	77.69
801.02	2,372.17	71	73	107.26	109.66	57.42	83.96
1,157.55	1,764.68	72	72	99.21	109.92	64.19	82.58
2,892.69	390.08	80	64	94.39	96.62	89.53	53.13
794.05	2,237.27	70	74	102.97	120.19	65.22	72.59
1,801.47	1,318.78	72	72	99.33	111.58	68.26	66.52
781.82	2356.92	67	77	115.37	114.25	67.97	91.63
153.47	3172.91	66	78	99.95	113.54	40.83	97.06
376.22	2779.15	67	77	104.84	105.54	52.38	99.99
3,487.14	188.30	91	53	93.58	87.68	92.59	38.66
1,804.57	1,455.43	74	70	89.38	104.43	70.82	62.47
2,882.76	542.91	80	64	89.57	100.01	82.80	41.53
2,654.92	478.79	79	65	92.60	101.57	70.47	50.83
1,147.05	1,976.01	72	72	96.25	102.44	51.24	73.36
2,018.59	1,006.13	74	70	91.37	103.62	60.93	50.87
3,252.29	267.86	89	55	130.09	97.82	100.52	68.76
1,317.34	1,720.52	69	75	108.40	110.43	76.26	78.80
2,224.70	731.21	70	74	118.95	106.08	88.17	56.52
2,156.86	934.95	74	70	129.20	105.52	95.65	89.62
500.01	2,602.36	65	79	112.23	103.27	76.38	92.35
1,230.76	1,852.12	70	74	118.86	118.45	85.40	106.28