

*INDEPENDENCE OF REINFORCEMENT DELAY AND  
MAGNITUDE IN CONCURRENT CHAINS*

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A three-component concurrent-chains procedure was used to investigate preference between terminal-link schedules that differed in delay and magnitude of reinforcement. Response and time allocation data were well described by a generalized matching model. Sensitivity to delay appeared to be lower when reinforcement magnitudes were unequal than when they were equal, but when obtained rather than programmed time spent responding in the initial links was used in the model, the difference vanished. The results support independence of delay and magnitude as separate dimensions of reinforcement value, as required by the matching law, and the assumption of the contextual choice model (Grace, 1994) that sensitivities to delay and magnitude are affected similarly by temporal context. Although there was statistical evidence for interaction between successive components, the effects were small and transient. The multiple-component concurrent-chains procedure should prove useful in future research on multidimensional preference, although it may be necessary to control obtained initial-link time more precisely.

*Key words:* concurrent chains, self-control, reinforcer magnitude, delay of reinforcement, choice, matching law, key peck, pigeons

Perhaps the most significant extension of the matching law—with the possible exception of Herrnstein's (1970) quantitative law of effect—is Baum and Rachlin's (1969) suggestion that different independent variables could be combined to form an intervening variable of reinforcement value:

$$\frac{B_L}{B_R} = \frac{R_L \cdot M_L \cdot 1/D_L}{R_R \cdot M_R \cdot 1/D_R} = \frac{V_L}{V_R} \quad (1)$$

As applied to concurrent schedules,  $B_L$  and  $B_R$  represent behavior maintained by left and right schedules and can be measured as number of responses or time allocated. Baum and Rachlin's matching law states that the ratio of behavior equals the ratio of value received from the schedules,  $V_L/V_R$ . In turn, value is defined as the multiplicative combination of three independent variables—reinforcement rate ( $R$ ), magnitude ( $M$ ), and immediacy ( $1/D$ , the reciprocal of delay). Equation 1 is the matching law made multidimensional, because it specifies how independent dimensions of reinforcement combine to determine

preference. Anticipating developments such as the generalized matching law (Baum, 1974), in which ratios in Equation 1 are transformed by power functions, Killeen (1972) noted that when arbitrary functional transformations are permitted for the independent variables, the theoretical content of the matching law is simply that an additive utility model (Tversky, 1969) is the best mathematical description of choice. The cardinal assumption of the additive model is that different variables, such as delay and magnitude of reinforcement, do not interact.

Davison and McCarthy (1988) noted that a complete test of Equation 1, with five different levels of each independent variable, required 125 experimental conditions. It is not surprising, then, that a two-dimensional paradigm has been more popular: choice between alternatives that differ in delay and magnitude, commonly referred to as the study of "self-control." When a subject chooses between a larger, delayed reinforcer and a smaller, more immediate reinforcer, it is said to demonstrate self-control if the larger reinforcer is chosen. Conversely, a subject shows "impulsiveness" if the smaller, more immediate reinforcer is chosen (see Logue, 1988, for review).

Early research successfully tested the prediction of Equation 1 that if the difference in delays to small and large reinforcers remained constant while absolute delay varied,

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subjects would prefer the smaller, more immediate reinforcer at short delay durations but would reverse their preference and choose the larger, delayed reinforcer at greater absolute durations (Ainslie, 1974; Rachlin & Green, 1972). This is a qualitative prediction that has been repeatedly confirmed (Ainslie & Herrnstein, 1981; Green, Fisher, Perlow, & Sherman, 1981; White & Pipe, 1987). Other research on self-control has been more quantitative, attempting to find the optimal mathematical description of choice between alternatives differing in amount and delay (Green & Snyderman, 1980; Ito & Asaki, 1982; Snyderman, 1983). Logue, Rodriguez, Peña-Correal, and Mauro (1984) suggested that an extension of the generalized matching law could accurately describe most of the data from these studies:

$$\frac{B_L}{B_R} = b \left( \frac{\mu_R}{\mu_L} \right)^{a_2} \left( \frac{M_L}{M_R} \right)^{a_3}. \quad (2)$$

In Equation 2 (which is a different but equivalent form to that used by Logue et al.),  $\mu_L$  and  $\mu_R$  are the average delays to reinforcement, and  $M_L$  and  $M_R$  are the reinforcement magnitudes for the left and right alternatives. There are three parameters: bias,  $b$ , which represents a proportional preference for either alternative due to factors such as position preference, and the exponents,  $a_2$  and  $a_3$ , which represent the sensitivity of behavior to changes in the delay and magnitude ratios, respectively. Equation 2 can be applied by taking logarithms of both sides and performing a multiple regression to estimate values for  $b$ ,  $a_2$ , and  $a_3$ . (In Logue et al.'s original equation, the delays were fixed; here the assumption is made that variable schedules of delays can be modeled as well.)

However, other research poses a serious difficulty for the generalized matching approach to self-control in Equation 2. Navarick and Fantino (1976) found that when the delays to the smaller and larger reinforcers were equal, preference for the larger reinforcer increased as delay increased, a result replicated by Ito and Asaki (1982). Ito (1985) obtained undermatching of relative response rate to relative reinforcement magnitude with short delays but obtained overmatching with long delays. Finally, White and Pipe (1987) showed that with unequal delays, sensitivity to mag-

nitude ( $a_3$ ) increased as absolute delay duration increased. These results cannot be explained by Equation 2, which assumes that preference is determined by the ratio of delays irrespective of their absolute values.

Such results are common in the concurrent-chains procedure, in which access to one of two mutually exclusive schedules ("terminal links") reinforces responding on concurrently available schedules ("initial links"). In concurrent chains, relative duration of initial and terminal links strongly affects preference. When initial links are increased, preference between a constant pair of terminal-link schedules moves toward indifference; that is, sensitivity to delay ( $a_2$ ) decreases (Fantino, 1969). When terminal links are increased, preference between terminal links in constant ratio increases; that is,  $a_2$  increases (MacEwen, 1972; Williams & Fantino, 1978). Although the matching law (Equation 1) was originally developed for simple concurrent schedules, whenever delay to reinforcement is manipulated the procedure is really a concurrent-chains arrangement. It is therefore not surprising that sensitivity to magnitude ( $a_3$ ) increases as absolute delay increases (White & Pipe, 1987).

Grace (1994) proposed an extension of the generalized matching law that represents the effect of relative initial- and terminal-link duration on preference as a model for concurrent chains. He showed that when terminal-link ratios were raised to an additional power—the ratio of the average time spent in the terminal and initial links per reinforcement—the model accurately described the results of a large number of concurrent-chains experiments. If terminal-link delay and magnitude are varied with initial links constant and equal, the following equation is obtained:

$$\frac{B_L}{B_R} = b \left[ \left( \frac{\mu_R}{\mu_L} \right)^{a_2} \left( \frac{M_L}{M_R} \right)^{a_3} \right]^{(Tt/Ti)}. \quad (3)$$

Equation 3 is called the contextual choice model, because it specifies how temporal context ( $Tt/Ti$ ) affects preference.  $Tt$  and  $Ti$  are the average times spent in the terminal and initial links per reinforcement. According to this model, effective sensitivities to delay and magnitude,  $a_2(Tt/Ti)$  and  $a_3(Tt/Ti)$ , will decrease as initial links increase relative to ter-

minal links (Fantino, 1969) and will increase as terminal links increase relative to initial links (Williams & Fantino, 1978). Equation 3 predicts the results of Navarick and Fantino (1976) and White and Pipe (1987) (the apparent interaction of sensitivity to magnitude and absolute delay duration) that are unexplained by the generalized matching model.

The contextual choice model and the generalized matching model (Equation 2) share with Equation 1 the fundamental assumption of the matching law that delay and magnitude are separate, independent dimensions of reinforcement value. Given the importance of this assumption, it is remarkable that it has been directly tested, with animal subjects, only once. Rodriguez and Logue (1986) arranged four different reinforcer magnitude and delay ratios and overall found no statistical evidence for an interaction (1 pigeon out of 8 had a significant interaction term). Logue, Forzano, and Tobin (1992) replicated this result with human subjects. However, it is possible that a magnitude–delay interaction may result if a different testing procedure is used. Such a result would present a serious challenge to models of preference based on the matching law, because it would contradict independence of delay and magnitude.

Specifically, sensitivity to one variable may be lower when values on a second variable are different than when values on the second variable are the same. This is a common finding in studies of human preference between multidimensional alternatives (Tversky, 1972). Cognitively oriented explanations of this phenomenon might stress the greater “information processing” demand placed on the subject when there are differences on more than one dimension; alternatively, it could be explained as selective attention, a failure of stimulus control. Regardless, Rodriguez and Logue (1986) did not test for same-different interactions, and given the importance of the delay–magnitude independence assumption for the matching law, it should be tested.

Another important limitation of previous research is simply that insufficient parametric data have been collected to test models based on the matching law (such as Equations 2 and 3) rigorously. Green and Snyderman (1980) studied only six conditions per subject; Snyderman (1983) studied eight. Rodriguez and

Logue (1986) examined 16, but the variance accounted for in their data by Equation 2, averaged across subjects, was only 84%; this falls short of the description given by the generalized matching law for concurrent schedules (Baum, 1979) or by the contextual choice model for concurrent-chains data (Grace, 1994). White and Pipe (1987) obtained a large amount of data by arranging three components within a session but did not use a stability criterion, conducting 20 sessions per condition, and some of their data were more variable than Rodriguez and Logue’s, although the overall effect reported (increase in sensitivity to magnitude) was clear.

The primary goals of the present research were therefore (a) to develop a concurrent-chains procedure optimized for producing high-quality parametric data on choice between multidimensional alternatives and (b) to test independence of reinforcement delay and magnitude by determining whether sensitivity to delay would change depending on whether magnitudes were equal or unequal. Three components, whose order varied randomly, were arranged within a session. Each component scheduled 12 left and 12 right terminal-link entries in an irregular order. The components differed only in key color and in the magnitude of reinforcers for the left and right terminal links. In one component the left terminal link delivered a small reinforcer and the right terminal link delivered a large reinforcer, in the second component this was reversed, and in the third the magnitudes were equal. Across conditions, the terminal-link schedules were varied while remaining constant for components within a session. This allowed five-point generalized matching lines relating preference to delay to be obtained for three different levels of magnitude in five conditions. All components within each condition were continued to a stability criterion.

Consistency within components and separation between components were enhanced by the use of a single color for all stimuli within a given component and a 3-min intercomponent blackout. Initial-link schedules were constant across conditions, a single variable-interval (VI) 20 s, and terminal-link schedule values always summed to 50 s. In this way programmed  $T_i/T_j$  in Equation 3 was constant,

which Grace (1994) suggested as a way to optimize concurrent chains for preference scaling; when temporal context is constant across conditions, the effects of terminal-link parameters on initial-link allocation should be maximally clear. Finally, the procedure arranged VI terminal links, because in nearly all previous research on choice between alternatives differing in magnitude and delay, fixed-delay terminal links have been used (but see Cheloni, King, Logue, & Tobin, 1994).

## METHOD

### *Subjects*

Four White Carneau pigeons (numbered 960, 963, 969 and 967) participated as subjects, and were maintained at 85% ad libitum weight  $\pm$  15 g. All had previous experience with a variety of multiple- and concurrent-schedule procedures.

### *Apparatus*

Four standard three-key operant conditioning chambers (35 cm deep by 35 cm wide by 35 cm high) were used. The keys were 26 cm above the floor and could be transilluminated red, green, or white. Each chamber was equipped with a houselight 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. A force of approximately 0.10 N was required to operate a key, which resulted in an audible feedback click. Each chamber was enclosed in a sound-attenuating box and fitted with a ventilation fan for masking extraneous noises. Event scheduling and data recording were controlled with a MEDSTATE<sup>®</sup> notation program and a MED-PC<sup>®</sup> system interfaced to an IBM<sup>®</sup>-compatible microcomputer.

### *Procedure*

*Preliminary training.* Because subjects were experienced, only several sessions of magazine training and autoshaping were necessary before a concurrent-schedule procedure was instituted. The side keys were illuminated either red, green, or white. When a single VI 10-s schedule timed out, a reinforcer (3 s magazine duration) was assigned with equal probability to either the left or right key. No

changeover delay (COD) was arranged, key colors appeared equally often, and 72 reinforcers were delivered in a session. Because steady responding was maintained for all subjects after three sessions, a multiple-component concurrent-chains procedure (as described below) with a VI 10-s initial-link schedule and equal VI 5-s terminal-link schedules was begun. After six sessions, a 1.5-s COD was imposed during the initial links. Finally, after three more sessions the initial-link schedule was increased to VI 20 s and the terminal-link schedules to VI 25 s; these schedules served as the baseline condition for the experiment.

*Concurrent-chains procedure.* A multiple-component concurrent-chains procedure was used. Every session consisted of three different components, defined by the color with which the side keys were illuminated (red, green, or white). Components finished after 24 initial-link and terminal-link cycles, each terminating in reinforcement. Components were separated by a 3-min blackout during which all keylights and the houselight were extinguished, and the order of the components within the session varied randomly from day to day. Components differed only in the color of the side keys and the reinforcement magnitude (duration of access to grain) for left and right terminal-link responses. For all conditions (except a brief reversal that will be discussed below), the red-key component arranged a small reinforcer for the left and a large reinforcer for the right terminal link, and the green-key component arranged a large reinforcer for the left and a small reinforcer for the right terminal link. Reinforcer magnitudes were equal in the white-key component except for two conditions. Sessions terminated after three components had been completed or 120 min had elapsed, whichever occurred first. Sessions were conducted 7 days a week.

At the start of a cycle, the side keys were illuminated the same color (red, green, or white), signifying 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 the terminal link on each side were arranged during the component. An initial-link response was reinforced by terminal-link entry, provided that (a) it was to the preselected key; (b) a VI 20-s schedule

had timed out; and (c) a 1.5-s COD was satisfied, that is, at least 1.5 s had elapsed between the response in question and the first response since changeover on the side that terminal-link entry was arranged.

For each cycle, the VI 20-s schedule did not begin timing until the first peck to either initial-link key occurred. This allowed postreinforcement pauses to be recorded separately and not counted toward the completion of initial-link schedule requirements. The initial-link VI 20-s schedule contained 12 intervals constructed from an arithmetic progression,  $a, a + d, a + 2d, \dots$ , in which  $a$  equals one 12th and  $d$  equals one sixth the schedule value. The intervals were sampled such that all 12 intervals preceded left and right terminal-link entries exactly once per component.

Terminal-link entry was signaled by a change in the keylight from continuous to blinking illumination, coupled with the other keylight being extinguished. Keylights blinked at the rate of twice per second during terminal links (0.25 s off, 0.25 s on). Terminal-link responses were reinforced according to VI schedules containing 12 intervals constructed from geometric progressions (Fleshler & Hoffman, 1962). Schedules varied for the left and right terminal links across experimental conditions but were constant for the three components within each session. The terminal-link VI schedules were sampled such that each interval was selected exactly once per component. When a terminal-link response was reinforced, the keylight and houselight were extinguished and the grain magazine was raised and illuminated for a specified duration. After reinforcement the houselight and initial-link keylights were reilluminated and the next cycle began, unless the 24th reinforcer in the component had just been delivered, in which case a 3-min intercomponent blackout began.

Experimental conditions were maintained for each bird until a stability criterion for each component had been reached five, not necessarily consecutive, times. The criterion was that the median relative initial-link response rate during the last five sessions did not differ by more than .05 from the median for the five immediately preceding sessions. Typically, performance remained stable with-

Table 1

Left and right terminal-link VI schedules for each experimental condition. The order of presentation for each bird is given in parentheses, followed by the number of sessions. Magnitudes arranged on the left and right keys within each component for a condition are as follows: Set A = red 1.5 s 4.5 s; green 4.5 s 1.5 s; white 3 s 3 s; Set B = red 1 s 5 s; green 5 s 1 s; white 3.5 s 2.5 s; Set C = red 2 s 4 s; green 4 s 2 s; white 2.5 s 3.5 s.

VI(s)		Rein- forcer magni- tude	Bird			
Left	Right		960	963	969	967
25	25	Set A	(2) 40	(2) 40	(1) 40	(2) 40
40	10	Set A	(1) 25	(3) 24	(5) 27	(3) 24
10	40	Set A	(3) 24	(1) 30	(2) 34	(1) 30
33.33	16.67	Set A	(4) 24	(5) 22	(3) 28	(5) 18
16.67	33.33	Set A	(5) 18	(4) 20	(4) 20	(4) 21
25	25	Set B	(6) 18	(6) 22	(6) 20	(6) 18
25	25	Set C	(7) 24	(7) 26	(7) 37	(7) 24

in components that met the criterion five times before the condition was changed.

The primary dependent variables recorded were the absolute and relative initial-link response rates and initial-link time allocation, as measured by time from first peck on a side until first peck on the other side (excluding any postreinforcement pauses). In addition these values were recorded separately for each component quarter (i.e., six cycles). Also recorded were initial-link postreinforcement pauses and terminal-link obtained times until reinforcement. All data analyzed, except where noted, were summed over the last five sessions in stability.

Table 1 lists the experimental conditions, order of presentation, and number of sessions for each bird. The initial-link schedule for all conditions was VI 20 s, and the terminal-link schedule values always summed to 50 s. Therefore the programmed average time spent responding, per cycle, in the initial and terminal links was equal across all conditions. Conditions were designed to provide parametric data on choice as a function of relative mean terminal-link delay to reinforcement (i.e., terminal-link reinforcement rate) at three different magnitude configurations: left small/right large, left large/right small, and equal magnitudes. Two final conditions were arranged to explore different magnitude ratios.

Training began with equal VI 25-s terminal links as a baseline, and the magnitudes of re-

Table 2

Estimated parameters ( $b$ , bias;  $a_2$ , sensitivity to reinforcer delay;  $a_3$ , sensitivity to reinforcer magnitude) and variance accounted for (VAC) by extension of generalized matching law (Equation 2) when fitted to molar data. Fits were performed for both response and time allocation data from all conditions, from just the conditions with equal reinforcer magnitudes, and from just the conditions with unequal magnitudes.

Conditions	Dependent variable	Bird 960				Bird 963			
		$b$	$a_2$	$a_3$	VAC	$b$	$a_2$	$a_3$	VAC
All	Response	1.15	1.01	1.42	0.94	1.24	1.04	1.70	0.94
All	Time	1.15	1.22	1.72	0.94	1.27	1.16	2.03	0.95
Equal magnitude	Response		1.21		0.90		1.59		0.98
Unequal magnitude	Response		0.90		0.96		0.74		0.96
Equal magnitude	Time		1.54		0.87		1.73		0.96
Unequal magnitude	Time		1.06		0.96		0.81		0.97

inforcement set as follows: red: 1.5 s left, 4.5 s right; green: 4.5 s left, 1.5 s right; white: 3 s left, 3 s right. The initial plan of the experiment was to use a fixed number of sessions for each condition rather than a stability criterion; therefore, to explore several different session totals, subjects were trained with terminal links of VI 25 s VI 25 s for 20 sessions, followed by VI 10 s VI 40 s for 30 sessions and VI 40 s VI 10 s for 25 sessions. Then a color reversal was arranged for 15 sessions. Data for Birds 963 and 967 in the VI 10-s VI 40-s condition and Bird 960 for the VI 40-s VI 10-s condition met the stability criterion and were used. Conditions that were not stable were replicated, and all subsequent conditions employed stability criteria. Only conditions that met the stability criterion are listed in Table 1.

The color reversal was an attempt to determine to what extent stimulus-reinforcer relations were arbitrary in the procedure. The terminal-link schedules were VI 25 s VI 25 s, and the magnitudes were set as follows: red: 4.5 s left, 1.5 s right; green: 1.5 s left, 4.5 s right; white: 3 s left, 3 s right. After 15 sessions of color reversal training, subjects' preferences had changed in the predicted direction, but not nearly as rapidly as the transition from VI 10 s VI 40 s to VI 40 s VI 10 s had been accomplished previously with the magnitudes unchanged. Because a primary goal of the experiment was to develop a multiple-component concurrent chain capable of producing data more rapidly than traditional single-component procedures, no further reversals were performed. The magnitudes were set at their original values (producing

the baseline condition) and 40 sessions of training were given, at which point all birds had reached stability at preference levels comparable to prereversal baseline.

The performances of Bird 969 were more erratic than those of the other birds, especially in early conditions, and it was observed that response topography was responsible. Bird 969 usually pecked at the rim rather than at the center of the keys, and ballistic head movements sometimes failed to make sufficient contact. Right-key pecking seemed to be more affected than left-key pecking. Although the data were generally orderly, at times the problem was exacerbated and Bird 969 failed to complete a session. Because the problem topography was correlated with a reduction in overall response rate, it was decided prior to the 40-session baseline recovery condition that only data from sessions in which 1,500 or more initial-link responses occurred, summed over components, were to be used for this bird. Later in training, response topography improved and only rarely were sessions discarded.

## RESULTS

Dependent variables analyzed were initial-link response and time allocation. These data, and other recorded measures such as cumulative initial-link time and postreinforcement pauses, are listed in the Appendix for all subjects and all conditions. Obtained rather than arranged terminal-link mean delays to reinforcement (i.e., reinforcement rates) were analyzed. Because subjects generally responded at a high rate during the terminal

Table 2  
(Extended)

Conditions	Dependent variable	Bird 969				Bird 967			
		$b$	$a_2$	$a_3$	VAC	$b$	$a_2$	$a_3$	VAC
All	Response	1.26	1.03	1.47	0.91	1.90	0.97	1.49	0.94
All	Time	1.69	1.07	1.65	0.94	2.90	0.78	1.35	0.92
Equal magnitude	Response		1.36		0.84		1.08		0.97
Unequal magnitude	Response		0.87		0.94		0.92		0.94
Equal magnitude	Time		1.49		0.90		0.89		0.86
Unequal magnitude	Time		0.92		0.92		0.72		0.93

links, the obtained times were close to the arranged times.

The first question is whether the molar data are well described by the extension of the generalized matching law proposed by Logue et al. (1984) for choice between alternatives differing in magnitude and delay (Equation 2). This is expected if the multiple-component concurrent-chains procedure is comparable to traditional single-component procedures, because the generalized matching equation has succeeded with previous data (Logue, 1988).

Table 2 shows the estimated parameter values and variance accounted for by the generalized matching model (Equation 2). Fits were performed, using both response and time allocation dependent variables, for the data from all seven conditions (21 data points) together. Then, using the estimated values of  $b$  and  $a_3$  (sensitivity to magnitude) for the entire data set, values of  $a_2$  (sensitivity to delay) were estimated separately for data from the unequal-magnitude components (red and green components from the first five conditions and all components for the last two conditions; 16 data points) and data from the equal-magnitude components (white components from the first five conditions). This was done to determine whether sensitivity to delay would change depending on whether magnitudes were equal or unequal.

From Table 2 it is clear that overall, the data were well described by the generalized matching model. Measures of variance accounted for by the model were consistently

above 90%, averaging 93.25% for response and 93.75% for time data across subjects. Although time allocation in concurrent chains has been considered an inferior measure of preference (Davison & McCarthy, 1988), here the quality of the fits to the time and response allocation data were comparable. The data fits for Bird 969 showed the largest improvement in variance accounted for in time versus response data, which is consistent with the response-topography problems for this bird noted previously. For 3 of 4 birds, time allocation sensitivities were consistently greater than response sensitivities, consistent with previous research (Davison, 1983). For Bird 967, sensitivities for time data were slightly lower than for response data.

A major objective of the present study was to determine whether sensitivity to delay would be affected by magnitude of reinforcement; specifically, it was anticipated that sensitivity might be greater when magnitudes were equal than when they were unequal. The fits in Table 2 seem to indicate that this effect was obtained. For all 4 subjects, estimated values of  $a_2$ , sensitivity to delay, were greater for the equal-magnitude data set than for the unequal-magnitude data set. This result held for both response and time allocation. The effect was rather small for Bird 967 but was strikingly large for Bird 963, whose values of  $a_2$  for the equal set were more than twice the values for the unequal set.

The data can be analyzed in more detail by plotting log response and log time allocation ratios as functions of log obtained immediacy ratios separately for each magnitude config-

uration. Figures 1 and 2 show, for both response and time data for each bird, three generalized matching functions, based on a 1:3 magnitude ratio (red component), a 1:1 magnitude ratio (white component), and a 3:1 magnitude ratio (green component). The lines in each panel depict the least squares regression equation. The slope of each line corresponds to  $a_2$  (sensitivity to delay). Intercept values reveal the effect of differential magnitude; as expected, all unequal-magnitude data are biased in favor of the large-magnitude side. The interaction effect is demonstrated by greater slopes for the middle panels (1:1) than for the side panels (1:3, 3:1). For 3 of 4 birds (960, 963, 969), for both response and time data middle-panel slopes were greater than both side-panel slopes. Bird 967 was the exception to this pattern. Although the overall fits in Table 2 indicated that the interaction effect was present for Bird 967, albeit smaller than that obtained with the other birds, this bird's response and time slopes for the 1:3 data were somewhat greater than those for the 1:1 data.

In general, the slopes for the 1:3 and 3:1 data were comparable for each bird, a result that is expected if delay and magnitude are separate dimensions of reinforcement. The largest discrepancy occurred for the response allocation slope for Bird 969 in the 3:1 condition, which was abnormally low at 0.57. However, this may have been caused by Bird 969's response topography problems, which affected pecking more on the right than on the left. Preference was strongly biased to the left side in the 3:1 ratio components; apparently the increased sampling variability due to the topography problem was more detrimental at low levels of right-key responding.

Nevertheless, the data from Figures 1 and 2 seem to indicate that a delay-magnitude interaction effect was present for 3 of the 4 birds. Such a result, if firmly established, would be an important limitation for models of preference based on the matching law because it would imply that delay and magnitude are not separate dimensions of reinforcement. Instead, delay and magnitude interact in a way that could be described, but not explained, by the matching law. Before reaching this conclusion, it is important to consider other explanations.

There are at least two possibilities. First, the

decreased sensitivity in the unequal-magnitude components may result from interdependent scheduling. An equal number of terminal-link entries were arranged for each side; therefore, as preference became more extreme, more time should have been spent responding in the initial links. Because it is well established in concurrent chains that sensitivity decreases as time spent in the initial links increases (Fantino, 1969), this could explain the apparent interaction. This can be investigated by fitting the contextual choice model (Equation 3; Grace, 1994), which incorporates effects of relative initial- and terminal-link duration, to the data and determining if the difference in slopes is still obtained.

A second possibility is that the difference in sensitivity is produced by successive interaction between the components within a session. McLean (1988) demonstrated that successive independence of multiple concurrent-schedule components was robust; however, this result may not hold for concurrent chains. The difficulty encountered in the color reversal, described previously, indicates that stimulus-reinforcer contingencies maintain behavior that is highly resistant to change in this procedure. Nevin, Mandell, and Whittaker (1978) obtained induction in a multiple discrete-trial concurrent schedule. They found that allocation in a constant component shifted in the direction of reinforcers in the varied component. Although in the present experiment components were separated by a 3-min blackout, it is possible that induction effects still might have occurred; for example, a green-key component might have produced an increase in left-key responding in the following white-key component. If induction effects on behavior in the white-key component were different between preceding red-key and green-key components (i.e., if induction was produced only by the component with the large reinforcer and smaller delay on the same side), then increased sensitivity might result in the white-key component, relative to red-key and green-key components, producing an apparent interaction.

The possibility that the interaction may be due to an increase in initial-link time will be investigated first. To determine if time spent responding in the initial links varied as a function of preference, cumulative initial-link



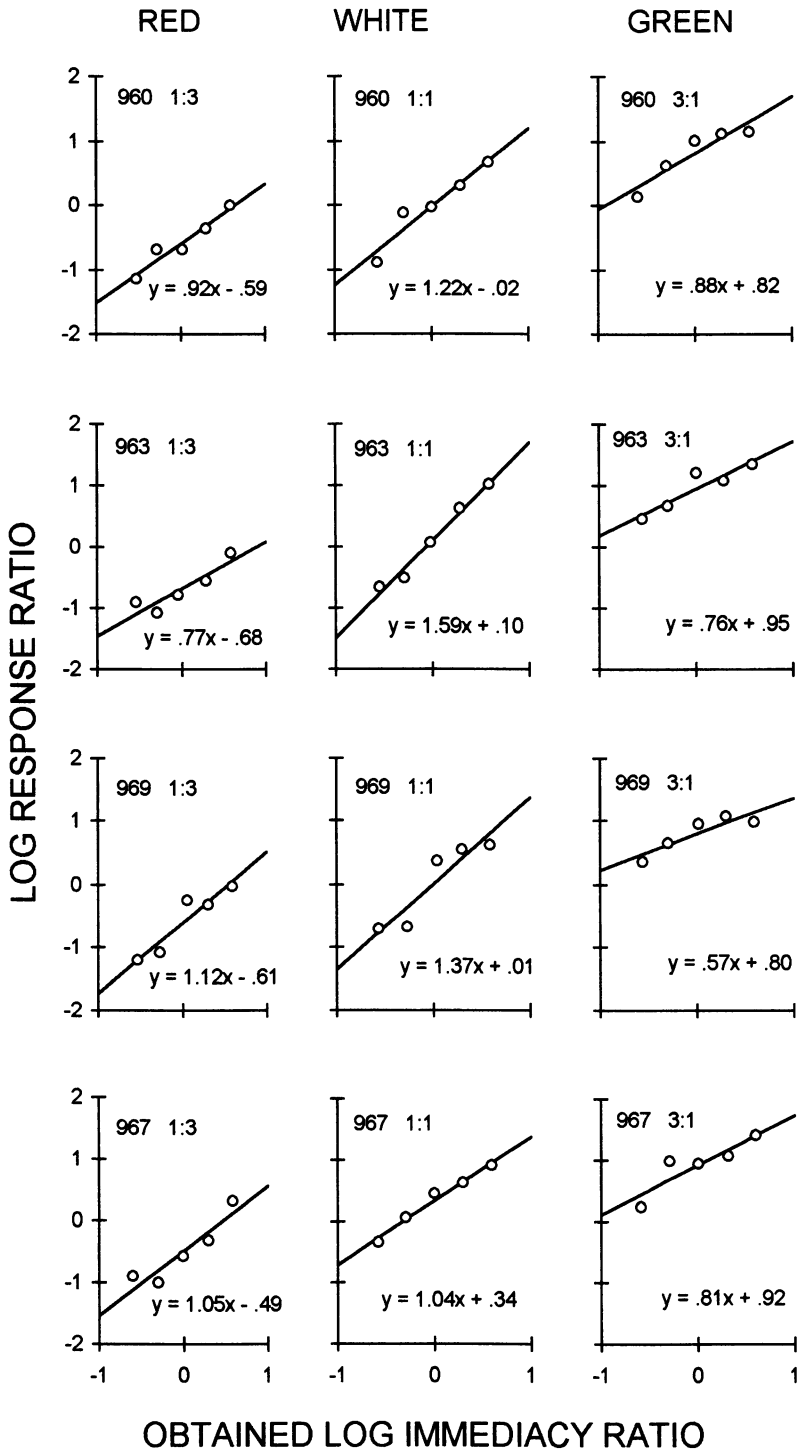


Fig. 1. Log obtained terminal-link immediacy ratio (ratio of reciprocal of mean terminal-link delays to reinforcement) plotted against log behavior ratio. There are three plots for each subject, corresponding to the red-key component (1:3 reinforcement magnitude ratio; 1.5 s left, 4.5 s right), white-key component (1:1 ratio; 3 s left, 3 s right), and green-key component (3:1 ratio; 4.5 s left, 1.5 s right). The solid line in each panel is the least squares regression equation.

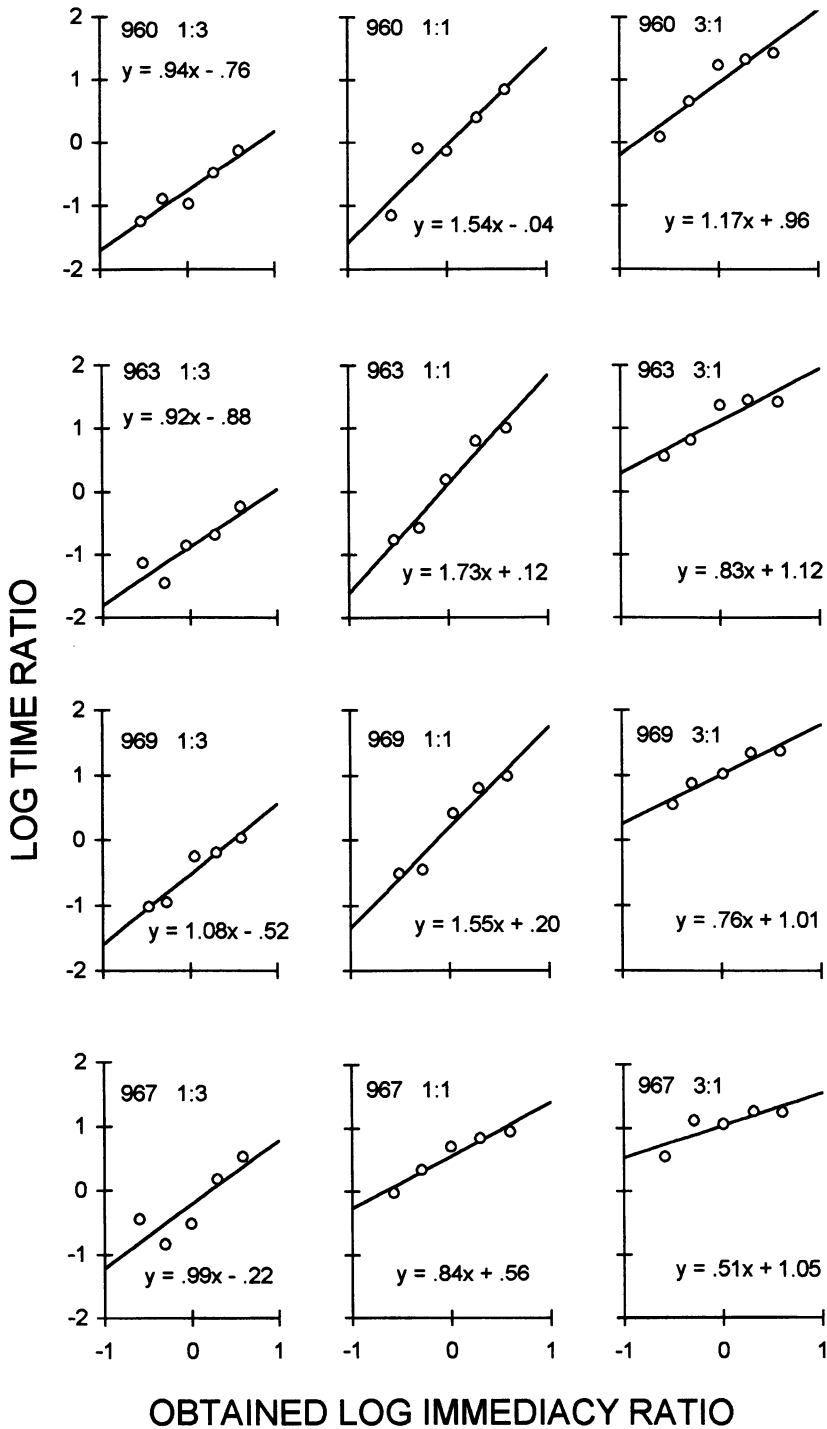


Fig. 2. Log obtained terminal-link immediacy ratio (ratio of reciprocal of mean terminal-link delays to reinforcement) plotted against log time allocation ratio. There are three plots for each subject, corresponding to the red-key component (1:3 reinforcement magnitude ratio; 1.5 s left, 4.5 s right), white-key component (1:1 ratio; 3 s left, 3 s right), and green-key component (3:1 ratio; 4.5 s left, 1.5 s right). The solid line in each panel is the least squares regression equation.

times were divided by the number of cycles within each component to produce a “mean  $T_i$ ” value, that is, the average time spent responding in the initial link per reinforcement. Mean  $T_i$  values were calculated both with and without postreinforcement pauses and are plotted in Figure 3 as a function of the logarithm of response ratios. Figure 3 clearly reveals that, for all subjects, mean  $T_i$  increased with magnitude of preference, that is, with the absolute value of the log response ratio. Comparison of the left and right panels shows that when pauses were excluded the data much more closely approximated a U-shaped function.

Even though an attempt was made to minimize the effect of temporal context by keeping average programmed initial- and terminal-link durations constant across conditions, variation in obtained  $T_i$  may have affected preference. Effect of  $T_i$  must be controlled for before differences in sensitivity to delay ( $a_2$ , Table 2) can unambiguously be attributed to a delay-magnitude interaction. Therefore a reanalysis of the response and time allocation data was conducted employing the contextual choice model, which incorporates effect of initial-link length on preference.

Table 3 presents an identical analysis to that in Table 2, except that Equation 3 was used instead of the generalized matching model (Equation 2). Postreinforcement pauses were excluded from  $T_i$  because of the better approximation to U-shaped functions in the right panels of Figure 3. Equation 3 provided a slightly better fit to the overall data, even though there was not much room for improvement in the overall fits in Table 2. Averaged across subjects, the variance accounted for by the contextual choice model was 94.25% for both response and time data.

When estimates of sensitivity to delay ( $a_2$ ) were made with the generalized matching model separately for the equal- and unequal-magnitude data sets in Table 2, estimates were greater for the equal-magnitude data than for the unequal-magnitude data, for both response and time data, for all 4 birds. In contrast, when  $a_2$  values were estimated with the contextual choice model, this consistent pattern disappeared. For Birds 960 and 967,  $a_2$  values were greater for the unequal data; for Bird 969, values remained greater in the equal data; and for Bird 963,

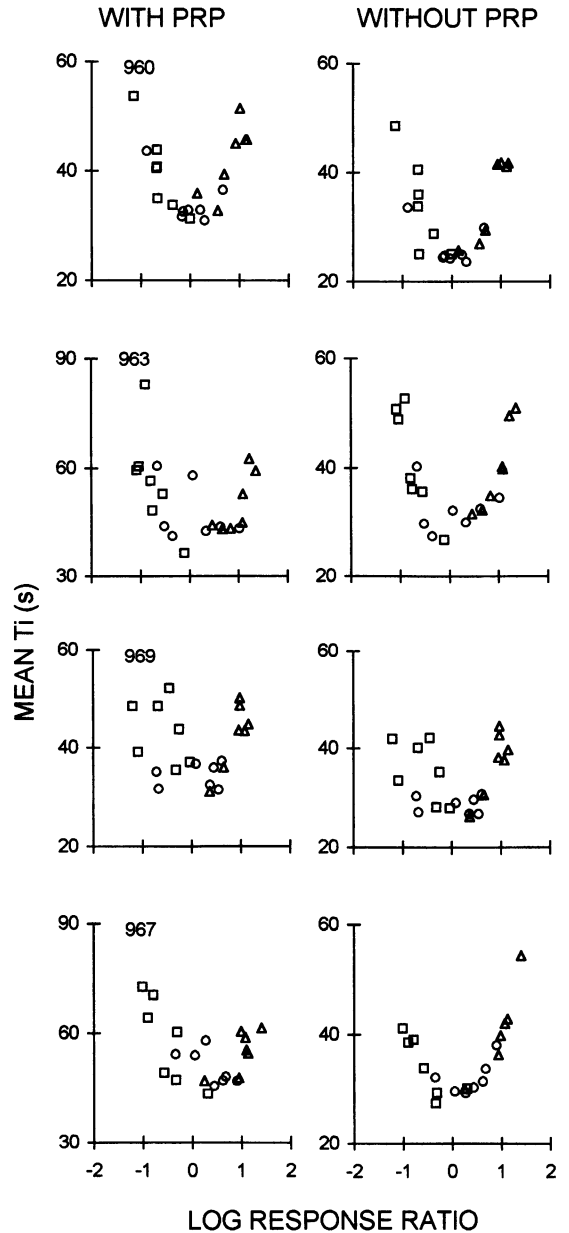


Fig. 3. Mean time, in seconds, spent in the initial links (mean  $T_i$ ) as a function of log behavior ratio, for all 4 subjects. Squares indicate data from red-key components, circles are data from white-key components, and triangles are data from green-key components. The left panels show average  $T_i$  when postreinforcement pauses are included; the right panels exclude the pauses.

$a_2$  was greater for the equal data for time allocation but was greater for the unequal data for response allocation. Also, differences in estimated  $a_2$  values between the equal and

Table 3

Estimated parameters ( $b$ , bias;  $a_2$ , sensitivity to reinforcer delay;  $a_3$ , sensitivity to reinforcer magnitude) and variance accounted for (VAC) by the contextual choice model (Equation 3) when fitted to molar data. Fits were performed for both response and time allocation data from all conditions, from just the conditions with equal reinforcer magnitudes, and from just the conditions with unequal magnitudes.

Conditions	Dependent variable	Bird 960				Bird 963			
		$b$	$a_2$	$a_3$	VAC	$b$	$a_2$	$a_3$	VAC
All	Response	1.15	1.48	2.06	0.93	1.20	1.91	2.81	0.96
All	Time	1.15	1.79	2.50	0.93	1.22	2.15	3.33	0.96
Equal magnitude	Response		1.30		0.82		1.59		0.98
Unequal magnitude	Response		1.45		0.94		1.77		0.96
Equal magnitude	Time		1.65		0.80		2.38		0.97
Unequal magnitude	Time		1.72		0.95		2.03		0.96

unequal data were much less with Equation 3. With the generalized matching model, the mean absolute difference was 0.49; with the contextual choice model, the mean absolute difference was 0.21.

Therefore, sensitivity to delay was no longer systematically different for the equal and unequal reinforcement-magnitude data sets when the effect of initial-link duration on preference was included in the model. The absence of a consistent pattern of parameter deviation across the subjects, when Equation 3 was fitted to the data, suggests that delay and magnitude are independent dimensions of reinforcement in concurrent chains, as required by the matching law. A possible explanation for the apparent delay-magnitude interaction depicted in Figures 2 and 3 is the effect of increased initial-link duration for those conditions in which preference was more extreme.

As a demonstration of the improvement provided by the contextual choice model over the generalized matching law for these data, Figure 4 shows predicted versus obtained preference for Bird 963, both excluding (generalized matching model) and including temporal context ( $Tt/Ti$ ). Without temporal context, there is a clear systematic deviation of predicted from obtained values, as evidenced by the S-shaped curve in the left panel. The systematic deviation is substantially reduced in the right panel. Although the data for Bird 963 showed the clearest elimination in systematic deviation, data for Birds 969 and 967 revealed similar tendencies. The improvement afforded by the contextual

choice model over already-excellent fits for 3 of 4 birds is evidence that temporal context effects in multiple-component concurrent chains with two independent variables are similar to those in traditional single-component, single-variable procedures.

To test whether the manipulation of reinforcer magnitude in the last two conditions was effective, Figure 5 shows preference as a function of log magnitude ratio for the three conditions in which terminal-link schedules were VI 25 s VI 25 s. The data fall into three groups, corresponding in order of increasing preference to the red-key, white-key, and green-key components. Figure 5 demonstrates that when the magnitude ratios were changed in the last two conditions, preference generally changed in the expected direction, indicating sensitivity to relative reinforcer magnitude within components. Although the changes in preference were less consistent for the red-key and green-key components than for the white-key components, this is predicted by the increase in initial-link duration at more extreme levels of preference shown in Figure 3.

Whether performances in successive components were independent remains an important issue, because for the multiple-component concurrent-chains procedure to provide data comparable to the traditional single-component procedure, successive independence, as McLean (1988) found for multiple concurrent-schedule components, would ideally be required. If successive independence were not obtained, it would be necessary to detail its violation to understand the

Table 3  
(Extended)

Conditions	Dependent variable	Bird 969				Bird 967			
		<i>b</i>	<i>a</i> <sub>2</sub>	<i>a</i> <sub>3</sub>	VAC	<i>b</i>	<i>a</i> <sub>2</sub>	<i>a</i> <sub>3</sub>	VAC
All	Response	1.30	1.49	2.09	0.93	2.12	1.56	2.24	0.95
All	Time	1.74	1.57	2.33	0.95	3.19	1.31	2.01	0.93
Equal magnitude	Response		1.57		0.85		1.36		0.98
Unequal magnitude	Response		1.45		0.94		1.67		0.95
Equal magnitude	Time		1.70		0.95		1.09		0.91
Unequal magnitude	Time		1.50		0.95		1.43		0.93

generality of data produced by the multiple-component procedure.

The following analysis was done to determine whether order of component presentation systematically affected preference. With three components arranged in each session, there were six possible orders. Because order was selected randomly, it was

not possible to analyze only data in stability (i.e., the last five sessions) due to inadequate sampling. Therefore, data from all sessions in a condition were divided into nine sets depending on component order; that is, data from red-key components were sorted into sets according to whether red was the first component or was preceded by

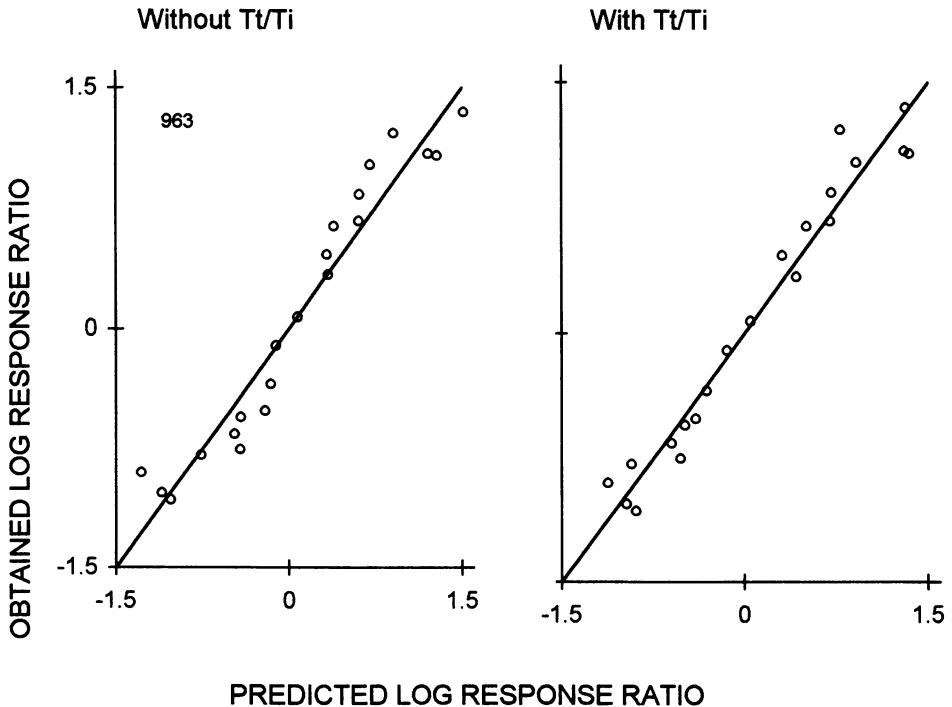


Fig. 4. Predicted log response ratio versus obtained log response ratio for Bird 963, for fits of both the generalized matching model (Equation 2; without  $T_i/T_i$ ) and the contextual choice model (Equation 3; with  $T_i/T_i$ ). The straight line is the line of perfect prediction.

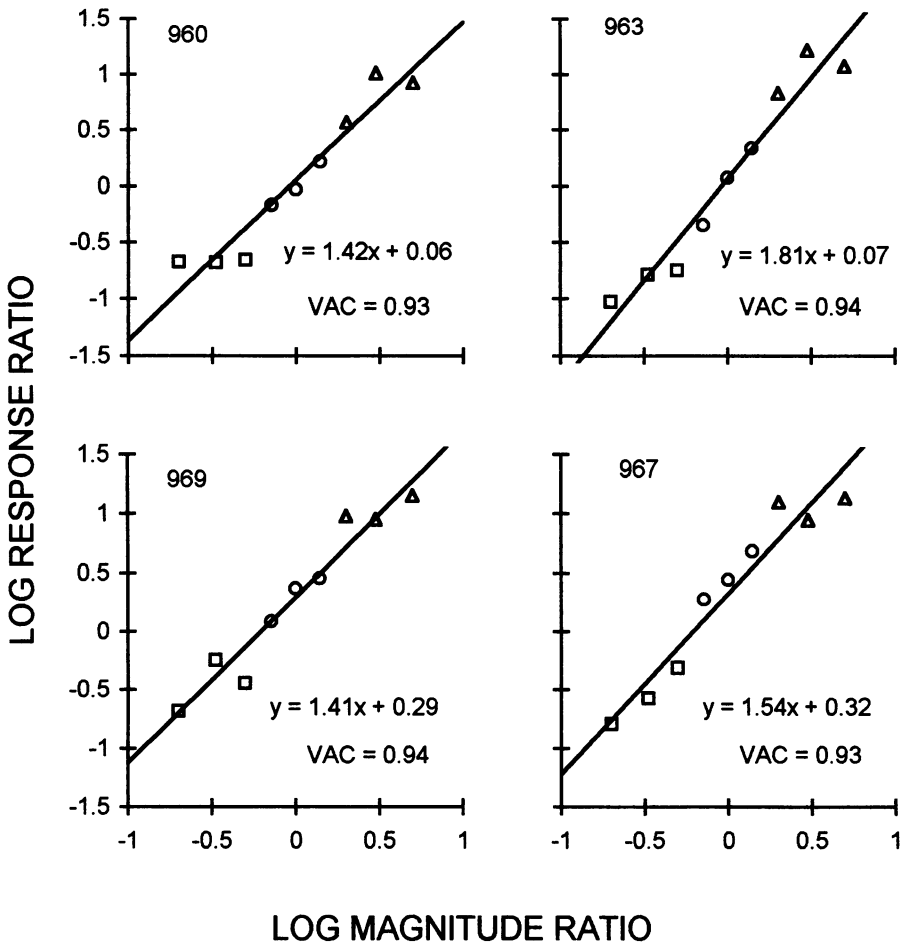


Fig. 5. Log reinforcer magnitude ratio versus log response ratio for all subjects for the conditions in which equal VI 25-s terminal links were arranged. Squares indicate data from red-key components, circles are data from white-key components, and triangles are data from green-key components. The lines through the points are the least squares regression equations.

green or white, and similarly for the other components. Log preference ratios for the sets in which a component was preceded by another component were reexpressed as difference scores with respect to the log preference ratio when the component was first. An analysis of variance (ANOVA; Condition  $\times$  Component Order) performed for each component should reveal whether there was any statistically significant tendency for preference to deviate systematically with respect to the preceding component. Specifically, if successive dependence in the form of induction (Nevin et al., 1978) is found, then log preference ratios for the white-key component should be negative,

relative to baseline (i.e., white component first), when preceded by the red-key component and positive, relative to baseline, when preceded by the green-key component. Log preference ratios for the red and green components should be positive and negative, respectively, when preceded by either of the other two components.

Table 4 presents the results from the 12 ANOVAs that were performed; six of the ANOVAs were statistically significant. Further, in every significant test, the average deviations from baseline were in the direction indicating that induction effects were present. And although none of the ANOVAs for Bird 969 reached significance, five out of six deviations

Table 4

Results of analyses of variance (Condition  $\times$  Component Order) that tested whether induction effects were present. For all subjects, response data for each component were aggregated within conditions and separated into sets according to component order. For each set, the preceding component is listed in parentheses after the component (unless the component was first). Log preference ratios for sets in which a component was preceded by another component were expressed as a difference score with respect to log ratio when component was first. For significant  $F$  ratios, average difference scores are given in parentheses below the  $F$  value. All significant difference scores are consistent with the hypothesis that large-magnitude reinforcers induce behavior in the same location in the following component.

Component	Bird 960	Bird 963	Bird 969	Bird 967
Red (first)	ns	$F(2, 12) = 7.13^{**}$	ns	$F(2, 12) = 6.68^{**}$
Red (green)		(.120)		(.080)
Red (white)		(.076)		(.134)
Green (first)	ns	$F(2, 12) = 4.49^*$	ns	ns
Green (red)		(-.094)		
Green (white)		(-.089)		
White (first)	$F(2, 12) = 7.31^{**}$	$F(2, 12) = 4.26^*$	ns	$F(2, 12) = 3.55^*$
White (red)	(-.135)	(-.061)		(-.060)
White (green)	(.103)	(.134)		(.115)

Note. ns = not significant; \*  $p < .05$ ; \*\*  $p < .01$ .

from baseline for this bird were in the predicted direction.

Therefore, when the preceding component delivered a larger reinforcer in a given location than the following component did, allocation in the following component shifted in the direction of the larger reinforcer. This is similar to the induction reported by Nevin et al. (1978) in discrete-trial concurrent schedules with very short intertrial intervals (6 s). It is perhaps surprising here, because components were separated by a 3-min blackout, which is sufficient to eliminate behavioral contrast in multiple schedules (Nevin, 1992). However, although the induction effects were statistically significant, they were small. The mean statistically significant absolute deviation in log preference was 0.100 log units; the largest was 0.135. This can be compared to the differences in steady-state preference between components in a condition, which often were greater than 1.5 log units.

The problem of transient effects caused by sequential interactions can be approached another way. Responses were recorded separately for each component quarter (six cycles). If the stable molar data are analyzed by quarter, parameter estimates may reveal systematic changes in sensitivity as a function of temporal location within components. Induction from the large-magnitude reinforcer in

the previous component should reduce sensitivity to magnitude in the first quarter, and its effect should be eliminated by the second quarter. Sensitivity to delay should not be affected, because terminal-link schedules remained constant between components.

Figure 6 shows, for all 4 subjects, the parameter estimates obtained when the contextual choice model was fitted to the component quarter data for the last five sessions of each condition. For all 4 subjects, sensitivity to magnitude ( $a_3$ ) for the second, third, and fourth quarters was greater than for the first quarter, substantially so for Bird 969. This confirms the prediction that the preceding component acts to decrease sensitivity to magnitude early in the following component. Also significant is that sensitivity to delay ( $a_2$ ) remained almost constant for 3 of 4 subjects; Bird 967 demonstrated a very small increase in  $a_2$ . Preceding-component induction should leave sensitivity to delay unaffected because terminal-link schedules were the same for all components. Finally, Figure 6 demonstrates that induction effects in the procedure were transient. For all subjects, the largest aggregate change in parameter values ( $b$ ,  $a_2$ ,  $a_3$ ) was between the first and second quarters. After the first quarter all parameter values were more or less constant, indicating that preceding-component induction affected preference in the first quarter only.

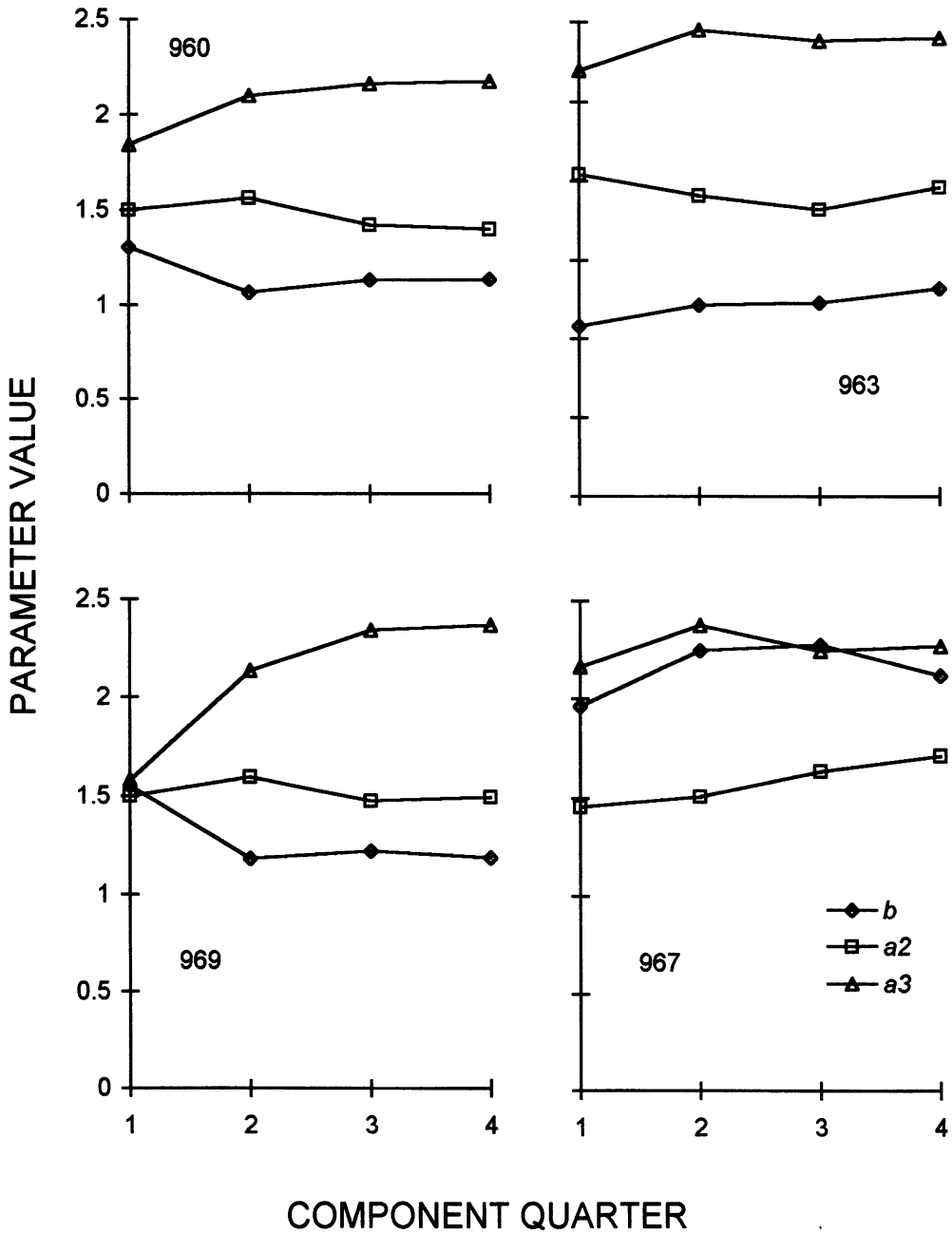


Fig. 6. Parameters estimated for the contextual choice model ( $b$ ,  $a_2$ ,  $a_3$ ) when data for all birds were analyzed separately by component quarter (six reinforcement cycles).

There is an apparent discrepancy between the evidence for induction effects in Table 4 and Figure 6. In Table 4, only the data for Bird 969 failed to produce a significant ANOVA, whereas in Figure 6 the parameter esti-

mates for Bird 969 showed the greatest change from the first to second quarter. However, as noted above, five of six average deviations from baseline for this bird were consistent with induction effects; the ANOVAs



did not reach significance because of excessive variability. Another possible explanation for the discrepancy is that only data from the last five sessions of each condition were analyzed for Figure 6, whereas all sessions were analyzed for Table 4.

## DISCUSSION

The orderly molar results depicted in Table 2 indicate that the multiple-component concurrent-chains procedure is an efficient and accurate method of generating choice data. Variances accounted for by the generalized matching model (Equation 2) and the contextual choice model (Equation 3) were always above 90%, often substantially so, for both response and time allocation measures. Excluding the baseline condition that ran for a fixed number of sessions (40), performance stabilized, on average, in 24 sessions. Because there were three components per condition, this translates into only eight sessions per data point—a dramatic improvement over traditional single-component concurrent-chains procedures.

Two factors likely contributed to the relative lack of noise in the data. First, programmed average  $T_t/T_i$  was constant across conditions, which Grace (1994) suggested as a way to optimize measurement resolution in concurrent chains. When  $T_t/T_i$  is constant, the effect of temporal context is minimized, thereby maximizing the sensitivity of initial-link allocation to terminal-link independent variables. Second, measurement of sensitivity to magnitude was likely enhanced by arranging within a session a magnitude configuration and its reversal (red and green components). If there were random shifts in bias across sessions, assumed to affect all components equally, this guaranteed that the difference in log preference ratios for the red-key and green-key components remained unaffected by bias shifts, improving measurement of sensitivity to magnitude ( $a_3$ ). Because it can easily be adapted to other variables (e.g., probability of reinforcement), the multiple-component concurrent-chains procedure should prove to be useful in future research on choice between multidimensional alternatives.

The experiment tested the hypothesis that sensitivity to delay would be lower when re-

inforcer magnitudes were unequal than when they were equal. If alternatives differ on more than one dimension, preference may become less sensitive to individual dimensions; such effects are demonstrated by humans choosing between multidimensional alternatives (Tversky, 1972). If obtained, this outcome might be explained as the result of selective attention, or in more cognitively oriented terms as "competition for processing resources" (Pearce & Hall, 1980).

When the generalized matching model (Equation 2) was fitted, data from all 4 subjects supported this prediction (Table 2). However, when obtained time spent responding in the initial links was included and the contextual choice model (Equation 3) was fitted to the data, systematic differences in sensitivity vanished (Table 3). An increase in obtained initial-link time can explain the attenuation of preference in the unequal-magnitude conditions evident in Table 2 and Figures 1 and 2; according to Equation 3, as initial-link time increases, effective sensitivities to delay and magnitude decrease. The increase in initial-link time is an artifact of the interdependent scheduling employed, which arranged 12 left and 12 right terminal-link entries per component: As preference became more extreme, more time was spent responding on the preferred side while an entry was set up for the nonpreferred side. The U-shaped functions of obtained average initial-link time as a function of preference (Figure 3) demonstrate that obtained average initial-link time was often between two and three times the programmed value (which was always 20 s). It should be noted, however, that evidence for initial-link time as the cause of preference attenuation is correlational. Another factor, such as a ceiling effect on relative response rate, might be responsible. Nevertheless, to the extent that the attenuation can be attributed to factors other than reinforcement value, such as obtained initial-link time or ceiling effects, the present data support independence of delay and magnitude of reinforcement in concurrent chains, and hence the assumption of all models based on the matching law that an additive utility model is the best representation of terminal-link value (Killeen, 1972).

Although the fits of the generalized matching model were excellent, the fits of the con-

textual choice model were even better. Inclusion of obtained initial-link time improved prediction, as evidenced by the elimination of systematic deviation in preference in Figure 4. This provides further support for the contextual choice model and its assumption that sensitivity to magnitude and delay are similarly affected by temporal context, the ratio of average times spent in the terminal and initial links per reinforcement ( $T_t/T_i$ ). However, it indicates that simply arranging constant average  $T_t$  and  $T_i$  values across conditions is insufficient to optimize concurrent chains as a preference scaling procedure. Apparently, variation in obtained initial-link time had substantial effects on preference. In fact it is possible, although perhaps unlikely, that such variation served to mask an actual delay-magnitude interaction. Future research should explore methods of controlling obtained time in the initial links more precisely. For example, the procedure could be programmed such that a running comparison of arranged versus obtained initial-link time be made, and subsequent initial-link intervals modified accordingly.

Somewhat surprising is that the fits for time allocation were equally as good, in terms of variance accounted for, as the fits for response allocation; Davison (1983) noted that time allocation is considered to be inferior as a preference measure in concurrent chains. Novel features of the present procedure that might be responsible for the orderly time allocation data were that the initial-link timer was not started until the first response had been made in each cycle, and that postreinforcement pauses were excluded from time allocation. Although analyses (not reported here) in which postreinforcement pauses were included in the time allocation and obtained initial-link time data revealed no systematic differences, across birds, in variance accounted for by Equations 2 and 3, the better approximation to U-shaped functions of obtained initial-link time when pauses were removed (Figure 3) suggests that pauses in concurrent chains should be counted as "other" behavior and should not contribute towards completion of initial-link schedule requirements. The right panel of Figure 3 implies that after the postreinforcement pause, subjects responded at a consistent overall rate in the initial links until terminal-link entry

was gained. If this is true, then the concurrent-chains procedure resembles a second-order schedule in which there is a ratio component. The present study, in its treatment of pausing, thus dovetails nicely with Baum's (1993) comparison of single-schedule ratio and interval performance. Baum showed that when postreinforcement pauses were classified separately, a more consistent account of ratio and interval response differences was obtained.

Previous researchers have found that sensitivity to reinforcer magnitude is typically lower than sensitivity to reinforcer delay in concurrent chains (Ito & Asaki, 1982; Rodriguez & Logue, 1986), although Logue et al. (1984) noted that the use of a fading procedure (Mazur & Logue, 1978) could result in greater sensitivity to magnitude. Because these studies all employed fixed rather than variable delays in the terminal links, it is interesting that the present data showed the opposite trend: Sensitivity to magnitude was greater than sensitivity to delay for all subjects, for both response and time data (see Tables 2 and 3). Because overmatching to relative immediacy is obtained with fixed terminal links (Duncan & Fantino, 1970; Killen, 1970) and undermatching is obtained with variable terminal links (Fantino & Davison, 1983), the greater sensitivity to magnitude obtained here probably resulted from the use of VI terminal-link schedules.

The statistical evidence for induction effects (Table 4) indicates that the multiple-component procedure, although more efficient in its production of data, introduces additional complexities into concurrent chains. There was a tendency for responding to be induced early in a component on the key for which the preceding component had delivered a larger reinforcer. The induction effects were small in magnitude and transient in duration, as is clear from an analysis of data across quarters of the component, which showed that parameters estimated for the contextual choice model did not change systematically after the first quarter (Figure 6). Nevertheless, that induction was obtained even though a 3-min intercomponent blackout was arranged testifies to the strength of the Pavlovian stimulus-reinforcer contingencies in the procedure. The strength of these contingencies was also reflected in the insen-

sitivity of behavior when the reinforcement magnitudes for the red-key and green-key components were reversed. However, such resistance to reversal may be peculiar to reinforcer magnitude manipulations or the use of three components. Preliminary work in this laboratory has indicated that pigeons can easily accomplish reversals in a two-component concurrent chain, in which terminal-link delay is the only variable, when reversals are instituted early in training.

Sensitivities to delay and magnitude ( $a_2$  and  $a_3$ ) estimated for the contextual choice model (Table 3) are consistently larger than values estimated for the generalized matching model (Table 2). This is because for all subjects and all conditions, obtained average initial-link time ( $T_i$ ) was greater than obtained average terminal-link time ( $T_t$ ). Thus  $T_t/T_i$  was always less than one, so larger parameter values were required to describe the same data. In contrast to the generalized matching model, the contextual choice model asserts that sensitivities can never be measured separately from temporal context ( $T_t/T_i$ ). In effect, whereas the generalized matching model provides ratio-scale measurement characteristics for its parameters, the contextual choice model provides interval-scale characteristics, in that sensitivity exponents are estimated relative to  $T_t/T_i$ . Parameter differences between the two models must be interpreted in this light.

The result that delay and magnitude are independent in their effects on preference in concurrent chains appears to be at odds with concurrent-schedule research on magnitude showing evidence of interactions that cannot be explained by the generalized matching law. Logue and Chavarro (1987) found that preference between alternatives with a constant magnitude ratio decreased as absolute magnitudes increased. Davison (1988) showed that preference between unequal magnitudes decreased as overall reinforcement rate increased. In these studies, sensitivity was not invariant with respect to the absolute value of an independent variable.

Although the measurement characteristics of concurrent schedules and concurrent chains (meaning the ability of these procedures to measure higher order dependent variables such as sensitivities) are not necessarily independent of the absolute values of

variables chosen, an additive utility model does not require them to be. Preference may be influenced by factors other than reinforcement value. As a hypothetical example, in concurrent schedules systematic change in postreinforcement pausing as a function of reinforcer magnitude could interact with measured preference. The contextual choice model addresses a similar problem for concurrent chains by showing that when temporal context effects are controlled for by the model, data are consistent with the generalized matching law. Somewhat paradoxically, accounting for such effects may prove to be an easier problem to solve for concurrent chains than for concurrent schedules, because although it is more complex procedurally, the separation of initial and terminal links affords concurrent chains a greater degree of experimental control than is possible with simple concurrent schedules. Therefore, instead of disconfirming the generalized matching law, the results of Logue and Chavarro (1987) and Davison (1988) can be taken to mean that a careful program of research is necessary to chart, using the generalized matching law as a descriptive tool, the measurement characteristics of concurrent schedules. Once these are better known, it may be that an additive utility model still remains the best description of reinforcement value.

In conclusion, the present experiment demonstrated that a multiple-component concurrent-chains procedure could produce rapid, orderly data on preference between alternatives that varied in reinforcer delay and magnitude. No unequivocal evidence was found for the hypothesis that sensitivity to delay would be reduced when magnitudes were unequal rather than equal. The results therefore support the fundamental assumption of the matching law (Killeen, 1972) that different dimensions of reinforcer value are additive and independent in their effects on preference. The data were well described by the contextual choice model (Grace, 1994) and supported its assumption that sensitivities to delay and magnitude are similarly affected by temporal context ( $T_t/T_i$ ). Although an attempt was made to minimize the effect of temporal context on preference (and thereby maximize the effect of terminal-link parameters) by arranging constant programmed av-

erage initial- and terminal-link durations, obtained initial-link time varied systematically with preference. Further measures to control initial-link time may be necessary to optimize concurrent chains for preference scaling.

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APPENDIX

Number of responses made, number of seconds spent responding in the left and right initial links, and postreinforcement pause time in seconds (PRP) for the red, green, and white components in each condition. Data are summed over the last five sessions.

Bird	Condition	Component	Terminal-link VI(s)		Reinforcer magnitude (s)		Responses		Time		PRP
			Left	Right	Left	Right	Left	Right	Left	Right	
960	1	Red	25	25	1.5	4.5	884	4,211	389.5	3,661.6	813.9
		Green	25	25	4.5	1.5	5,244	512	4,746.9	277.1	1,160.7
		White	25	25	3	3	2,260	2,436	1,216.1	1,693.8	1,047.8
	2	Red	40	10	1.5	4.5	392	5,463	314.7	5,512.4	627.2
		Green	40	10	4.5	1.5	2,301	1,667	1,712.1	1,378.7	1,240.5
		White	40	10	3	3	523	3,991	265.6	3,764.2	1,214.1
	3	Red	10	40	1.4	4.5	2,685	2,659	1,287.3	1,719.4	753.4
		Green	10	40	4.5	1.5	5,588	391	4,823.2	181.7	494.3
		White	10	40	3	3	5,310	1,133	3,131.7	460.4	806.4
	4	Red	33.33	16.67	1.5	4.5	877	4,237	491.6	3,831.7	574.7
		Green	33.33	16.67	4.5	1.5	3,263	775	2,893.3	645	1,196.3
		White	33.33	16.67	3	3	2,153	2,823	1,318.2	1,658	946.8
	5	Red	16.67	33.33	1.5	4.5	1,667	3,781	862.8	2,593.8	609.7
		Green	16.67	33.33	4.5	1.5	5,064	383	4,709.8	221.1	566.1
		White	16.67	33.33	3	3	3,598	1,800	2,018.2	817.4	890.1
	6	Red	25	25	1	5	997	4,705	713.4	4,156.1	401.1
		Green	25	25	5	1	4,668	552	4,693	288.7	424.7
		White	25	25	3.5	2.5	3,173	1,947	2,026.4	973.9	959.6
	7	Red	25	25	2	4	1,059	4,816	594.4	3,044.9	569.2
		Green	25	25	4	2	4,182	1,140	2,604.9	636.8	697
		White	25	25	2.5	3.5	2,330	3,424	1,206.8	1,735.5	867.7
963	1	Red	25	25	1.5	4.5	423	2,584	549.1	4,026.7	2,195.8
		Green	25	25	4.5	1.5	3,990	244	5,726.4	240	1,539.9
		White	25	25	3	3	1,745	1,477	2,340.7	1,532.7	3,087.2
	2	Red	40	10	1.5	4.5	362	2,887	426.9	5,894.8	3,626.6
		Green	40	10	4.5	1.5	2,345	817	2,970	831.6	1,519.8
		White	40	10	3	3	542	2,456	706.7	4,137.4	2,430.4
	3	Red	10	40	1.5	4.5	1,166	1,475	1,177.9	2,040.6	1,160.7
		Green	10	40	4.5	1.5	4,097	184	5,907.5	222.2	981.4
		White	10	40	3	3	3,498	338	3,764.5	379	1,071.2
	4	Red	33.33	16.67	1.5	4.5	255	3,013	204.3	5,881.9	1,047
		Green	33.33	16.67	4.5	1.5	2,862	618	3,358.8	523.1	1,306.8
		White	33.33	16.67	3	3	634	2,054	746.2	2,831.9	1,702.8
	5	Red	16.67	33.33	1.5	4.5	593	2,099	730.9	3,548.9	2,060.7
		Green	16.67	33.33	4.5	1.5	3,633	299	4,621	161	1,563.9
		White	16.67	33.33	3	3	2,529	590	3,365.3	544.7	1,355.7
	6	Red	25	25	1	5	336	3,594	397.8	5,484.3	1,373
		Green	25	25	5	1	3,871	328	4,626.4	220.5	564.9
		White	25	25	3.5	2.5	2,150	1,002	2,684.6	918.4	1,517.3
	7	Red	25	25	2	4	492	2,766	616.6	3,721.6	1,473.7
		Green	25	25	4	2	3,165	465	3,644.2	553.5	1,018.1
		White	25	25	2.5	3.5	846	1,872	1,056	2,255.9	1,664.7

APPENDIX  
(Continued)

Bird	Condi- tion	Compo- nent	Terminal-link VI(s)		Reinforcer magnitude (s)		Responses		Time		PRP
			Left	Right	Left	Right	Left	Right	Left	Right	
969	1	Red	25	25	1.5	4.5	879	1,555	1,510.9	2,720.9	1,007.3
		Green	25	25	4.5	1.5	3,470	387	4,200.5	393.1	622.1
		White	25	25	3	3	2,380	1,019	2,308.2	908.5	671.6
	2	Red	40	10	1.5	4.5	308	4,878	437	4,593.4	777.9
		Green	40	10	4.5	1.5	2,235	973	2,468.5	696	562.4
		White	40	10	3	3	652	3,378	857.4	2,788	569.9
	3	Red	10	40	1.5	4.5	1,110	1,183	1,727.7	1,612.8	1,097.4
		Green	10	40	4.5	1.5	3,191	336	4,935.5	206.5	677
		White	10	40	3	3	3,011	722	3,348.9	349.8	765.7
	4	Red	33.33	16.67	1.5	4.5	334	4,052	399.3	3,615.3	673.9
		Green	33.33	16.67	4.5	1.5	3,125	696	3,252.6	435	628
		White	33.33	16.67	3	3	701	3,322	858.1	2,396.9	545.9
	5	Red	16.67	33.33	1.5	4.5	1,186	2,447	1,320.5	2,053.4	883.2
		Green	16.67	33.33	4.5	1.5	4,358	367	4,333.7	194.4	671.4
		White	16.67	33.33	3	3	3,196	894	2,770	443	552.2
	6	Red	25	25	1	5	420	2,017	709.4	4,112.7	985
		Green	25	25	5	1	3,821	268	4,590.8	188.4	587.3
		White	25	25	3.5	2.5	2,560	902	2,689.2	865.4	747.8
	7	Red	25	25	2	4	399	1,112	835.6	4,229.4	1,171.9
		Green	25	25	4	2	3,999	423	4,882.5	478.9	649.5
		White	25	25	2.5	3.5	1,449	1,189	1,998.4	1,484.4	912.2
967	1	Red	25	25	1.5	4.5	1,305	4,868	945	3,122	1,850.5
		Green	25	25	4.5	1.5	5,014	570	4,028.6	341.7	1,382.2
		White	25	25	3	3	3,722	1,333	3,049.2	597.7	1,826.7
	2	Red	40	10	1.5	4.5	453	3,600	1,217.1	3,411.2	3,079.4
		Green	40	10	4.5	1.5	2,806	1,621	2,829.3	793.7	2,045.1
		White	40	10	3	3	1,454	3,179	1,869.6	1,991.4	2,670.3
	3	Red	10	40	1.5	4.5	2,469	1,198	2,785.3	829.9	1,614.4
		Green	10	40	4.5	1.5	6,843	268	6,195.7	349.6	844
		White	10	40	3	3	4,903	603	4,109.1	461.1	1,068.8
	4	Red	33.33	16.67	1.5	4.5	433	4,405	635.6	4,301.1	3,803.1
		Green	33.33	16.67	4.5	1.5	4,315	446	4,452	334.2	2,488.6
		White	33.33	16.67	3	3	1,996	1,755	2,450.9	1,114	2,923
	5	Red	16.67	33.33	1.5	4.5	1,280	2,717	1,971.3	1,326.9	2,388.2
		Green	16.67	33.33	4.5	1.5	4,731	398	4,783	262.6	2,043
		White	16.67	33.33	3	3	3,545	836	3,308.9	470.1	1,889.2
	6	Red	25	25	1	5	625	3,852	1,094.9	3,591.8	3,789
		Green	25	25	5	1	4,226	312	4,944.6	204.7	1,406.1
		White	25	25	3.5	2.5	3,192	666	3,445.1	606.9	1,742.4
	7	Red	25	25	2	4	1,052	2,156	1,657.1	1,871.9	3,718.9
		Green	25	25	4	2	3,641	292	3,875	440.7	2,361.6
		White	25	25	2.5	3.5	2,269	1,209	2,320.8	1,207.7	3,445.9