BIAS AND SENSITIVITY TO REINFORCEMENT IN A CONCURRENT-CHAIN SCHEDULE

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Six pigeons were trained on concurrent-chain schedules in which the initial links were either dependent (Experiment 1) or independent (Experiment 2) concurrent variable-interval schedules and the terminal links were fixed-duration delays to reinforcement in blackout. A changeover delay of three seconds operated in the initial links. Both the initial- and terminal-link schedule values were varied over 61 experimental conditions. An analysis of the data using the generalized matching law showed that the sensitivity of initial-link response allocation to the frequency of terminal-link production was independent of both the duration of the terminal-link delays and, though less clearly, of the duration of the initial-link schedules. Sensitivity of initial-link response allocation to terminal-link reinforcer-rate ratios was a joint function of the terminal-link durations and the smaller average initial-link duration. The results showed that the generalized matching law is useful in analyzing concurrent-chain schedule performance and that a changeover delay in the initial links eliminates some terminal- to initial-link interactions that have made quantitative predictions for concurrent-chain performances difficult.

Key words: concurrent-chain schedules, generalized matching law, sensitivity to reinforcement, response allocation, time allocation, bias, delay of reinforcement, pigeons

In a concurrent-chain schedule, responding on concurrent variable-interval (VI) schedules is reinforced by the production of a period of time in which, typically, a single food reinforcer is gained. The concurrent VI VI initial links are then reinstated. A diagrammatic representation of the procedure is shown in Figure 1. In general, a concurrent chain differs from a concurrent schedule in that, in the former, the reinforcement period is extended over time. It is evident that shortening the terminal-link reinforcement periods in a concurrent-chain schedule moves the procedure closer to a concurrent schedule and that when the terminal links are 0 sec in duration, the procedure is a concurrent schedule. It may thus be helpful to subsume concurrent-chain schedule performances under the heading of concurrent schedules and to deal with the effects of terminal-link schedules as if chang-

ing these was akin to changing the magnitudes of reinforcers in concurrent VI VI schedules.

Viewing the concurrent-chain schedule as a concurrent schedule with different magnitudes of reinforcers brings the benefit of the availability of a considerable amount of published research and an existing and well-supported theory—the generalized matching law (Baum, 1974b). The present experiment was designed to answer the question: Can the generalized matching law account for any or all aspects of concurrent-chain schedule performance?

The generalized matching law is written:

$$\log \left(\frac{B_1}{B_2} \right) = a \log \left(\frac{R_1}{R_2} \right) + \log c, \quad (1)$$

where the subscripts 1 and 2 denote the two response alternatives, B denotes pecks, and R denotes reinforcers obtained. The parameter a is called sensitivity to reinforcement and measures the amount of change in the log-response ratio as a function of changes in the log-reinforcer ratio. The parameter $\log c$ is called bias and normally measures a constant proportional preference for one alternative, due to some variable, like differing key pressures on the two keys, which is unchanged throughout the experiment.

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Fig. 1. A diagram of the concurrent-chain schedule procedure. Responding on keys A and B (white) in the initial links on nonindependent (Experiment 1) or independent (Experiment 2) schedules occasionally produced one of two delays to reinforcement in blackout. On key A, responding on VI T_{a1} produced a delay of T_{a2} sec, and on key B, responding on VI T_{b1} produced a delay of T_{b2} sec. These blackouts terminated in the delivery of food and, following this, the initial links were reinstated.

A version of this law, and by implication Equation 1 itself, was extended by Baum and Rachlin (1969) to the situation in which more than one independent variable is manipulated. For example, if both reinforcer frequency and magnitude were varied in an experiment, the following equation would apply:

$$\log \left(\frac{B_1}{B_2} \right) = a \log \left(\frac{R_1}{R_2} \right) + b \log \left(\frac{M_1}{M_2} \right) + \log c, \quad (2)$$

where M is the reinforcer magnitude. Such an additive-logarithmic model has been shown to account well for combinations of two independent variables (Hunter & Davison, 1982; Schneider, 1973; Todorov, 1973). Equation 2 implies that if M_1 and M_2 were kept constant, but unequal, in an experiment, and R_1 and R_2 were varied, the relationship between $\log (B_1/B_2)$ and $\log (R_1/R_2)$ would be a straight line of slope a with an intercept of $b \log (M_1/M_2) + \log c$. This is a biased matching line. Equally, if R_1 and R_2 were kept constant and unequal while M_1 and M_2 were varied, the relationship between $\log (B_1/B_2)$ and $\log (M_1/M_2)$ would be a straight line of slope b with an intercept of $\log (R_1/R_2) + \log c$. If we assume that this equation might apply to concurrent-chain performance, the log-magnitude term is replaced by a measure of the effects of the terminal-link

schedules or delays. These effects, as previous research has shown (Fantino, 1977), are a function of the terminal-link reinforcer rates. Thus, we can write:

$$\log \left(\frac{B_{a1}}{B_{b1}} \right) = a \log \left(\frac{T_{b1}}{T_{a1}} \right) + b \log \left(\frac{T_{b2}}{T_{a2}} \right) + \log c, \quad (3)$$

using the nomenclature of Figure 1. If the generalized matching law applied to concurrent-chain performances, a should be independent of $\log (T_{b2}/T_{a2})$ and b should be independent of $\log (T_{b1}/T_{a1})$. A similar equation should apply when the dependent variable was time spent responding, rather than numbers of responses, in the initial links.

Davison (1976) followed this logic. He arranged terminal links of FI 5-sec vs. FI 5-sec, FI 5-sec vs. FI 15-sec, and FI 15-sec vs. FI 5-sec, and varied the initial-link VI schedules keeping the smaller always VI 27-sec. The logic of the generalized-matching-law approach requires that the sensitivity (a) of the initial-link response ratio to the ratio of terminal-link entries be the same for each pair of terminal-link schedules. They were not. The unequal terminal-link schedule data deviated maximally from the equal terminal-link data when both initial links were VI 27-sec. But the more different were the initial links, the less this deviation became. These results appear to be a fundamental demonstration that the generalized matching law does not apply to concurrent-chain schedule performance. The bias caused by the terminal links was affected by the initial-link schedule values, and such an interaction rules out the Baum-Rachlin (1969) concatenation (Equations 2 and 3).

If such an interaction does occur, it is of interest to document its development in the transition between concurrent and concurrent-chain schedules. However, a problem immediately arises if an experiment is designed encompassing both concurrent and concurrent-chain schedules. It is that, by and large, concurrent-chain schedules have not used changeover delays (Herrnstein, 1961) in the initial-link concurrent VI VI schedule components, whereas concurrent schedules are usually arranged with changeover delays (de Villiers, 1977). Because I wanted to arrange both concurrent and concurrent-chain schedules in the present experiments to investigate the dif-

ference between them, I used a changeover delay in the initial links throughout. Nonindependent concurrent VI VI schedules (Stubbs & Pliskoff, 1969) were used to overcome the problem, raised by Davison and Temple (1973), of obtained terminal-link entries being very different from those arranged when initial-link response allocation is strongly biased by differences in the terminal-link schedules.

The design of the present experiment was to use fixed delays-to-reinforcement in the terminal links of a concurrent-chain schedule and, for a number of terminal-link delay combinations, to vary the initial-link VI schedules over a range of both relative and absolute values.

EXPERIMENT 1

METHOD

Subjects

Six homing pigeons, numbered 181 to 186, were maintained at 80% of their free-feeding body weights. Birds 181 and 185 provided data beginning with Condition 9 due to the deaths of two birds that initially started the experiment.

Apparatus

The experimental chamber, which was situated remotely from solid-state experimental control equipment, contained three response keys 2 cm in diameter, 11 cm apart, and 25 cm from the grid floor. Each key was operated by a peck exceeding about .1 N and could be illuminated with three different-colored lights. The food magazine, which contained wheat, was situated beneath the center key and 12 cm from the grid floor. The food magazine operated for a nominal 3 sec, during which time the hopper was illuminated and the keylights were extinguished. There was no other illumination in the chamber. Pecks to blacked-out keys were always ineffective and were not counted. An exhaust fan fitted to the chamber helped mask external noise.

Procedure

The pigeons had extensive experience of responding on concurrent schedules and were placed directly on the first experimental condition (Table 1). Initially, the two side keys were both illuminated white, and the concur-

rent initial links (see Figure 1) were in effect. A changeover delay of 3 sec was arranged such that a response on a key could not produce a terminal link, even though an entry was arranged by the VI schedules, until 3 sec had elapsed since the first peck on that key following responses to the other key. The schedules in the initial links were arranged nonindependently; that is, when one VI schedule had arranged a terminal-link entry, both schedules stopped until that entry had been taken. When an initial-link VI schedule had arranged a terminal-link entry and the changeover delay on that key had elapsed, a peck to the appropriate key turned off all the keylights and started a delay period. At the end of this period, which was fixed for each key (Table 1), the food magazine operated and, following this, the initial links were again available and both initial-link schedules recommenced. This procedure (Stubbs & Pliskoff, 1969) ensured that the relative number of terminal-link entries obtained on each key would be similar to that arranged by the initial-link VI schedules.

Sessions ended in blackout after a fixed number of reinforcers had been obtained. The birds were then returned to their home cages, where water and grit were available, and were fed the amount of food necessary to maintain 80% of their normal body weights.

In each condition, the number of responses emitted on each key in the initial links and the number of entries into each terminal link were recorded. Also recorded was the time spent responding on each key in the initial links, measured from the first peck on one key to the first peck on the other. Time-allocation measurement ceased when 5 sec had elapsed without an initial-link response or on terminal-link entry.

Table 1 shows the sequence of experimental conditions and the number of sessions of training given on each. Apart from Condition 1, in which an immediate reinforcer was arranged in both terminal links, the terminal delays were 0 and 3 sec and the initial-link VI schedules were varied, both relatively and absolutely. From the nine conditions with 0- and 3-sec terminal delays, there were three conditions with smaller initial-link VI schedules of 60 sec and five with smaller initial-link VI schedules of 30 sec. There was also a set of data (Conditions 2, 5, and 8) in which the initial links were kept equal and the absolute

Table 1

Experiment 1. Sequence of experimental conditions, initial-link VI schedules, terminal-link delays (both sec), and number of sessions training given in each condition.

Condition	Initial-link VI Schedules		Terminal-link Delays		Sessions
	Right	Left	Right	Left	
1	60	60	0	0	28
2	60	60	0	3	27
3	60	120	0	3	21
4	120	60	0	3	20
5	120	120	0	3	27
6	30	120	0	3	23
7	120	30	0	3	27
8	30	30	0	3	30
9	30	60	0	3	19
10	60	30	0	3	18
11	60	30	0	0	23
12	30	120	0	0	26
13	30	30	0	0	24
14	30	60	0	0	19
15	120	30	0	0	27
16	30	30	0	10	29
17	60	120	0	10	20
18	120	30	0	10	29
19	30	120	0	10	24
20	120	60	0	10	24
21	120	30	0	30	43
22	30	120	5	5	23
23	60	30	5	5	16
24	30	60	5	5	23
25	120	30	5	5	23
26	30	30	5	5	21
27	30	120	15	15	33
28	30	120	30	30	26
29	30	30	15	30	30
30	30	120	15	30	19
31	120	60	15	30	30
32	60	120	15	30	21
33	120	30	15	30	24
34	30	60	15	30	24
35	60	30	15	30	20
36	30	180	15	30	37
37	180	30	15	30	29
38	30	90	15	30	19
39	90	30	15	30	34
40	30	240	15	30	28
41	240	30	15	30	31

values of these were 30, 60, or 120 sec. In Conditions 1 and 11 to 15, the terminal delays were both 0 sec (concurrent VI VI schedules), and the initial-link VI schedules were varied keeping (apart from Condition 1) the smaller initial link at VI 30-sec. In Conditions 16 to 20, the terminal-link delays were 0 and 10 sec, and the initial-link schedules were varied. In all of these conditions, except 17 and 20, the smaller initial-link VI schedule was VI 30-sec. In Condition 21, the terminal-link delays were

0 and 30 sec. This condition was arranged to complete a data set with initial-link VI schedules of 120 and 30 sec, one terminal link of 0 sec, and the other varied from 0 to 3 to 10 to 30 sec (Conditions 7, 15, 18, and 21).

In Conditions 22 to 26, the delays in both terminal links were 5 sec, and the initial-link VI schedules were varied with one kept at VI 30-sec. Equal terminal-link delays were also arranged in Conditions 27 (both 15 sec) and 28 (both 30 sec) with concurrent VI 30-sec VI 120-sec schedules in the initial links. These conditions, with Condition 12 (0-sec delays) and Condition 22 (5-sec delays), provided four conditions in which the absolute values of the equal terminal-link delays were varied with constant initial-link schedules. Finally, in Conditions 29 to 41, the terminal delays were 15 and 30 sec while the initial-link schedules were varied. In Conditions 29, 30, and 33 to 41, the smaller initial-link VI schedule was VI 30-sec, and in Conditions 31 and 32 it was 60 sec.

Each experimental condition remained in effect until all birds had reached a defined criterion of stability five, not necessarily consecutive, times. The criterion was that the median relative initial-link response numbers over five sessions did not differ by more than .05 from the median of the five sessions prior to these. The number of sessions training in each condition is shown in Table 1.

The initial-link VI schedules comprised an irregular sequence of the first 12 terms from an arithmetic progression with the shortest interval being one-twelfth the mean interval.

RESULTS AND DISCUSSION

Because of the complexity of the present data, it will be easier if they are dealt with not in the order in which the experimental conditions were conducted but in a more logical order. I shall also deal only with matching law analyses of response and time allocation in the initial-link schedules as a function of frequencies of terminal-link entries and the values of terminal-link delays. The full data, which are shown in Appendix 1, are available for other analyses.

The logical place to commence the analysis of these data is with Conditions 11 to 15 in which the terminal delays were both 0 sec (that is, concurrent VI VI schedules), and the smaller initial-link schedule was VI 30-sec. In Figure 2, the logarithm of the ratio of initial-

Fig. 2. Log initial-link response ratios (right/left) as a function of log terminal-link entry ratios (i.e., log initial-link reinforcement ratios) when no terminal delays were arranged in either terminal link. Straight lines were fit by the method of least squares; beneath these equations are shown the standard deviations of the slopes and intercepts. The origins of the graphs are shown by a cross. Unfilled and filled data points distinguish between birds.

link responses is shown as a function of the ratio of terminal-link entries when the initial-link schedules were varied with one kept at VI 30-sec. In this and subsequent figures, negative values on the X axis came from conditions in which fewer right than left reinforcers were obtained and positive values from the reverse of this. Straight lines were fit to the data by the method of least squares. The slopes and intercepts of the best-fitting lines are shown in Figure 2 with the standard deviations of these estimates. These plots correspond to Equation 3, and the intercepts are a measure of $b \log (T_{b2}/T_{a2}) + \log c$. Figure 2 shows a wide range of intercepts, ranging from $-.28$ to $+.12$ and averaging $-.08$. Clearly, there was no consistent bias to either key or terminal delay.

In concurrent VI VI schedules, response-allocation sensitivities (the slopes in Figure 2, and a in Equation 1) generally have a mean of about .8 and vary from .5 to 1.5 (Baum, 1979). The slopes obtained here averaged .66 and ranged from .36 to 1.11. Although in view of Baum's work, the present slopes were generally low, the slope for Bird 182 (1.11) shows that this effect was not caused by the procedure used. The fits were not particularly good, with rather high standard deviations of slope esti-

mates. The equal initial-link condition (13) always gave data that fell above the fitted lines, and I can offer no explanation for this. But in view of subsequent analyses, it is important to note that this particular condition does not affect the estimate of sensitivity to the initial-link reinforcement ratio (a).

In concurrent-schedule performance, the sensitivity of time-allocation ratios to reinforcer ratios is usually greater than the sensitivity of response-allocation ratios (Baum, 1979), and this was true of the present data. Time-allocation sensitivities (Table 3) averaged .80, ranged from .37 to 1.22, and were greater than response-allocation sensitivities for all six birds. (Note that Table 3 in the General Discussion summarizes all response and time slopes and their standard deviations.) Time-allocation biases (Table 3) averaged $-.07$ and ranged from $-.35$ to $+.19$. They were very similar to response-allocation biases.

Figure 3 shows response-allocation data obtained when the terminal-link delays were both 5 sec and the smaller initial-link schedule was VI 30-sec. Straight lines were again fitted by least-squares linear regression. The response biases averaged $-.05$ (range $-.13$ to $.06$), and for four of the six birds they were in the same direction as, though generally not as extreme as, those in Figure 2. The slopes, or sensitivities, averaged .65, similar to the value for

Fig. 3. Log initial-link response ratios (right/left) as a function of log terminal-link entry ratios when both terminal delays were 5 sec. Least-squares regression lines, and below these the standard deviations of the parameter estimates, are shown for each bird. Crosses show the origins of the graphs. Unfilled and filled data points distinguish between birds.

Fig. 4. Log initial-link response ratios (right/left) as a function of log terminal-link entry ratios when the terminal delays were 0 and 3 sec. Least-squares regression lines, and below these the standard deviations of the parameter estimates, are shown for each bird. Crosses show the origins of the graphs. Unfilled and filled data points distinguish between birds.

Figure 2, but the range (.43 to .89) was smaller. Across individual birds, there were no reliable directional changes in slope from terminal delays of 0 sec to delays of 5 sec, the slopes increasing for three birds and decreasing for three birds.

For the 5-sec delays, time-allocation sensitivities (Table 3) averaged .88 (range .71 to 1.06) and were greater than response-allocation sensitivities for all birds. There were no consistent changes in time-allocation sensitivity between 0-sec and 5-sec terminal delays. Time-allocation biases averaged .10 and ranged from .01 to .30.

The response-allocation data for terminal delays of 0 vs. 3 sec are shown in Figure 4. Again, the smaller initial link was always a VI 30-sec schedule. The unequal terminal-link delays produced a consistent bias in the initial link leading to the 0-sec terminal delay. This bias ($b \log [T_{b2}/T_{a2}]$ in Equation 3) averaged .22 (range .02 to .39). For each of the four birds completing this part of the experiment, the biases were greater than those found in both the equal 0-sec and equal 5-sec terminal delays (Figures 2 and 3). Sensitivities to the terminal-link entry ratios averaged .62 (range .54 to .81), and they were not consistently different from the equal 0- and 5-sec terminal-delay data (Figures 2 and 3). The standard deviations of the slopes showed that these were estimated precisely, and the fits in general were excellent.

Fig. 5. Log initial-link response ratios (right/left) as a function of log terminal-link entry ratios when the terminal delays were 0 and 10 sec. Least-squares regression lines, and below these the standard deviations of the parameter estimates, are shown for each bird. Crosses show the origins of the graphs for Birds 181, 182, 184, and 185. The origins for Birds 183 and 186 fell on the X axis. Unfilled and filled data points distinguish between birds.

Time-allocation sensitivities for the 0- vs. 3-sec terminal-delay conditions averaged .81 (range .60 to 1.26, Table 3) and were greater than response sensitivities for all birds. There was no consistent difference in time-allocation sensitivity between 0- vs. 3-sec terminal delays and equal 0- or 5-sec delays. Time-allocation biases averaged .29 (range .07 to .43) and were greater than response-allocation biases for three of the four birds. For all four birds, the time-allocation biases were greater than those in equal 0- and 5-sec terminal delays.

The response-allocation data obtained when the terminal delays were 0 vs. 10 sec are displayed in Figure 5. The data are a combination of three points with shorter initial-link VI 30-sec schedules, and two with shorter initial-link VI 60-sec schedules (Conditions 17 and 20). The data from the latter conditions fall at $\pm .3$ on the log-entry ratio axis. Inspection of Figure 5 shows that these data did not differ systematically from the smaller initial-link VI 30-sec data. This finding of no difference is further documented in Experiment 2. The biases caused by 0- vs. 10-sec terminal delays averaged .49 and ranged from .11 to .64. All showed an increase compared with the 0- vs. 3-sec terminal-delay data (Figure 4). The sensitivities to the terminal-link entry ratio averaged .68 (range .34 to .95). There were no

consistent differences in sensitivity to terminal-link entries between these data and those obtained from equal 0-, equal 5-, or 0- vs. 3-sec terminal delays (Figures 2, 3, and 4). The small standard deviations of both the slope and intercept measures show that these parameters were estimated precisely.

Time-allocation sensitivities in the 0- vs. 10-sec terminal-delay conditions (Table 3) averaged .75, ranged from .28 to 1.07, and were greater than response-allocation sensitivities for four of the six birds. Time-allocation sensitivities for the 0- vs. 10-sec delay data were not consistently different from those found for equal 0- and 5-sec delays and for 0- vs. 3-sec terminal delays. Time-allocation biases averaged .73 (range .56 to .81). They were all greater than the response biases from these conditions and greater than the time-allocation

biases for the equal 0-, equal 5-, and 0- vs. 3-sec conditions.

Figure 6 shows the initial-link response-allocation data obtained when the terminal delays were 15 and 30 sec, and the smaller initial-link schedule was VI 30-sec. Except for Bird 182, there were large biases toward the shorter terminal delay, averaging .43 and ranging from .02 to .67. All the biases were more positive than those found with equal terminal delays (Figures 2 and 3). Sensitivity to the terminal-link entry ratio averaged .8 with a range of .6 to .98. Four of the six slopes were higher than those found for 0-sec terminal delays (Figure 2), five of the six were higher than those for 5-sec terminal delays (Figure 3), three of four were higher than those for 0- vs. 3-sec terminal delays (Figure 4), and five of six were higher than for 0- vs. 10-sec delays (Figure 5).

Fig. 6. Log initial-link response ratios (right/left) as a function of log terminal-link entry ratios when the terminal delays were 15 and 30 sec. Least-squares regression lines, and below these the standard deviations of the parameter estimates, are shown for each bird. Crosses show the origins of the graphs; the data for Birds 181 and 182 share the same origin, and the origin for Bird 186 fell on the X axis. Unfilled and filled data points distinguish between birds.

Thus, although the sensitivities to terminal-link entry for 15- vs. 30-sec delays were not consistently larger than those for any other terminal-delay conditions, their average was somewhat higher. An omnibus test for differences, using a Friedman analysis of variance (Siegel, 1956), was carried out using the data from the four birds which completed the $k = 5$ experimental conditions. The obtained value of χ^2 was 1.6, which is not significant at $\alpha = .05$. The conclusion is that none of the response sensitivities to terminal-link entry ratios found in Experiment 1 differed significantly from any other. Overall, the average response-allocation sensitivity to the terminal-link entry ratio found in Experiment 1 was .66.

An average time-allocation sensitivity (Table 3) of .82 (range .58 to 1.09) was obtained in the 15- vs. 30-sec delay conditions. This value, unlike the corresponding response-allocation sensitivity, was well within the range of time-allocation sensitivity values obtained in this experiment, and a Friedman analysis of variance, as above, found no significant differences in time-allocation sensitivity across different terminal delays ($\chi^2 = 2.7$). Again, for these data time-allocation sensitivities were greater than response-allocation sensitivities for five of the six birds. For the 15- vs. 30-sec delays, time-allocation bias values averaged .61 (range .16 to .83, the lowest being obtained from Bird 182), and all these biases were larger than the equivalent response-allocation biases. The biases were not consistently different from those obtained with 0- vs. 10-sec terminal delays but were all larger than those obtained with equal delays or with 0- vs. 3-sec delays.

In Conditions 12, 22, 27, and 28, initial-link concurrent VI 30-sec VI 120-sec schedules were arranged, and the equal terminal-link delays were varied from 0 to 5 to 15 to 30 sec. The log initial-link response- and time-allocation ratios for these conditions are shown in Figure 7 as a function of the duration of the terminal-link delays. There were inconsistent changes in both response- and time-allocation measures with increasing delays, and a nonparametric trend test (Ferguson, 1965) confirmed that no significant trend was present in either measure. A significant trend would indicate that a in Equation 3 was affected by the terminal-delay duration. These results thus support the findings from the generalized matching analysis

Fig. 7. Log initial-link response and time ratios (right/left) obtained when the initial links were concurrent VI 30-sec VI 120-sec and the equal terminal links were varied from 0 to 30 sec.

(Figures 2 to 6) that sensitivity to terminal-link entries is not consistently affected in this procedure.

Figure 7 serves to highlight another consistent finding from Experiment 1. In 21 of 24 possible comparisons in Figure 7, time-allocation measures were more positive than response-allocation measures. Time-allocation sensitivities in the equivalents of Figures 2 to 6 (mean .81) were also greater than response sensitivities (mean .66) in 23 of 28 comparisons. Thus, the value of a in Equation 3 is reliably greater for time than for response measures. A similar difference in time- vs. response-allocation biases was found when unequal terminal delays were arranged (Figures 4, 5, and 6). In 15 of 16 possible comparisons, time-allocation intercepts were more extreme. In Equation 3, this indicates that b for time-allocation measurement is greater than b for response allocation. Overall, then, time allocation is more sensitive than response allocation to both the terminal-link entry ratio and the terminal-link reinforcer-rate ratio. These differences in sensitivity are well known in concurrent-schedule research (Baum, 1979).

Four birds (182, 183, 184, and 186) were exposed to Conditions 8, 2, and 5 over which equal initial-link VI 30-sec, VI 60-sec, and VI 120-sec schedules were arranged with 0- vs. 3-sec terminal delays. A trend test carried out across all four birds and three conditions using both response- and time-allocation measures showed no significant trend with increasing initial-link duration. These data thus indicate that the bias caused by differences in terminal delays, hence b in Equation 3, was not affected by changing the durations of the initial-link schedules from 30 to 120 sec. However, it is worthwhile noting here that Experiment 2 did find changes in b outside this range.

Conditions 15, 7, 8, and 21 (in order) can be used to assess the effects of increasing the length of one terminal delay over the range 0 to 30 sec when the other delay was 0 sec and when the initial links were concurrent VI 120-sec VI 30-sec. Condition 7 data were not available for Birds 181 and 185. Log response ratios generally increased in a negatively accelerated fashion with the increasing terminal delay. Consideration of the data on the relation between the value of the bias caused by the terminal links and the values of the delays is deferred until the General Discussion.

The data obtained in this experiment were quite different in some respects from those reported previously. Davison (1976) found a different sensitivity to the terminal-link entry ratio when the shorter initial link (VI 27-sec) led to the shorter terminal FI (5 sec) than when it led to the longer terminal FI (15 sec). Because a constant a value was not obtained, that finding indicates that the bias caused by the unequal terminal FI schedules was affected by either the average or the longer initial-link VI schedule. Such a context effect, or interaction, was absent in the present data. The initial-link schedule values were much the same here as in Davison's (1976) experiment, leaving three possible explanations of the difference in results: (1) the use of terminal delays vs. fixed-interval terminal links; (2) the use here of dependent, rather than independent, concurrent initial-link VI schedules; and (3) the use here of a changeover delay in the initial links.

The first of these explanations can be rejected on empirical grounds. Neuringer (1969), Shimp (1969), and Williams and Fantino (1978) have all shown that pigeons are indifferent between fixed delays in blackout and fixed intervals to reinforcement in the terminal links. The second and third explanations cannot, however, be rejected. Experiment 2 investigated the contribution of the initial-link scheduling procedure by replicating some of the conditions of Experiment 1 using independent concurrent VI VI initial links.

EXPERIMENT 2

Experiment 2 commenced by replicating the conditions of Experiment 1 in which the terminal delays were 15 and 30 sec and the smaller initial link was VI 30-sec, but using independent initial-link concurrent VI schedules. Following this, the effects of other shorter initial-link schedules were investigated by arranging 0- and then 60-sec shorter initial links.

METHOD

Subjects, Apparatus, and Procedure

The subjects, apparatus, and procedure were the same as those used in Experiment 1, except that the initial-link VI schedules were arranged independently. In this procedure it was possible that, at any time, both initial-link schedules could arrange a terminal-link entry. In this case, only the VI timer associated with the

Table 2

Experiment 2. Sequence of experimental conditions, initial-link VI schedules (sec), and number of sessions training in each condition. The initial-link schedules were arranged independently. The terminal-link delays were 15 sec (right) and 30 sec (left) throughout.

Condition	Initial-link Schedules		Sessions
	Right	Left	
42	30	240	21
43	60	30	34
44	30	30	24
45	240	30	53
46	30	60	29
47	120	30	30
48	30	150	33
49	180	30	35
50	30	180	21
51	180	0	51
52	30	0	40
53	120	0	39
54	60	0	28
55	240	0	43
56	240	60	38
57	60	60	20
58	120	60	25
59	60	120	18
60	90	60	21
61	60	90	18

just-entered terminal link was started when the initial links recommenced. The other initial-link timer remained timed out. When one initial-link schedule was 0 sec, the 3-sec change-over delay requirement resulted in more than one initial-link response being emitted per terminal-link entry on this key.

Bird 186 died after Condition 50.

RESULTS AND DISCUSSION

The data obtained from Experiment 2 are shown in Appendix 2, but again I shall investigate only initial-link response and time allocation. A comparison of the data in Appendices 1 and 2 shows that, as expected, the independent initial-link VI schedules allowed a much greater variation in terminal-link entries.

Figure 8 shows log initial-link response ratios for the conditions with 15- and 30-sec terminal delays when the smaller initial link was VI 30-sec. Straight lines were fit to the data as in Experiment 1, and it is evident from the standard deviations shown in Figure 8 that the data were well fitted by straight lines. The mean response intercept was .34 (range -.29 to .60), compared to .43 with the same terminal

links in Experiment 1 (Figure 6), but there were no consistent differences in the values of these intercepts for the six birds. There was one inexplicable result in these data—the bias value for Bird 182, which was similar to that obtained in Experiment 1 when both terminal links were 0 sec, and smaller than the bias obtained when both terminal delays were 5 sec (Figure 3). The data fit for this bird was quite good.

The mean sensitivity to the terminal-link entry ratio for response measures was .68, with a range of .49 to .81. This may be compared to the value of .8 found in Experiment 1 (Figure 8) for the same terminal delays. For the group of birds, there were no consistent differences in the slopes between the dependent and independent initial-link procedures, and the value of response sensitivity to reinforcement was much the same as the sensitivity to reinforcement values obtained throughout Experiment 1.

Mean time-allocation sensitivity to reinforcement was .75 (range .54 to .93; Table 3), and five of the six birds' time-allocation sensitivities were greater than response-allocation sensitivities. Time-allocation sensitivities showed no consistent changes from those obtained with dependent initial-link schedules. Bias values averaged .48 (range -.27 to .90), compared with .61 for the same terminal links in Experiment 1. As with response biases, it was Bird 182 which produced the negative bias. All the time-allocation intercepts were more positive than the equivalent response-allocation intercepts.

Figure 9 shows the effects of varying the initial-link schedules when one was always 0 sec in duration. The terminal delays were again 15 and 30 sec. The mean bias value was .91 (range .15 to 1.23), and all birds showed an increased bias when compared with the shorter initial-link VI 30-sec conditions (Figure 8). The mean sensitivity to the terminal-link entry ratio was .51 and ranged from .37 to .69, representing a consistent decrease for all five birds from the sensitivity obtained when the smaller initial link was VI 30-sec. It also represents a consistent decrease from the sensitivities obtained when the same terminal delays were arranged with dependent initial-link schedules (Experiment 1, Figure 6).

Time-allocation sensitivity averaged .42 and ranged from -.06 (Bird 182) to .70 (Table 3).

Fig. 8. Log initial-link response ratios (right/left) as a function of log terminal-link entry ratios when the terminal delays were 15 and 30 sec, and the smaller initial-link schedule was VI 30-sec. Least-squares regression lines, and below these the standard deviations of the parameter estimates, are shown for each bird. The origins of the graphs are shown by crosses, and the data for Birds 181 and 182 share the same origin. Unfilled and filled data points distinguish between birds.

For four of the five birds, time-allocation sensitivities were greater than the equivalent response-allocation sensitivities, and for all five birds time-allocation sensitivities were less than those obtained when the smaller initial-link was VI 30-sec. On the other hand, time-allocation biases (mean 1.27, range .34 to 1.69) were all larger than those obtained when the smaller initial link was VI 30-sec. Time-allocation biases were also all greater than response-allocation biases.

Finally, Figure 10 shows the effects of varying one initial-link schedule when the smaller schedule was VI 60-sec and the terminal delays were 15 and 30 sec. The mean bias was .37, consistently smaller than that obtained when the smaller initial-link schedule was 0 sec (Figure 9) but not consistently different from those obtained when the smaller initial link was VI 30-sec. Again, Bird 182 produced an intercept that was strongly negative, rather than positive as expected. The mean slope was

.78 (range .57 to 1.01), which was consistently larger than those obtained with 0-sec smaller initial links but not consistently different from those obtained using 30-sec smaller initial links (Figure 8).

With VI 60-sec smaller initial-link schedules, time-allocation sensitivities (Table 3) averaged .91 (range .63 to 1.32), all sensitivities were greater than equivalent response-allocation sensitivities, and none were consistently different from those obtained with smaller initial links of 30 sec. But all the 60-sec shorter initial-link sensitivities were greater than those obtained with smaller initial links of 0 sec. The mean time-allocation bias was .53 (range -.5, Bird 182, to 1.38), and three of the four biases were greater than the equivalent response-allocation biases. All time-allocation biases were smaller than those obtained with 0-sec smaller initial links but were not consistently different from those obtained with 30-sec smaller initial links.

Fig. 9. Log initial-link response ratios (right/left) as a function of log terminal-link entry ratios when the terminal delays were 15 and 30 sec and the smaller initial-link schedule was FR 1. Least-squares regression lines, and below these the standard deviations of the parameter estimates, are shown for each bird. The origins of the graphs are shown by crosses, with the data for Birds 181 and 182 sharing the same origin. The origins for Birds 183 and 186 fell on the X axis. Unfilled and filled data points distinguish between birds.

Overall in Experiment 2, it was clear from both time- and response-allocation data that 0-sec smaller initial links increased the bias caused by the differing terminal delays. Thus, because the terminal links were constant, the shorter initial-link interval affected b in Equation 3. There was no change in b between smaller initial-link VI 30-sec and VI 60-sec schedules. Generally, time- and response-allocation sensitivities were the same as in Experiment 1, but there was an indication from both measures that sensitivities were lower when the smaller initial link was 0 sec. This result, though, is not strong: The number of comparisons was small, and the performances of Bird 182, although not irregular, were quite idiosyncratic. As in Experiment 1, time-allocation sensitivities (a in Equation 3) were normally larger than response allocation sensitivities, and time-allocation biases (b in Equation 3) were also normally larger than response-allocation biases.

GENERAL DISCUSSION

Experiment 1 found a constant value of a in Equation 3 for all values of terminal-link delays. These data, obtained using dependent initial-link VI schedules with a 3-sec change-over delay, were quite different from the results reported by Davison (1976) and by Squires and Fantino (1971). Those experiments gave data that indicated that a , sensitivity to the terminal-link entry ratio, was a function of the values of the terminal-link schedules. The first part of Experiment 2 (a smaller initial-link schedule of VI 30-sec and 15- vs. 30-sec terminal delays) was carried out to determine whether the difference between Experiment 1 and the previous results arose from the use of dependent initial-link schedules. Comparisons of the obtained values of a (Figures 6 and 8 for response allocation; Table 3 for time allocation) showed no consistent differences in a between independent and de-

Fig. 10. Log initial-link response ratios (right/left) as a function of log terminal-link entry ratios when the terminal delays were 15 and 30 sec and the smaller schedule in the initial links was VI 60-sec. Least-squares regression lines, and below these the standard deviations of the parameter estimates, are shown for each bird. Crosses show the origins of the graphs, with the data for Birds 181 and 182 sharing the same origin. Unfilled and filled data points distinguish between birds.

pendent scheduling, though the obtained entry ratio varied much more widely in Experiment 2. If dependent vs. independent scheduling cannot explain the difference in results, the strong implication is that they arose from the use of a changeover delay in the present experiment. The changeover delay is thought to be a potent controlling variable in concurrent-schedule performance (de Villiers, 1977). Its

Table 3

Slopes and intercepts, and their standard deviations, for each subject in each generalized matching analysis conducted in Experiments 1 and 2. Both response- and time-allocation data are shown. The slopes are estimates of a , and the intercepts are estimates of b log (T_{b2}/T_{a2}), both in Equation 3.

Bird	Responses		Times	
	Slope (SD)	Intercept (SD)	Slope (SD)	Intercept (SD)
<i>Experiment 1: Nonindependent schedules</i>				
<i>0- vs. 0-sec terminal delays</i>				
181	.69(.11)	.12(.05)	.77(.15)	.16(.06)
182	1.11(.20)	-.28(.09)	1.22(.23)	-.35(.10)
183	.39(.12)	-.04(.05)	.70(.11)	.07(.05)
184	.36(.15)	.10(.06)	.37(.11)	.19(.05)
185	.69(.15)	-.14(.07)	.80(.13)	-.32(.06)
186	.73(.20)	-.25(.09)	.96(.23)	-.18(.10)

Bird	Responses		Times	
	Slope (SD)	Intercept (SD)	Slope (SD)	Intercept (SD)
<i>5- vs. 5-sec terminal delays</i>				
181	.60(.05)	.06(.02)	.71(.14)	.30(.07)
182	.89(.14)	-.07(.06)	1.06(.24)	.02(.11)
183	.43(.09)	-.13(.04)	.75(.09)	.01(.04)
184	.53(.07)	-.12(.03)	.77(.10)	.02(.04)
185	.57(.06)	.05(.03)	.96(.18)	.11(.08)
186	.89(.14)	-.11(.06)	1.02(.19)	.11(.08)
<i>0- vs. 3-sec terminal delays</i>				
182	.54(.07)	.32(.03)	.67(.12)	.07(.05)
183	.58(.04)	.16(.02)	.71(.06)	.38(.02)
184	.56(.03)	.39(.03)	.60(.04)	.43(.02)
186	.81(.08)	.02(.04)	1.26(.14)	.29(.06)
<i>0- vs. 10-sec terminal delays</i>				
181	.63(.07)	.55(.03)	.62(.09)	.76(.04)
182	.93(.29)	.63(.12)	1.02(.35)	.77(.14)
183	.69(.08)	.52(.03)	.70(.07)	.74(.03)
184	.34(.04)	.51(.02)	.28(.07)	.71(.03)
185	.56(.14)	.64(.06)	.78(.11)	.81(.05)
186	.95(.22)	.11(.09)	1.07(.18)	.56(.07)
<i>15- vs. 30-sec terminal delays</i>				
181	.79(.06)	.55(.04)	.82(.09)	.69(.05)
182	.97(.08)	.02(.05)	.96(.07)	.16(.05)
183	.83(.11)	.47(.07)	.88(.16)	.69(.10)
184	.60(.10)	.47(.06)	.58(.11)	.73(.07)
185	.98(.06)	.38(.04)	1.09(.10)	.55(.06)
186	.62(.17)	.67(.10)	.61(.14)	.83(.09)
<i>Experiment 2: Independent schedules, 15- vs. 30-sec delays</i>				
<i>30-sec shorter initial link</i>				
181	.56(.07)	.54(.06)	.73(.10)	.63(.09)
182	.81(.09)	-.29(.10)	.73(.08)	-.27(.09)
183	.81(.07)	.27(.09)	.87(.11)	.44(.14)
184	.63(.08)	.60(.08)	.69(.11)	.90(.12)
185	.80(.10)	.50(.11)	.93(.13)	.63(.14)
186	.49(.08)	.42(.07)	.54(.06)	.55(.05)
<i>0-sec shorter initial link</i>				
181	.55(.08)	1.19(.08)	.58(.07)	1.41(.08)
182	.37(.45)	.15(.63)	-.06(.22)	.34(.31)
183	.69(.12)	1.00(.09)	.70(.12)	1.48(.09)
184	.55(.08)	1.23(.09)	.41(.08)	1.69(.08)
185	.41(.14)	.98(.12)	.46(.11)	1.41(.09)
<i>60-sec shorter initial link</i>				
181	.74(.07)	.43(.04)	.97(.08)	.45(.04)
182	.60(.05)	-.47(.02)	.63(.06)	-.50(.02)
183	.97(.07)	.35(.09)	1.00(.14)	.78(.18)
184	.57(.29)	1.09(.31)	.64(.33)	1.38(.36)
185	1.01(.11)	.47(.11)	1.32(.12)	.59(.12)

absence is often, but not invariably, associated with abnormally low sensitivities to reinforcement-frequency ratios. In the present experiments, rather low response and time sensitivities to reinforcement were found with a 3-sec changeover delay in the concurrent-schedule conditions (Figure 2 and Table 3). The effects of a changeover delay on concurrent-chain schedule performance seemed quite different

from the effects generally reported for concurrent-schedule performance. Here, it appeared to eliminate any effect of terminal-delay values on sensitivity (a in Equation 3) to the terminal-link entry ratio. Although this effect needs replication, and is being replicated, the benefits of using the present procedure are clear. In it, preference changes produced by changing terminal delays result only from changes in b $\log(T_{b2}/T_{a2})$ in Equation 3. In the usual (no changeover delay) procedure, a also changes as the terminal delays are varied. Thus, the present procedure will make quantification of terminal-link effects (i.e., the relationship between terminal-link values and the bias they cause in initial-link performance) much easier. This possibility is further discussed below.

Supporting evidence that changeover delays have an important simplifying effect when they are arranged in the initial links of concurrent chains comes from Baum (1974a). He used a concurrent-chain schedule in which the terminal links were concurrent, rather than single, schedules. He varied the ratio of entries into the terminal links (the initial-link reinforcement ratio) and found sensitivity (a) values of between .93 and 1.08, a close approximation to matching. Baum suggested that the difference between his results and those predicted by the Squires and Fantino (1971) concurrent-chain model was caused by Baum's use of a 1.5-sec changeover delay in the initial links.

An important result of Experiment 1 was that the sensitivity to the terminal-link entry ratio (a in Equation 3) was unaffected by the values of the terminal-link delays investigated. Values of a in Experiment 2 (independent schedules) were similar to those obtained in Experiment 1 for the VI 30-sec shorter initial link (Figure 8) and for the VI 60-sec shorter initial link (Figure 10) for both response- and time-allocation measures (Table 3). Thus, a for these parts of Experiment 2 was also unaffected by the value of the shorter initial-link schedule. However, there was some indication that a for both response- and time-allocation data fell when 0-sec shorter initial links were arranged (Figure 9 and Table 3). A Friedman analysis of variance (Siegel, 1956) was used to determine whether the values of a for any condition (Experiments 1 and 2) were different from those obtained in any other condition. In order to carry out this test, it was

necessary to estimate the values of a in conditions in which data were missing. This was done by taking the median of the obtained values for other birds in that condition. This procedure makes the test less conservative—i.e., more likely to reject the null hypothesis—than taking the median of the data for a bird. For response-allocation sensitivity, the result was $\chi^2 = 12.2$, $N = 6$, $k = 8$, not significant at $\alpha = .05$. Thus, there was no evidence that the data in any condition were different from those in any other condition. For time-allocation sensitivity, $\chi^2 = 16.2$, which was significant at $\alpha = .05$. The maximally different data were from the 0-sec shorter initial-link conditions of Experiment 2. Although this result could indicate that a in Equation 3, at least for time allocation, was affected by the value of the smaller initial link, this conclusion is not strong. First, the idiosyncratic performance of Bird 182 (response- and time-allocation sensitivities of .37 and -.06) has already been mentioned. Second, the time estimate of a for the 0-sec smaller initial-link conditions fell within two standard deviations of the mean for the other seven parts of the experiments for Birds 181, 183, and 184 but outside two standard deviations for Birds 182 and 185. Third, analyses of variance on response- and time-allocation sensitivities gave conflicting results. It is therefore premature to conclude that a is a function of the value of the shorter initial-link schedule. Rather, a could be taken as unaffected by the shorter initial link, with the proviso that some further investigation is needed.

The present data show that a was consistently greater for time allocation than it was for response allocation. The same was true of the values of the biases caused by the terminal-link delays, indicating that b in Equation 3 was also greater for time allocation. The first of these results has been commonly found in concurrent-schedule research (Baum, 1979; Taylor & Davison, 1983), and the latter effect has also been reported (e.g., Hunter & Davison, 1982). The present results are again shown to be consistent with a generalized matching-law analysis (Equations 2 and 3) such as is typically applied to concurrent-schedule performance.

Although the focus of the present work was on varying the relative frequency of terminal-link entries while keeping the terminal delays

constant, a considerable amount of data was collected using different-valued smaller initial-link VI schedules. These data relate to the effects of initial-link schedule values on $b \log (T_{b2}/T_{a2})$ in Equation 3. Experiment 1 showed that when the terminal delays were 0 vs. 3 sec, initial-link response allocation did not change over the range of equal initial-link VI schedules from 30 sec to 120 sec. Experiment 2 supported this finding with 15- vs. 30-sec delays over the range from VI 30-sec to VI 60-sec (Figures 8 and 10) but additionally showed large increases in response allocation when the shorter initial link was decreased to 0 sec (Figure 9). The effect of the smaller initial link on the bias caused by constant terminal-link differences (that is, b in Equation 3) is thus nonlinear, and asymptotes (in these data) at a smaller initial-link value below 30 sec. A similar effect of initial-link context has been reported before (Fantino, 1969; Wardlaw & Davison, 1974), and a decreasing preference with increasing initial-link time was also noted by Fantino and Davison (1983) with VI 20-sec vs. VI 40-sec terminal links. This trend is predicted by both the Squires and Fantino (1971; see their Figure 1) model and that proposed by Fantino and Davison (1983). But both models predict that the asymptote of preference is indifference. The present preference data reached an asymptote that represented a considerable preference for the shorter terminal delay (see the intercepts in Figures 8 and 10). The divergence of the present results from both previous results and theories must arise from the different procedures used here.

The present experiment also provided a high-quality set of data for the choice between 0-sec terminal delays and delays of 0, 3, and 10 sec. These data are the intercepts of the fitted lines in Figures 2, 4, and 5 in which the smaller initial-link schedule was VI 30-sec. A further single data point was available from Condition 21 in which 0- vs. 30-sec delays were arranged. For this condition, the initial links were concurrent VI 30-sec VI 120-sec. Knowing the sensitivity (a) to the terminal-link entry ratio for each bird allows an estimate of the bias caused by this pair of delays to be calculated. All of these bias estimates are estimates of $b \log (T_{b2}/T_{a2})$ in Equation 3.

Bias thus estimated is shown in Figure 11 as a function of the logarithm of the ratio of the

Fig. 11. Initial-link bias values as a function of the log reinforcer-rate ratio in the terminal links. One arranged terminal-link delay was always 0 sec but was taken as an obtained delay of 1 sec. The other arranged values were varied from 0 sec (taken as 1 sec) to 30 sec. The first three data points on the graph came from the curve fits in Figures 2, 4, and 5, and are each based on five experimental conditions. The last data point was obtained from Condition 21.

terminal-link reinforcement rates. As arranged, of course, the terminal-link reinforcement-rate ratio was always infinite as one delay was 0 sec. However, as in Chung and Herrnstein (1967), the 0-sec delay was taken as a constant delay of 1 sec. The actual value of this constant will determine the slope of the relation (b) and, to a small extent, its linearity. The response-allocation data are shown for all birds in Figure 11 (time-allocation data followed the same function but were slightly more extreme). An assessment of the deviations of the individual-bird data from either a pooled fitted line or from their individual fitted lines was done using a Friedman analysis of variance. Neither test indicated any significant deviation from linearity in the data. Thus, it is possible that the measured biases were a linear function of the log terminal-link reinforcement-rate ratio for constant smaller initial and terminal links. That is, b (terminal-link sensitivity) in Equation 3 is constant for constant smaller initial and terminal links. Such an hypothesis was effectively suggested by Duncan and Fantino

(1970). But the value of b was certainly not the same for other values of smaller terminal links. For instance, the biases obtained when the smaller terminal delays were 15 sec fell above the functions shown in Figure 11 in 10 of 12 cases. Thus, as the shorter terminal-link delay was lengthened, terminal-link bias and b in Equation 3 increased (Duncan & Fantino, 1970).

Were the data obtained in this experiment well predicted by the Squires and Fantino (1971) model or the modification of that model suggested by Fantino and Davison (1983)? An analysis of the present data showed that the Squires and Fantino model (Equation 1 of Fantino & Davison) predicted group-average initial-link response proportions with a mean unsigned deviation of .09 (59% of the data variance accounted for) compared with a mean deviation of .08 for this model predicting the Fantino and Davison data. The modified model (Fantino & Davison's Equation 2) does predict the present data better (mean deviation .076, 72% of the variance accounted for), but this is a poor fit when compared with the ability of the Fantino and Davison model to account for their data (mean deviation .06, 93% of the variance accounted for). Linear regressions between obtained and predicted proportions showed that the Squires-Fantino model reliably overpredicts the present data, but the obtained slope (1.06, SD .07) and intercept (0, SD .05) obtained with Fantino and Davison's modified model show that it neither under nor over predicts reliably. Thus, the large mean deviation, and small variance accounted for, by Fantino and Davison's Equation 2 might simply result from error variance in the present data. But that explanation is untenable as the Fantino-Davison model cannot predict constant sensitivities to initial-link reinforcer ratios (a in Equation 2 of this paper) when the initial links are varied with constant, but different, terminal schedules or delays. Thus, the reconciliation of the two theoretical approaches, or of the two procedures used for generating the data (the presence or absence of a changeover delay, and fixed-delay or variable-interval terminal links) is problematical.

In conclusion, the present concurrent-chain procedure produced data which were, in one respect, consistent with concurrent-schedule data. Sensitivity to the initial-link reinforcer-rate ratio remained constant from concurrent

to concurrent-chain performances and was independent of the bias caused by terminal-link delay differences. This sensitivity was also independent of the size of the smaller initial link, with the possible exception of very short smaller initial links. However, unlike concurrent-schedule performances (e.g., Hunter & Davison, 1982), sensitivity to the terminal-link reinforcer-rate ratio (b in Equation 3) was not constant but increased with increases in shorter terminal-link delays and with decreases in the shorter initial-link schedule. Further research can take one of two options: to quantify the relationship between b and the two shorter schedule values, or to develop procedures that will eliminate this remaining troublesome interaction. Equation 3, the generalized matching approach, but with b a variable rather than a constant, is thus validated for the present procedure. This may be a useful basis on which to build more general quantitative concurrent-chain models.

REFERENCES

- Baum, W. M. Chained concurrent schedules: Reinforcement as situation transition. *Journal of the Experimental Analysis of Behavior*, 1974, 22, 91-101.
- (a)
- Baum, W. M. On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, 1974, 22, 231-242.
- (b)
- Baum, W. M. Matching, undermatching, and overmatching in studies of choice. *Journal of the Experimental Analysis of Behavior*, 1979, 32, 269-281.
- Baum, W. M., & Rachlin, H. C. Choice as time allocation. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 861-874.
- Chung, S., & Herrnstein, R. J. Choice and delay of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1967, 10, 67-74.
- Davison, M. C. Preference for fixed-interval schedules: Effects of unequal initial links. *Journal of the Experimental Analysis of Behavior*, 1976, 25, 371-376.
- Davison, M. C., & Temple, W. Preference for fixed-interval schedules: An alternative model. *Journal of the Experimental Analysis of Behavior*, 1973, 20, 393-403.
- de Villiers, P. Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior*. Englewood Cliffs, N.J.: Prentice-Hall, 1977.
- Duncan, B., & Fantino, E. Choice for periodic schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1970, 14, 73-86.
- Fantino, E. Choice and rate of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 723-730.

- Fantino, E. Conditioned reinforcement: Choice and information. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior*. Englewood Cliffs, N.J.: Prentice-Hall, 1977.
- Fantino, E., & Davison, M. Choice: Some quantitative relations. *Journal of the Experimental Analysis of Behavior*, 1983, 40, 1-13.
- Ferguson, G. A. *Nonparametric trend analysis*. Montreal: McGill University Press, 1965.
- Herrnstein, R. J. Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1961, 4, 267-272.
- Hunter, I., & Davison, M. Independence of response force and reinforcement rate on concurrent variable-interval schedule performance. *Journal of the Experimental Analysis of Behavior*, 1982, 37, 183-197.
- Neuringer, A. J. Delayed reinforcement versus reinforcement after a fixed interval. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 373-383.
- Schneider, J. W. Reinforcer effectiveness as a function of reinforcer rate and magnitude: A comparison of concurrent performances. *Journal of the Experimental Analysis of Behavior*, 1973, 20, 461-471.
- Shimp, C. P. The concurrent reinforcement of two interresponse times: The relative frequency of an interresponse time equals its relative harmonic length. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 403-411.
- Siegel, S. *Nonparametric statistics for the behavioral sciences*. New York: McGraw-Hill, 1956.
- Squires, N., & Fantino, E. A model for choice in simple concurrent and concurrent-chains schedules. *Journal of the Experimental Analysis of Behavior*, 1971, 15, 27-38.
- Stubbs, D. A., & Pliskoff, S. S. Concurrent responding with fixed relative rate of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 887-895.
- Taylor, R., & Davison, M. Sensitivity to reinforcement in concurrent arithmetic and exponential schedules. *Journal of the Experimental Analysis of Behavior*, 1983, 39, 191-198.
- Todorov, J. C. Interaction of frequency and magnitude of reinforcement on concurrent performances. *Journal of the Experimental Analysis of Behavior*, 1973, 19, 451-458.
- Wardlaw, G. R., & Davison, M. C. Preference for fixed-interval schedules: Effects of initial-link length. *Journal of the Experimental Analysis of Behavior*, 1974, 21, 331-340.
- Williams, B. A., & Fantino, E. Effects on choice of reinforcement delay and conditioned reinforcement. *Journal of the Experimental Analysis of Behavior*, 1978, 29, 77-86.

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Appendix 1

Experiment 1. The numbers of responses emitted and seconds spent responding, and the number of terminal-link entries obtained, in each experimental condition. The data were averaged over the last five sessions of each condition.

Condi- tion	Initial-link Responses		Initial-link Time (sec)		Terminal-link Entries		Condi- tion	Initial-link Responses		Initial-link Time (sec)		Terminal-link Entries	
	Right	Left	Right	Left	Right	Left		Right	Left	Right	Left	Right	Left
BIRD 181							BIRD 182—continued						
9	578	322	855	288	32	18	24	534	347	722	269	27.4	12.6
10	761	440	826	378	17	33	25	155	909	177	1193	7.6	32.4
11	403	507	547	830	17.2	32.8	26	441	542	551	808	19.8	20.2
12	769	287	1089	325	39.6	10.4	27	617	372	721	469	32	8
13	543	298	672	292	25	25	28	474	263	711	323	29	6
14	685	306	917	353	33.4	16.6	29	325	187	554	175	18.2	16.8
15	445	1005	490	1009	10	40	30	506	161	826	164	28.6	5
16	792	271	794	155	26	24	31	320	648	540	970	11.2	22
17	1304	227	1248	137	33	17	32	626	458	998	669	23.8	10.4
18	971	611	921	403	10.6	39.4	33	152	559	250	680	7	28
19	1071	119	1290	96	32	8	34	405	233	658	304	23	12
20	765	295	879	177	13.8	26.2	35	205	511	331	581	12.4	22.6
21	777	233	958	151	6.8	29	36	839	78	1181	104	30.2	4.8
22	726	238	893	150	33.2	6.8	37	170	562	263	715	5.6	29.4
23	399	506	542	345	12.2	27.8	38	583	187	804	231	26	9
24	630	326	815	184	27.8	12.2	39	186	643	284	737	8.4	26.6
25	274	625	418	690	7.2	32.8	40	715	89	1095	90	31.2	3.8
26	532	544	782	577	20	20	41	91	656	174	835	4.4	30.6
27	616	306	968	237	33.2	6.8	BIRD 183						
28	640	182	841	137	27.8	6	1	1152	1290	786	921	24	26
29	580	157	687	102	17.2	17.8	2	1614	903	883	592	23.4	26.6
30	647	53	1137	47	29.4	5.8	3	2146	1233	1364	832	33.8	16.2
31	667	427	897	440	8.2	20.6	4	1810	1715	958	901	17	33
32	714	146	1214	115	18.2	9.2	5	2155	1567	1200	919	17.4	17.6
33	360	399	506	429	7.2	25.8	6	1528	414	1223	184	40.6	9.4
34	862	109	993	72	23.2	11.8	7	813	1153	543	648	10	40
35	651	222	763	234	11.4	23.4	8	702	504	722	246	25.4	24.6
36	858	77	1089	100	30.8	4.2	9	1120	581	958	268	32.6	17.4
37	477	491	596	457	5	29	10	911	931	661	424	17.2	32.8
38	833	53	1056	56	26.8	7.4	11	848	1080	458	696	17	33
39	521	415	659	328	9.6	25.2	12	1319	909	1053	371	40.4	9.6
40	798	46	1130	46	31.4	3.6	13	814	639	583	332	25	25
41	387	483	455	570	4.4	28.6	14	1087	1055	762	427	33.2	16.8
BIRD 182							15	841	2063	375	1008	9.2	40.8
1	1097	1292	722	1046	23.6	26.4	16	1400	395	858	136	25.6	24.4
2	1032	947	850	751	24	26	17	1298	324	1153	162	32.8	17.2
3	1675	897	1324	737	33.8	16.2	18	1244	995	833	426	10.2	39.8
4	1462	1137	1144	942	16.2	33.8	19	1352	135	1305	83	32.2	7.8
5	1341	897	1012	1003	18.2	16.8	20	877	367	732	187	14	26
6	1174	256	1087	317	40	10	21	1400	186	1372	223	8	29
7	614	601	426	907	9.6	40.4	22	794	594	827	251	32.6	7.4
8	742	459	500	651	24.6	25.4	23	593	838	334	522	12.8	27.2
9	1042	311	829	446	33.8	16.2	24	704	718	596	313	27	13
10	870	595	587	639	16.8	33.2	25	366	1141	280	798	7.4	32.6
11	447	1403	283	1193	17	33	26	772	1094	586	790	20.2	19.8
12	1273	611	1050	508	40.6	9.4	27	916	629	862	438	33.4	6.6
13	574	658	505	625	25	25	28	868	317	827	260	28.8	6.2
14	752	791	665	810	32.4	17.6	29	391	433	335	376	16.8	18.2
15	143	1874	108	1966	10.4	39.6	30	1151	150	1096	123	28.2	6.8
16	984	324	767	209	27	23	31	889	1146	694	860	10.4	23.4
17	1049	225	1148	168	32.6	17.4	32	1078	640	1269	491	23.8	11.2
18	764	698	656	536	10.2	39.8	33	533	609	581	410	7.6	27.4
19	1431	58	1405	35	31.6	8.4	34	1193	145	1263	94	23.2	11.8
20	977	235	932	145	13.4	26.6	35	1034	266	1067	118	12.4	22.2
21	669	453	595	483	7.4	31.6	36	910	77	1170	51	30.4	4.6
22	796	271	914	210	32.2	7.8	37	598	615	572	460	5	30
23	385	551	451	455	12.8	27.2	38	1025	133	1192	81	25.6	9.4

Condi- tion	Initial-link Responses		Initial-link Time (sec)		Terminal-link Entries		Condi- tion	Initial-link Responses		Initial-link Time (sec)		Terminal-link Entries	
	Right	Left	Right	Left	Right	Left		Right	Left	Right	Left	Right	Left
BIRD 183—continued							BIRD 185—continued						
39	689	555	878	266	9	26	24	722	376	694	241	27.6	12.4
40	941	48	1276	28	30.8	4.2	25	278	666	201	952	7	33
41	357	1040	346	769	3.4	31.6	26	708	532	664	682	19.8	20.2
BIRD 184							27	757	278	1106	247	32.4	7.6
1	966	1597	794	888	24	26	28	402	106	884	79	28.2	6.8
2	1832	729	1045	566	24	26	29	362	162	690	145	17	18
3	2958	941	1416	629	34	16	30	628	79	1082	84	29	6
4	1970	1935	918	1208	15.6	34.4	31	328	515	552	868	10.2	22
5	2643	1439	1210	882	17.4	17.6	32	709	181	1456	308	24	11
6	2368	445	1278	188	41.6	8.4	33	179	367	300	701	6.8	28.2
7	1233	1290	653	639	8.8	41.2	34	507	136	905	185	22.2	12.8
8	1701	537	775	254	24.8	25.2	35	313	261	549	400	11.6	23.5
9	2013	563	1008	265	32.8	17.2	36	728	42	1214	28	30.2	4.8
10	1481	962	783	444	17	33	37	245	486	408	671	4.4	30.6
11	1207	1254	623	627	17	33	38	702	72	1114	60	25.6	9.4
12	1835	963	973	414	40.8	9.2	39	415	363	673	405	8.8	26.2
13	1236	594	627	284	25	25	40	646	43	1149	57	31	4
14	1571	1155	820	422	32.4	17.6	41	124	624	212	853	3.6	31.4
15	1286	2005	679	771	10	40	BIRD 186						
16	1515	480	766	174	26.2	23.8	1	938	1087	824	939	24	26
17	1941	478	1039	174	32.8	17.2	2	1132	666	1012	586	23.8	26.2
18	1860	986	1067	323	10.4	39.6	3	1587	692	1646	506	34	16
19	1747	333	1019	126	32.2	7.8	4	1172	1345	1105	919	16.4	33.6
20	1552	532	811	163	13	27	5	1572	1150	1352	773	17.8	17.2
21	1804	342	1351	142	6	27.6	6	652	149	1320	71	41.2	8.8
22	948	565	844	230	32.2	7.6	7	398	1138	308	982	9.4	40.6
23	424	1007	377	500	13.6	26.4	8	627	568	702	428	24.8	25.2
24	818	736	586	346	26.6	13.4	9	638	432	996	296	33.8	16.2
25	455	1100	284	805	7.8	32.2	10	508	860	634	592	17.2	32.8
26	846	1119	600	785	20	20	11	490	1194	397	929	17.4	32.6
27	1013	507	914	326	32.2	7.8	12	663	430	1093	395	39.8	10.2
28	543	650	537	496	28.8	6.2	13	396	407	463	388	25	25
29	610	402	549	217	18.8	16.2	14	501	882	554	788	33.2	16.8
30	885	259	968	161	29	6	15	298	2017	198	1619	9.2	40.8
31	677	1229	464	1036	10.2	23.2	16	494	287	835	193	25.8	24.2
32	1278	447	1525	287	24.6	10.4	17	627	347	1300	203	32.6	17.4
33	614	723	668	378	5.4	29.4	18	272	1083	479	767	11.2	38.8
34	1064	195	1029	108	23.4	11.6	19	614	135	1197	82	31.8	8.2
35	1026	322	975	133	12.2	22.8	20	476	437	822	302	13	27
36	1081	109	1157	64	29.6	5.4	21	774	182	1141	200	7	28.4
37	744	720	611	395	5.6	29.4	22	785	269	1029	163	31.8	8.2
38	1098	128	1173	65	26.6	8.4	23	405	844	447	465	13.6	26.4
39	875	379	897	174	9.2	25.8	24	691	424	729	298	26.2	13.8
40	1128	73	1297	61	31.6	3.4	25	275	1134	265	935	7.4	32.6
41	636	699	647	443	4.4	30.6	26	554	1142	623	857	20.2	19.8
BIRD 185							27	510	543	835	469	32.6	7.4
9	640	363	984	194	33	17	28	432	565	664	520	27	6
10	326	574	666	400	17.6	32.4	29	317	494	439	336	18.8	16.2
11	384	839	263	1073	16.2	33.8	30	824	112	1164	84	28.6	6.4
12	951	550	792	648	40.6	9.4	31	812	975	901	737	10.4	22.6
13	540	455	351	493	25	25	32	1063	245	1377	205	22	8.4
14	773	780	601	654	33	17	33	618	391	731	307	7	26.4
15	256	1165	183	1313	10.2	39.8	34	968	93	1255	82	23.8	11.2
16	781	161	837	104	27	23	35	725	224	970	185	12.4	22.6
17	1172	130	1291	104	33.6	16.4	36	1164	95	1321	96	29.4	5.6
18	947	593	785	464	10	40	37	969	450	921	333	5	30
19	791	109	1079	65	32.4	7.6	38	963	69	1217	56	26.2	8.8
20	922	243	905	182	14	26	39	832	235	891	221	8.4	24.6
21	1046	134	1124	163	6.6	27	40	1161	28	1368	29	31	4
22	508	228	849	169	32.6	7.4	41	662	381	748	307	3.2	28.4
23	494	659	497	427	13	27							

Appendix 2

Experiment 2. Numbers of responses emitted and seconds spent responding, and the number of terminal-link entries obtained, in each experimental condition. The data were averaged over the last five sessions of each condition.

Condi- tion	Initial-link Responses		Initial-link Time (sec)		Terminal-link Entries		Condi- tion	Initial-link Responses		Initial-link Time (sec)		Terminal-link Entries	
	Right	Left	Right	Left	Right	Left		Right	Left	Right	Left	Right	Left
BIRD 181							BIRD 183—continued						
42	502	33	896	34	33.4	1.6	57	1304	44	1887	16	31.8	3.2
43	726	119	922	110	20.8	13.8	58	1250	322	1741	185	18.2	11.8
44	539	34	887	24	30.4	4.6	59	1099	13	1722	12	29.6	.4
45	446	423	480	456	4	30.6	60	889	130	1838	86	23.4	6.6
46	684	30	940	20	32.4	2.6	61	796	2	1741	1	29.8	.2
47	514	302	556	311	7.2	26.8	BIRD 184						
48	584	50	917	36	32.4	2.6	42	832	33	986	21	33.4	1.6
49	441	409	399	527	5.2	29.8	43	1204	51	1745	26	29.2	5.8
50	553	86	811	93	31.6	3.4	44	700	24	1077	10	33.2	1.8
51	212	81	207	40	2	33	45	632	592	819	407	5.4	28.8
52	590	6	1032	5	33.8	1.2	46	873	56	947	35	31.4	3.6
53	420	94	376	55	6.4	29.4	47	838	433	1149	293	10.4	24.2
54	960	45	1139	39	20.8	14.2	48	786	67	1004	45	33.4	1.6
55	368	63	346	40	2.4	32.6	49	936	372	1130	255	9	26
56	434	664	430	950	4.2	27.8	50	920	15	1102	6	34.4	.6
57	899	206	1043	206	21.6	13.4	51	243	90	233	21	1.8	33.2
58	672	483	700	581	10.4	19.6	52	949	5	1099	4	34.6	.4
59	829	105	1360	112	24.8	5.2	53	1073	59	1491	27	13.4	20.4
60	785	220	1038	263	15	15	54	344	64	401	20	8.2	26.8
61	675	130	1035	143	22.4	7.6	55	867	82	1004	27	5	30
BIRD 182							56	1439	324	1734	216	8.4	17.4
42	483	207	769	306	31.6	3.4	57	1592	43	1955	25	31.4	3.6
43	188	321	270	394	10.2	24.8	58	1744	9	2415	4	21	3
44	45	388	88	657	7.8	27.2	59	1205	22	1798	12	29.2	.8
45	4	539	10	824	.2	34.8	60	1993	44	2362	24	26	3.4
46	53	560	126	997	12.4	21.6	61	1287	30	1812	21	28.8	1.2
47	8	540	21	833	.4	34	BIRD 185						
48	406	149	692	279	28.6	6.4	42	496	44	1001	56	33.6	1.4
49	60	436	87	722	3.4	31.6	43	724	124	1229	152	22.8	12.2
50	467	195	682	361	29.4	5.6	44	480	8	1065	4	33.8	1.2
51	42	51	74	18	.8	34.2	45	154	385	258	606	3.4	31.6
52	41	55	62	23	4.4	30.6	46	475	20	979	14	32.6	2.4
53	13	44	26	12	.8	34.2	47	247	310	451	496	5.4	29
54	9	39	21	11	1.4	33.6	48	661	4	1083	4	34	1
55	14	44	26	9	1.2	33.8	49	381	301	665	513	5.6	29.4
56	79	622	131	1190	5.6	27.6	50	510	26	993	46	33	2
57	137	550	207	1013	12	23	51	415	78	681	54	3.4	31.6
58	105	679	159	1095	6.8	23.2	52	611	0	1144	0	35	0
59	237	550	392	942	17.8	12.2	53	361	78	516	51	5.6	29.4
60	111	521	183	917	8.6	20.4	54	614	57	1274	40	21	14
61	150	500	243	911	14.4	15.6	55	135	58	239	36	2.2	32.8
BIRD 183							56	401	572	597	1004	6.4	27.6
42	620	14	1069	12	34.4	.6	57	841	44	1845	36	30.2	4.8
43	1251	71	1704	46	28.8	6.2	58	938	221	1540	254	15.4	14.6
44	522	21	1024	15	32.8	2.2	59	819	8	1830	4	29.2	.8
45	231	589	244	542	5	30	60	799	118	1918	149	23.8	5
46	570	20	980	14	33.2	1.8	61	780	6	1769	4	29	1
47	204	587	232	597	6	29	BIRD 186						
48	814	22	1042	16	34.6	.4	42	629	82	893	80	32.2	2.8
49	233	686	268	579	4.6	30.4	43	735	283	999	187	19.6	15.4
50	814	16	1025	19	34.6	.4	44	392	65	863	71	29	6
51	252	94	317	45	3.2	31.8	45	348	661	454	572	4.4	30.6
52	538	16	921	10	31.4	3.6	46	532	129	798	124	28.2	6.8
53	775	71	1106	34	14.4	17.8	47	630	236	765	303	8.8	24.8
54	831	26	1563	14	27.2	7.8	48	717	48	994	65	32.8	2.2
55	271	158	514	91	4.8	28.6	49	719	336	746	375	7.4	27.6
56	598	939	982	629	7.8	25.8	50	695	115	941	106	31.6	3.4