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PREFERENCE FOR FIXED-INTERVAL SCHEDULES: EFFECTS OF INITIAL-LINK LENGTH[1]

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Six homing pigeons were trained on a variety of concurrent-chains schedules in which the initial links were equal variable-interval schedules and the terminal links were fixed-interval schedules. Both terminal-link and initial-link schedules were systematically varied. The results showed that preference for a particular terminal-link schedule combination was greater, the shorter the initial-link schedules. The data closely matched predictions from the model of choice suggested by Davison and Temple (1973), but did not match predictions from two other models. An alternative method for analyzing concurrent-chains performance by assuming that the schedule consists of both chained schedules and successive, discriminated components that comprise multiple schedules, was suggested.

In concurrent-chains schedules (Autor, 1960), the preference for two mutually exclusive terminal-link schedules is measured by the relative number of responses (the number of responses on one key divided by the sum of the number of responses on both keys) emitted on concurrently available variable-interval (VI) schedules that constitute the initial links. The mutually exclusive terminal links are produced by responding in the initial links when the appropriate VI timer has completed operating. When a terminal link is entered, both initial-link timers stop operating, and the other key is blacked out and becomes inoperative. Research in this area has suggested that initial-link responses are related to terminal-link reinforcement rates in various ways (Herrnstein, 1964; Duncan and Fantino, 1970; Squires and Fantino, 1971; Davison and Temple, 1973), but no account consistent with data from all terminal-link schedules has emerged. Most experiments have used initial-link VI schedules with a mean interval of 60 sec, and only one major experiment has been reported that systematically varied initial-link parameters (Fantino, 1969). This experiment showed that preference for VI schedules, as measured by the ratio of the numbers of initial-link responses, was more extreme with shorter and equal initial-link schedules. However, recent work (*e.g.*, MacEwen, 1972) has shown that Fantino's (1969) model of choice generally underestimates preference ratios in the choice between fixed-interval (FI) schedules. An alternative model, suggested by Davison and Temple (1973), appears to have more generality than the Fantino model. The present experiment examined preference for several pairs of terminal-link FI schedules, and also investigated the effect of varying the size of the equal initial-link schedules.

METHOD

Subjects

Six homing pigeons, which had previously been trained on multiple schedules, were maintained at 80% ±15% of their free-feeding body weights, and were numbered 131 to 136.

Apparatus

Solid-state scheduling equipment, situated remote from the experimental chamber, controlled all experimental events. All data were recorded on impulse counters.

The sound-attenuated experimental chamber was fitted with an exhaust fan, which helped mask external noise, and contained three response keys 2 cm in diameter, 9.5 cm

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apart, and 22.5 cm from the grid floor. The center key was not used and was dark and inoperative at all times. The left key was transilluminated with either white or red light, and the right key by either white or green light. Two sources of feedback for pecks exceeding approximately 0.1 N were arranged: a 30-msec offset of the keylight and the click of a relay situated inside the experimental chamber. A grain hopper was situated directly below the center key and 10 cm from the floor. During reinforcement, the keylights were extinguished and the magazine illuminated. Apart from the key and magazine lights, there was no illumination in the chamber. In all parts of the experiment, pecks on darkened keys were ineffective. The reinforcer consisted of 3-sec access to wheat, and sessions ended in blackout after a fixed number of reinforcements (50 or 30) had been obtained. Supplementary feeding of mixed grain was given, if required, immediately after the daily experimental sessions.

Procedure

Since the animals had previously been trained to respond, no key-peck or schedule training was necessary, and they were placed directly on the standard concurrent-chains procedure (Autor, 1960). During the initial links, the animal was presented with two white keys, each associated with independent VI schedules of the same mean interval. When the left-key timer had timed an appropriate interval, the next response to that key turned the left key red and, simultaneously, the right key blacked out and became inoperative for the duration of the terminal link on the left key. Responses on the red key were followed by a single reinforcement according to an FI schedule, and following reinforcement both keys reverted to the white (initial-link) conditions. Similarly, when the right-key timer had timed an appropriate interval, a response to this key turned it green and, simultaneously, the left key blacked out and became inoperative for the duration of the terminal link on the right key. Responses on the green key were followed by a single reinforcement according to an FI schedule, and following reinforcement both keys reverted to the white (initial-link) conditions.

The timing of an interval by one initial-link timer had no effect on the operation of the other timer. For example, if both initial-link timers had timed intervals before the animal entered one terminal link, only the timer associated with the initial link preceding the terminal link just entered was restarted when the initial links again commenced.

Performance was assumed stable when each animal had reached a defined criterion five (not necessarily consecutive) times. Specifically, the criterion required that the median of the relative numbers of responses on one key (in the initial links) over five days be not more than 0.05 different from the median of the preceding five days. Thus, a minimum of 14 sessions was required to achieve stability. When all animals had met this criterion five times, the experimental parameters were changed for all animals as a group.

In the present experiment, both the initial- and terminal-link schedules were varied over the experimental conditions. The initial-link VI schedule intervals were all randomised from the arithmetic progression a, a + d, a + 2d, *etc*. The respective values of *a* and *d* for the schedules used were: VI 27-sec, 5 and 4; VI 38-sec, 5 and 6; VI 49-sec, 5 and 8; VI 115-sec, 5 and 20. The initial-link schedules were always equal, and one terminal-link schedule was always FI 5-sec. The other terminal-link schedule was either FI 5-sec, FI 7.5-sec, FI 10-sec, FI 15-sec, or FI 30-sec. All combinations of initial- and terminal-link comparisons were carried out, except for the choice between FI 5-sec and FI 30-sec with VI 27-sec initial links. In this case, preference would have been almost exclusive to the FI 5-sec terminal link. The sequence of conditions was designed to reverse preference between the keys in each successive condition when possible.

In all conditions of the experiment, the number of responses on the two keys in the initial and terminal links, and the number of entries into each terminal link, were recorded.

RESULTS

All measures of performance for the individual animals used in data calculation were the sum of the various measures over the last five sessions of each condition.[2] Response ra-

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[2] The complete data for all individual animals are available upon request from either author.

tios were calculated from these sums, and the group ratio data used were the geometric means of the response ratios of the individual birds. Table 1 shows the sequence of experimental conditions, number of sessions, average response and reinforcement rates, group initial-link response ratios, and the response ratios predicted by various models of choice.

The results (Figure 1) are similar to those reported by Fantino (1969), who studied the choice between VI terminal-link schedules when the initial-link VI schedules were varied. Fantino found that choice for a particular pair of terminal-link schedules became more extreme when the size of the equal initial-link schedules was reduced. This also describes the results of the present experiment, which used FI terminal-link schedules. The trend is evident in both the individual and the grouped data, but is less clear in the former due to the occurrence of some reversals from the trend, especially when the experimental conditions produced small choice ratios.

As Davison and Temple (1973) reported, entries into the two terminal links were not always equal, especially when choice ratios were large.

Figure 2 shows, on logarithmic coordinates, the initial-link response ratios from each condition for the grouped data as a function of the predicted choice ratios from Davison and Temple's model. This model is:

$$\frac{P_1}{P_2}=\frac{R_1}{R_2}\cdot\frac{E\cdot t_2}{t_1} \qquad \ldots.(1)$$

where subscripts 1 and 2 refer to Keys 1 and 2. *P* is the number of responses emitted in the initial links, *R* is the mean overall rate of reinforcement on a key (initial and terminal links), and *t* is the scheduled time in the terminal link. *E* is a factor that describes the number of times the animal entered each terminal link as a ratio of the number of times entries were arranged by the schedules in the initial links. In the present case, with equal initial-link schedules, this factor is simply the ratio of the number of terminal-link entries on the two keys.

Davison and Temple's model accounts for 85% of the variance of the grouped data and for between 58% and 90% of the variance for each individual (Table 2). The variance-accounted-for statistic is the difference between the variance of the data around the predictions

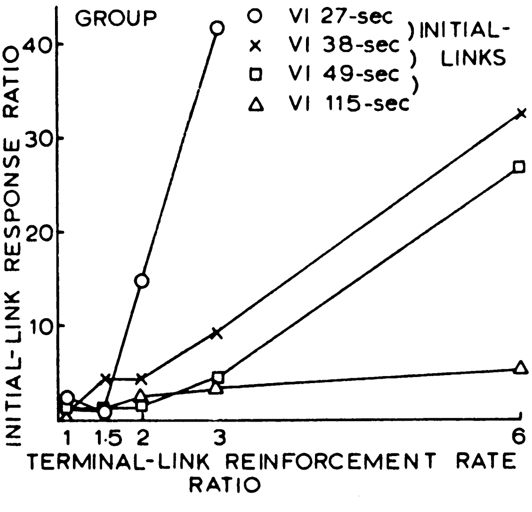

Fig. 1. Initial-link response ratios in the various experimental conditions as a function of the ratio of reinforcement rates in the terminal links. The data are geometric means of response ratios for the individual birds.

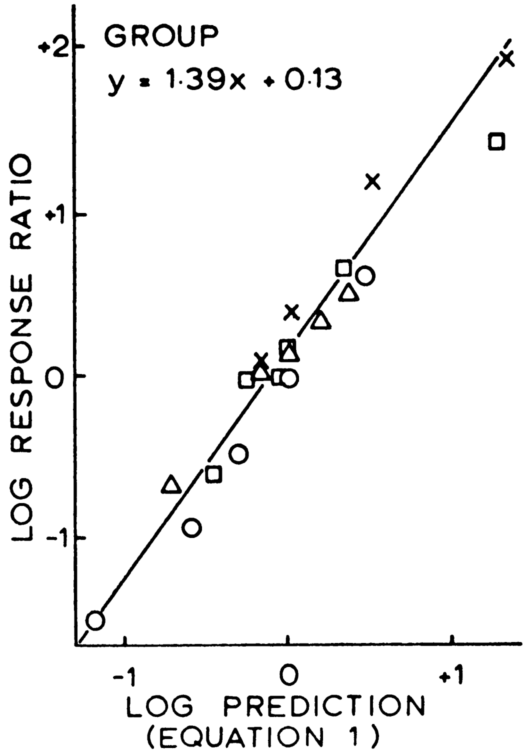

Fig. 2. Initial-link response ratios in the various experimental conditions as a function of the initial-link response ratios predicted from the model suggested by Davison and Temple (1973). Both coordinates are logarithmic. The data are geometric means of response ratios for the individual birds. See the legend on Figure 1.

Table 1

Sequence of experimental conditions, number of sessions, initial- and terminal-link response rates, and average number of terminal-link reinforcements per session in the final five sessions of each experimental condition. All data are group averages. This table also shows the group initial-link response ratios and the ratios predicted by various models of choice, each in terms of the initial-link key that leads to the shorter terminal-link schedule.

Terminal Links		*No. of Sessions*	*Initial-link Response Rates*		*Terminal-link Response Rates*		*Terminal-link Reinforcements Per Session*	
Red	*Green*		*Red*	*Green*	*Red*	*Green*	*Red*	*Green*
VI 27-sec Initial Links								
FI 5	FI 15	18	36.30	0.65	145.30	68.20	40.80	9.20
FI 7.5	FI 5	32	15.16	13.19	81.60	106.60	24.70	25.30
FI 5	FI 10	31	32.61	2.64	116.80	62.80	31.17	18.83
FI 5	FI 5	47	20.75	8.98	116.60	81.80	25.67	24.33
VI 115-sec Initial Links								
FI 30	FI 5	24	5.01	22.37	56.00	121.20	14.67	15.33
FI 5	FI 10	42	15.70	7.89	136.80	73.40	14.60	15.40
FI 7.5	FI 5	24	12.37	13.85	105.60	88.60	14.50	15.50
FI 5	FI 15	23	18.99	6.62	107.20	66.70	14.80	15.20
FI 5	FI 5	19	13.98	11.43	93.10	99.80	15.37	14.63
VI 49-sec Initial Links								
FI 10	FI 5	19	10.81	13.48	85.60	84.24	24.87	25.13
FI 5	FI 30	24	40.03	2.47	100.30	59.70	33.53	16.47
FI 7.5	FI 5	24	11.93	14.09	95.80	97.70	25.10	24.90
FI 5	FI 5	21	14.66	14.63	105.70	88.10	25.30	24.70
FI 15	FI 5	31	5.39	22.87	64.70	100.20	23.93	26.07
FI 5	FI 10	28	21.86	6.37	108.40	77.10	27.57	22.43
VI 38-sec Initial Links								
FI 30	FI 5	30	2.31	40.97	61.80	105.60	15.77	34.23
FI 5	FI 7.5	34	20.34	8.16	111.40	82.70	27.40	22.60
FI 15	FI 5	33	4.04	32.10	76.40	116.20	20.87	29.13
FI 5	FI 5	24	12.95	15.74	115.20	101.50	24.87	25.13
FI 10	FI 5	28	6.55	25.04	77.50	95.60	23.40	26.60

			Predicted Initial-Link Response Ratios			
Terminal Links		*Initial-link Response Ratios*	*Killeen (1968)*	*Squires and Fantino (1971)*	*Davison and Temple (1973)*	*Equation 6a*
Red	*Green*					
VI 27-sec Initial Links						
FI 7.5	FI 5	82.04	3.00	2.77	17.26	25.12
FI 5	FI 10	1.17	1.50	1.26	1.45	2.82
FI 5	FI 5	14.55	2.00	1.63	3.20	8.30
FI 5	FI 15	2.33	1.00	1.00	1.05	1.14
VI 115-sec Initial Links						
FI 30	FI 5	5.09	6.00	1.88	5.21	2.77
FI 5	FI 10	2.05	2.00	1.14	1.61	1.77
FI 7.5	FI 5	1.09	1.50	1.07	1.43	1.14
FI 5	FI 15	3.01	3.00	1.29	2.37	2.29
FI 5	FI 5	1.29	1.00	1.00	1.05	1.14
VI 49-sec Initial Links						
FI 10	FI 5	1.21	2.00	1.34	1.80	2.60
FI 5	FI 30	26.60	6.00	4.51	13.37	18.58
FI 7.5	FI 5	1.08	1.50	1.16	1.37	1.66
FI 5	FI 5	1.40	1.00	1.00	1.02	1.14
FI 15	FI 5	4.12	3.00	1.80	2.90	5.90
FI 5	FI 10	4.52	2.00	1.34	2.18	3.35
VI 38-sec Initial Links						
FI 30	FI 5	32.73	6.00	7.66	15.49	33.19
FI 5	FI 7.5	3.79	1.50	1.21	1.69	2.58
FI 15	FI 5	8.93	3.00	2.11	3.93	8.15
FI 5	FI 5	1.05	1.00	1.00	1.01	1.14
FI 10	FI 5	3.55	2.00	1.46	2.07	3.59

Table 2

The percentage of data variance accounted for by various models according to whether bias was present in the data or removed from the data (the latter are in parentheses). The statistic is the difference between the variance of the data around the data mean and the variance of the data around the prediction as a percentage of the variance of the data around the data mean.

Bird	*Killeen (1968)*	*Squires and Fantino (1971)*	*Davison and Temple (1973)*
131	37(41)	45(46)	58(62)
132	32(48)	31(38)	80(83)
133	57(57)	48(47)	82(82)
134	36(75)	39(74)	60(69)
135	65(72)	58(63)	90(87)
136	57(56)	45(46)	76(76)
Group	64(67)	55(57)	85(88)

and the variance of the data around the data mean as a percentage of the variance of the data around the data mean. Thus, if x is the variance of the data around the data mean and y is the variance of the data around the prediction (both expressed in logarithmic terms), then the per cent of the variance accounted for is given by

$$100\,\frac{(x-y)}{x}.$$

All such calculations were carried out in logarithmic terms to prevent variance being spuriously inflated by large choice ratios and large predictions.

Figure 2 also shows the line of best-fit, by the method of least squares in logarithmic terms, of the group data to the predictions from Equation 1. The slopes of the best-fit lines for the group and for individual animals are shown in Table 3. The slopes of the lines are mostly somewhat larger than the prediction of unit slope, and some of the lines have large intercepts. For example, the best-fitting line for Bird 134 has an intercept of +0.28. This suggests that when the terminal-link schedules were equal, the animal would have a choice ratio of about 1.9 to the initial link leading to the red terminal link. Such a result implies that the animal has a reasonably constant bias to one key, and the individual data show that when equal terminal-link schedules were arranged for this animal, it emitted many more responses on the initial link leading to the red terminal link than on that leading to the green terminal link.

Table 3

The values of the slopes and, in brackets, the intercepts, of the lines fitted by the method of least squares to the present data according to the presence or absence of bias.

Bird	*Biased*	*Unbiased*
131	0.95(+0.04)	0.95(−0.01)
132	1.49(+0.19)	1.49(−0.07)
133	1.50(+0.12)	1.50(−0.13)
134	1.06(+0.28)	1.06(+0.02)
135	1.35(+0.15)	1.35(+0.03)
136	1.74(−0.02)	1.74(+0.04)
Group	1.39(+0.13)	1.39(−0.02)

If bias is present in these data, comparisons with predictions from models of concurrent-chains choice may give misleading results. Based on results reported by Baum and Rachlin (1969), Davison and Temple (1973) suggested a method for removing bias. The same method was used here. An overall measure of bias was obtained from the geometric mean of the group response ratios in the four equal terminal-link schedule conditions, and this estimate of bias was removed from the data in all conditions by dividing the data by the bias estimate. This procedure increased the variance accounted for to 88% for the group, and similar calculations carried out for individual birds gave a range of accounted variances from 62% to 89%. Removing bias improved the fit for three individuals (including Bird 134) and worsened it for two.

Removing bias from the data for each individual bird, and for the group, should make the intercepts of the fitted lines closer to zero. Table 3 shows that the logarithmic intercepts of lines fitted by the least-squares method after bias was removed were closer to zero in four of the six birds. For the grouped data, the intercept was decreased from 0.13 to −0.02. The slopes of the fitted lines are, of course, unaffected by the removal of bias from the data.

A further analysis of the data in Table 1 shows that there is a strong relation between the choice ratio in the initial links and the ratio of response rates in the terminal links. A line fitted to the logarithms of both these measures gives a slope of about 3.63 and an intercept of +0.03, the dependent variable being the initial-link response ratio. The fitted line accounts for 80% of the variance in the initial-link choice ratios.

DISCUSSION

The present results are similar to those reported by Fantino (1969) for the choice between VI terminal links in concurrent chains when the size of the initial links was changed. These data also appear to be described very well by the model of choice given by Davison and Temple (1973) based on data obtained from the choice between FI terminal-link schedules with constant and equal initial-link schedules. The adequacy of the fit is shown by comparing the fit of the present data to Davison and Temple's model with the fit of Squires and Fantino's (1971) data to the model proposed by them. The model accounts for about 59% of the group data variance when the equal initial-link schedules were arranged. The variance accounted for falls to 31% when unequal initial-link data are included. When used to predict the present data, Squires and Fantino's model accounts for 57% of the unbiased group data variance (Table 2), and for between 38% and 74% of the variance of individual data. We conclude that Squires and Fantino's model is less effective in predicting the present data than Davison and Temple's model.

A second model for choice in concurrent-chains schedules (Killeen, 1968) may be used to give predictions for the present experimental conditions. In this model, choice equals the ratio of terminal-link reinforcement rates, and there is no specific provision for dealing with effects of changes in initial-link length. Despite this, Killeen's model accounts for 67% of the unbiased group data variance (Table 2), and for between 41% and 75% of the variance of individual data. However, it should be noted that the fact that Killeen's model predicts these data relatively well may be due to the rather restricted range of initial-link values employed in this study.

In summarizing the effectiveness of the three models, we agree with the assessment of Davison and Temple (1973) that both Killeen's and Squires and Fantino's models do not accurately predict choice between FI terminal links in concurrent-chains schedules. Of the available models, Davison and Temple's appears to be the best, the major drawback being that the lines fitted to the data as a function of predictions from this model generally have a slope somewhat greater than expected from the model. This may be shown in another way. The best-fitting straight line for the grouped unbiased data, which is $y = 1.39x - 0.21$, accounts for 96% of the data variance, while predictions from Davison and Temple's model accounts for only 88%. If the variance of the data around the model was the same as the variance of the data around the fitted line, the fit of the model to the data would be optimal, and the variance accounted for could not be increased. Thus, in the present case, some 8% of the variance is likely to be systematic and may be accountable with some variations in the model used for prediction.

A problem with the present analysis is that the predictions from the Davison and Temple model decrease in accuracy as the size of the initial links decreases. For unbiased data, the percentages of variance accounted for were, for the various initial-link schedules; VI 27-sec, 72%; VI 38-sec, 88%; VI 49-sec, 94%; and VI 115-sec, 97%. Generally, for the shorter initial-link schedules, the model predicted a choice ratio that was smaller than that obtained. The same general trend was evident in the analysis of the predictions from the models given by Killeen (1968) and Squires and Fantino (1971). A similar finding was obtained when data were analyzed according to the combination of terminal-link schedules, that is, all conditions in which the longer terminal link was FI 7.5-sec, all conditions in which it was FI 10-sec, *etc.* The variances accounted for in the data from each terminal-link combination were: FI 5-sec, 11%; FI 7.5-sec, 81%; FI 10-sec, 75%; FI 15-sec, 87%; and FI 30-sec, 94%. Unbiased data were used in this analysis. The poor predictions made when both terminal-link schedules were FI 5-sec are best explained by the extremely small variance in the data. As would be expected, the group choice ratio was close to one.

Concurrent-chains performance may be analyzed in other ways by assuming that the schedule is made up of both chained schedules and successive, discriminated components that comprise multiple schedules. We may first analyze the present data in terms of two chains in the manner used by Davison (1974) to investigate chained FI FI schedule performance. Davison used a variant of the matching law (Lander and Irwin, 1968; White and Davison, 1973) to show a relation between the ratio of response rates in the two links of a chain

(P_1/P_2) and the ratio of reinforcement rates in the two links (R_1/R_2). The relation takes the general form

$$\frac{P_1}{P_2} = c\left(\frac{R_1}{R_2}\right)^a \quad \ldots. (2).$$

For chained FI FI schedule performance, both *c* and *a* were constant (0.21 and 0.19) for various combinations of initial- and terminal-link schedules. This general equation may be applied to the present data, viewed as two chains, by fitting a straight line to the function relating the logarithm of the response-rate ratio to the logarithm of the reinforcement-rate ratio. The slope of the straight line gives *a*, and the antilog of the constant gives *c*. For this analysis, each initial-link schedule value was taken separately and, for each initial link, the chains on both keys were taken together. Thus, for example, there were eight chained schedules with VI 27-sec initial links. The obtained values of *a* and *c*, respectively, were found to be: for VI 27-sec initial links, −2.46 and −2.51; for VI 38-sec initial links, −1.62 and −2.02; for VI 49-sec initial links, −1.15 and −1.75; and for VI 115-sec initial links, −0.23 and −1.22. The values of *a* and *c* are clearly dependent on the initial-link values, and appear to be well predicted as straight-line functions of the reinforcement rate (reciprocal of the average time) in the initial link of the chain. Specifically,

$$a = -1.31\, R_1 + 0.46$$
$$c = -0.76\, R_1 - 0.83 \quad \ldots. (3a, b).$$

Davison (1974) found the values of both *a* and *c* were specific to the type of schedules comprising a chain (chain FI FI, chain VI VI, and chain VI FI), but were constant for each chain when the parameters of the schedules were varied. Therefore we suspect that the variation of *a* and *c* in the present data is due to the interactions between the chains when their initial links are arranged concurrently and their terminal links occur successively, and separated by periods of initial-link responding.

Since Equation 2, with appropriate values of *a* and *c*, is appropriate for both chains, an equation may be derived for the ratio of response rates in the initial links.

$$\frac{P_1}{P_1'} = \frac{P_2}{P_2'} \cdot \left(\frac{R_2'}{R_2}\right)^a \quad \ldots. (4).$$

In the derivation, primed variables refer to responses and reinforcements on the second chain. Since, in the present experiment, the initial-link schedules were identical, $R_1 = R_1'$ and both these variables, and the constant *c*, divide out.

Equation 4 predicts the choice ratio in the initial links in terms of both the reinforcement rates and the response rates in the terminal links. Such an expression is not useful to predict choice if the terminal-link response rates are unknown. But this problem may be overcome by an analysis of responding in the terminal links as a function of reinforcement rates in the terminal links. The analysis is similar to that used by Barron and Davison (1972) for multiple fixed-interval schedule performance, and again requires a fit to the weak matching law, Equation 2. In this analysis, which was carried out exactly as above, it was found unnecessary to deal with the various initial-link schedule combinations separately. The best-fitting relation is,

$$\frac{P_2}{P_2'} = 1.14\left(\frac{R_2}{R_2'}\right)^{0.41} \quad \ldots. (5)$$

which accounts for 80% of the variance in the data.

Given Equations 4 and 5, an expression can be derived for the ratio of response rates in the initial links of the concurrent-chains schedule in terms of the reinforcement rates in the terminal links

$$\frac{P_1}{P_1'} = 1.14\left(\frac{R_2}{R_2'}\right)^{0.41 - a} \quad \ldots. (6).$$

Finally, Equation 3a shows how the value of *a* changes with the initial-link reinforcement rates, allowing Equation 6 to be rewritten:

$$\frac{P_1}{P_1'} = 1.14\left(\frac{R_2}{R_2'}\right)^{1.31 R_1 - 0.06} \quad \ldots. (6a).$$

Equation 6a was used to give predictions of initial-link choice ratios for the present experiment and the adequacy of the predictions was assessed in logarithmic terms by the variance accounted for in the data. The variance accounted for was 92%. Figure 3 shows, on logarithmic coordinates, the initial-link response ratios from each condition for the group data as a function of the predicted choice ratios from Equation 6a. The slope of the fitted line to the relation between the predictions of Equation 6a and the present data is very close to one (0.99), and the logarithmic intercept is small (0.09). Comparing these results with those from Davison and Temple's model, in which the slope of the relation was somewhat different from one, suggests that the analysis in terms of chained and multiple schedules may be preferable.

Equation 6a was also used to make predictions for individual birds in the present experiment, and the adequacy of these predictions was assessed in logarithmic terms by the variance accounted for in the data. For the individuals, the variances accounted for ranged between 34% and 88%. The slopes of the fitted lines to the relation between the individual predictions of Equation 6a and the present data ranged between 1.69 and 0.88. It should be noted that for this analysis, the individual data were calculated as a function of the group prediction. However, each bird could require different individual parameters (*cf.* Davison, 1974) which may give much improved individual predictions. The variation here suggests that, within limits, choice could be idiosyncratic for each bird. If this variation is confirmed by further research, the analysis in terms of Equation 6 could allow for such individual parameters, but it is not clear how previous models of choice would be able to incorporate such factors.

Hursh and Fantino (1973) reported interactions between responding in the terminal links of concurrent-chains schedules, which they showed were consistent with results from previous concurrent-chains experiments. The results showed that when one terminal link was lengthened, response rate in the other terminal link increased, an effect that has been demonstrated in multiple schedules (Reynolds, 1961*a, b;* Lander and Irwin, 1968). These types of effect were investigated in the present data by fitting a straight line to a double logarithmic plot of the sums of response and reinforcement rates. An analysis of the total response rates in the initial links ($P_1 + P_1'$) as a function of the total reinforcement rates in these links ($R_1 + R_1'$) showed:

$$(P_1 + P_1') = 26(R_1 + R_1')^{0.18} \quad \ldots . (7).$$

This relation was found to be significant when tested by a Friedman two-way analysis of variance (Siegel, 1956). This equation is similar to that given by Catania (1963) for the total response output on concurrent variable-interval schedules, based on the analysis of four experiments and including data from single VI schedule performance. It is also similar to the equation for total response output on multiple variable-interval schedules given by Lander and Irwin (1968), though their data were the numbers, rather than the rates, of responses and reinforcements. However, since their multiple-schedule components were equal, the equation can be interpreted in terms of either rates or numbers. The values of the constant multipliers, which represent an individual animal parameter, would not be expected to be similar. Given equations 6a and 7, the absolute response rates on each key in the initial links may be calculated. In summary, total performance on the concurrent aspects of the present concurrent-chains schedule, which comprised VI schedules, was similar to the total output equations for single, concurrent, and multiple VI schedule performance.

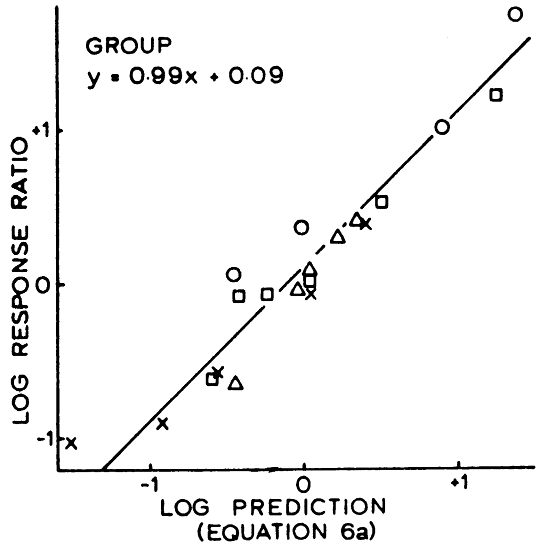

Fig. 3. Initial-link response ratios in the various experimental conditions as a function of the initial-link response ratios predicted by the chain/multiple analysis. Both coordinates are logarithmic. The data are geometric means of response ratios for the individual birds. See the legend on Figure 1.

Further analyses of the same type were carried out on the other possible relations. The Friedman test showed that there was no significant relation between the sum of the response rates in the initial links and the sum of the reinforcement rates in the terminal links. The same was found to be the case for the relation between the terminal-link response rates and the initial-link intervals. Finally, there was no significant relation between the sum of response rates and the sum of the reinforcement rates in the terminal links.

These analyses have shown that the varied relations between response and reinforcement rates (chained, multiple, and total output) occurring in concurrent-chains schedules may be investigated separately and be combined to produce predictions of choice performance. If this type of analysis is to be successful for concurrent-chains performances generally, it must first be shown that such analyses can be carried out for other types of concurrent chains, and, second, that the values of the constants and powers are predictable before experimentation. While a full analysis of all extant concurrent-chains data must await a future review, we have carried out a preliminary analysis of some other available data on the choice between terminal-link FI schedules in the standard concurrent-chains procedure. The data reported by Davison and Temple (1973) show that in the chain analysis, the value of *a* may be dependent also on the length of the shorter terminal-link interval to reinforcement (*cf.* Duncan and Fantino, 1970). Specifically, the value of *a* appears to be a linear function of the square root of the shorter interval (S) in seconds.

$$a = -0.38\, S^{0.5} - 0.03 \qquad \ldots.(8).$$

In the chain analysis, Killeen's (1970) data show a larger negative multiplier of the square root of the shorter interval, and Duncan and Fantino's data a multiplier that is larger still. The only consistent difference between these experiments is the use of 3-sec reinforcement by Davison and Temple, 3.5-sec in Killeen's experiment, and 4-sec in Duncan and Fantino's study.

Analysis of the terminal-link response and reinforcement rates in terms of Equation 5 gives a power of 0.29 (Davison and Temple, 1973), 0.36 (Killeen, 1970), and 0.43 (Duncan and Fantino, 1970). All these are reasonably close to the value of 0.41 found in the present experiment.

A complete analysis of the parametric data reported by Davison and Temple (0-, 10-, and 20-sec shorter terminal-link intervals), using the chained and multiple parameters as given above, showed that 95% of the data variance was accounted for by this model.

The analysis of concurrent-chains schedule performance in terms of chained and multiple schedules seems promising. It has various advantages over the model given by Davison and Temple (1973). It has a strong empirical base and the type of analysis is consistent with that which has proved effective with a number of other schedule types. Its disadvantages, at least at present, are that the parameters of the model are not predictable. Further research on chained schedule performance, and the analysis of more available concurrent-chains data, may solve these problems.

REFERENCES

Autor, S. M. *Strength of conditioned reinforcers as a function of the frequency and probability of reinforcement.* Unpublished doctoral dissertation, Harvard University, 1960. Reprinted in D. P. Hendry (Ed.), *Conditioned reinforcement.* Homewood, Ill.: The Dorsey Press, 1969. Pp. 127-162.

Baum, W. M. and Rachlin, H. C. Choice as time allocation. *Journal of the Experimental Analysis of Behavior,* 1969, **12,** 861-874.

Barron, B. and Davison, M. C. Performance in multiple fixed-interval schedules. *Journal of the Experimental Analysis of Behavior,* 1972, **17,** 375-379.

Catania, A. C. Concurrent performances: reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior,* 1963, **6,** 253-263.

Davison, M. C. A functional analysis of chained fixed-interval schedule performance. *Journal of the Experimental Analysis of Behavior,* 1974, **21,** 323-330.

Davison, M. C. and Temple, W. Preference for fixed-interval schedules: an alternative model. *Journal of the Experimental Analysis of Behavior,* 1973, **20,** 393-403.

Duncan, B. and 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.

Herrnstein, R. J. Secondary reinforcement and the rate of primary reinforcement. *Journal of the Experimental Analysis of Behavior,* 1964, **7,** 27-36.

Hursh, S. R. and Fantino, E. Relative delay of reinforcement and choice. *Journal of the Experimental Analysis of Behavior,* 1973, **19,** 437-450.

Killeen, P. On the measurement of reinforcement frequency in the study of preference. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 263-269.

Killeen, P. Preference for fixed-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1970, **14,** 127-131.

Lander, D. G. and Irwin, R. J. Multiple schedules: effects of the distribution of reinforcements between components on the distribution of responses between components. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 517-524.

MacEwen, D. The effects of terminal-link fixed-interval and variable-interval schedules on responding under concurrent chained schedules. *Journal of the Experimental Analysis of Behavior,* 1972, **18,** 253-261.

Reynolds, G. Behavioral contrast. *Journal of the Experimental Analysis of Behavior,* 1961, **4,** 57-71. (*a*)

Reynolds, G. Relativity of response rate and reinforcement frequency in a multiple schedule. *Journal of the Experimental Analysis of Behavior,* 1961, **4,** 179-184. (*b*)

Siegel, S. *Nonparametric statistics for the behavioral sciences.* New York: McGraw-Hill, 1956.

Squires, N. and Fantino, E. A model for choice in simple concurrent and concurrent-chains schedules. *Journal of the Experimental Analysis of Behavior,* 1971, **15,** 27-38.

White, A. J. and Davison, M. C. Performance in concurrent fixed-interval schedules. *Journal of the Experimental Analysis of Behavior,* 1973, **19,** 147-153.

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