*PREFERENCE FOR FIXED-INTERVAL SCHEDULES:
EFFECTS OF UNEQUAL INITIAL LINKS*

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Six homing pigeons were trained on concurrent chain schedules in which the terminal links were fixed-interval schedules of 5 sec or 15 sec. One initial-link schedule was always VI 27-sec; the other was varied over conditions from VI 27-sec to VI 181-sec. Preference measured in the initial links varied as a joint function of the initial- and terminal-link schedules. When the initial links were varied with constant, but unequal, terminal links, the slope of the function relating the logarithm of the initial-link response ratio to the logarithm of the terminal-link entry ratio differed from that obtained with equal terminal links. This result indicates that biases attributable to the terminal-link schedules were not constant. The rate of change of preference, or degree of undermatching, in the initial links depended on whether the shorter initial link led to the shorter or the longer terminal link. These results raise the question of whether bias and undermatching in concurrent schedule performance are independent measures.

Key words: concurrent chain schedules, variable-interval schedules, fixed-interval schedules, preference, bias, pecking, pigeons

In concurrent chain schedules (Autor, 1960), preference between two mutually exclusive terminal-link schedules is measured by the ratio of response rates in concurrent variable-interval (VI) initial-link schedules. Research in this area initially investigated the effects of various types and values of terminal-link schedules (*e.g.*, Davison, 1969, 1972; Davison and Temple, 1973; Duncan and Fantino, 1970; Fantino, 1967; Herrnstein, 1964*a*, 1964*b*; Killean, 1968, 1970), but has lately moved to a consideration of the effects of varying the values of the initial-link VI schedules (Davison and Temple, 1974; Fantino, 1969; Squires and Fantino, 1971; Wardlaw and Davison, 1974). Wardlaw and Davison provided data on performance in concurrent chain schedules with fixed-interval (FI) terminal links with four different equal-VI initial links. The present experiment investigated how unequal initial-link schedules affected the preference between FI terminal links.

METHOD

Subjects

Six homing pigeons, which had served in the Wardlaw and Davison (1974) study, were maintained at $80\% \pm 15$ g of their free-feeding weights as determined before the Wardlaw and Davison study. One bird (132) died during the

experiment and was replaced by 132b, which had experienced considerable training on multiple schedules.

Apparatus

The apparatus and reinforcement conditions were identical to those used by Wardlaw and Davison (1974). Briefly, the animals worked on the two outside keys of a three-key sound-attenuated chamber with two sources of feedback (30 msec keylight offset and a click) for responses to lighted keys. The reinforcer was 3-sec access to wheat, and the daily sessions terminated in blackout after 50 reinforcements had been obtained.

Procedure

The details of the procedure were identical to those used by Wardlaw and Davison (1974). In the initial links, the animals were presented with two white keys, each associated with an independent VI schedule. One of these was always VI 27-sec, while the other was either

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VI 27-sec, VI 38-sec, VI 49-sec, VI 115-sec, or VI 181-sec. The 12 intervals in these schedules were randomized from an arithmetic progression with common differences of respectively 4, 6, 8, 20, and 32 sec. When the left-key timer had timed an appropriate interval, the next response on that key turned that 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 on an FI schedule, which was either 5-sec or 15-sec long in different conditions (see Table 1); following reinforcement, the keys reverted to the white (initial-link) conditions. Similarly, when the right-key timer had timed an appropriate interval, a response on 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 on either an FI 5-sec or an FI 15-sec schedule (Table 1); 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. If both initial-link timers had timed intervals before the animal entered a 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. The criterion required that the median of the relative number of initial-link responses (responses on one initial link divided by all initial-link responses) over five days be not more than 0.05 different from the preceding five days. When all animals had met this criterion five times (a minimum of 14 sessions), the experimental conditions for all animals were changed. The sequence of experimental conditions is shown in Table 1.

In all conditions, the number of responses on each key in the initial and terminal links, and the number of terminal-link entries, were recorded.

RESULTS

The data are shown in Table 1. To save space, they have been averaged across birds

and across the last five sessions of each experimental condition. The averaging was done arithmetically for response rates using the initial-link time estimated from the maximum of the two values of terminal-link entries multiplied by the arranged initial-link schedule on that key. This gives a minimum value of the time spent in the initial links. As well as data from the present experiment, the Table includes two relevant conditions from the Wardlaw and Davison (1974) study. The method of obtaining average initial-link response ratios was to take the geometric mean of the ratios of individual birds, the appropriate method for averaging ratios. Therefore, initial-link response ratio (column 12) is not identical to the division of column 7 by column 8, especially when the preference was large. No account was taken in group data of the change of Bird 132 for Bird 132b part way through the experiment.

Table 1 shows that preference varied as a function of both the initial- and the terminal-link schedule values (Fantino, 1969; Squires and Fantino, 1971), and also that, when preference was large, the number of terminal-link entries was not always the same as arranged by the initial-link schedules. For example, in the choice between FI 5-sec and FI 15-sec with, respectively, VI 115-sec and VI 27-sec initial links (condition 9) the number of entries into the FI 5-sec terminal link was almost twice those arranged by the schedules.

The changes in preference are more easily seen if the ratio of initial-link responses is plotted as a function of the ratio of obtained terminal-link entries on double-logarithmic coordinates (Baum and Rachlin, 1969). This procedure essentially treats this concurrent chain performance as performance on a concurrent schedule, with the differing terminal links acting as equivalent to, for example, different reinforcement magnitudes. Such a plot is shown in Figure 1. Apart from a number of apparently aberrant points, the data seem to be reasonably well predicted by three straight lines: a steep line relating changes in the initial-link schedules to performance when the terminal links were FI 5-sec *versus* FI 15-sec; an almost flat line when the terminal links were FI 15-sec *versus* FI 5-sec; and a line of intermediate slope when both terminal links were FI 5-sec.

Table 1

Sequence of experimental conditions, numbers of sessions training, initial- and terminal-link response rates, numbers of terminal-link entries (which equals the number of reinforcements obtained in each terminal link), and the geometric initial-link response ratio in each experimental condition. Response-rate and terminal-link entry data are averaged across the last five sessions on each condition and across the six subjects.

Condition	Initial-Link VI Schedules (sec)		Terminal-Link FI Schedules (sec)		Sessions	Initial-Link Responses per Sec		Terminal-Link Responses per Sec		Terminal-Link Entries per Session		Initial-Link Response Ratio
	Key 1	Key 2	Key 1	Key 2		Key 1	Key 2	Key 1	Key 2	Key 1	Key 2	
*	27	27	5	5	47	40.4	17.5	116.4	81.9	25.7	24.3	2.33
*	27	27	5	15	18	43.9	0.82	145.3	68.3	40.8	9.2	82.0
1	38	27	5	15	25	60.7	1.72	75.2	68.5	34.0	16.0	63.3
2	38	27	5	5	40	32.2	24.4	98.8	81.2	21.6	28.4	1.53
3	49	27	5	15	25	53.7	3.54	76.6	77.7	28.0	22.0	17.6
4	27	49	15	5	32	10.9	55.7	58.2	81.6	29.6	20.4	0.40
5	38	27	5	15	20	55.9	2.64	84.6	75.6	32.3	17.7	27.3
6	38	27	5	5	25	31.8	24.8	97.2	87.3	22.0	28.0	1.49
7	115	27	5	5	39	27.6	35.3	90.7	74.6	9.1	40.9	0.90
8	115	27	15	5	24	13.2	48.3	61.1	74.2	9.1	40.9	0.32
9**	115	27	5	15	31	48.5	7.88	93.1	61.4	14.7	34.2	6.52
10	181	27	15	5	20	11.8	44.7	83.5	92.7	6.4	43.6	0.24
11	181	27	5	15	39	42.7	18.1	126.7	69.6	7.7	42.3	2.23
12	49	27	5	5	29	37.7	30.0	111.0	102.0	18.6	31.4	1.34
13	181	27	5	5	27	20.9	42.8	90.5	82.5	6.2	43.8	0.52
14	27	27	15	5	34	12.8	56.7	75.6	88.2	22.1	27.9	0.21
15	49	27	15	5	25	10.1	51.2	62.1	89.2	14.5	35.5	0.17
16	27	115	5	5	24	44.2	12.5	94.4	70.0	41.4	8.6	3.33
17**	27	115	15	5	40	16.4	48.2	65.6	86.3	39.3	10.4	0.49
18	27	115	5	15	35	66.2	4.60	94.9	75.7	42.5	7.5	21.8

*Conditions from Wardlaw and Davison (1974).

**In these conditions, the obtained number of terminal-link entries do not add to the arranged total as sessions were timed out due to low response rates in one bird.

Fig. 1. The logarithm of the ratio of the numbers of responses in the initial links as a function of the logarithm of the ratio of the number of terminal-link entries. The data from the three different sets of terminal links, FI 5-sec versus FI 15-sec, FI 5-sec versus FI 5-sec and FI 15-sec versus FI 5-sec are shown separately. The lines drawn through the three sets of data were fitted by the method of least squares, and their slopes and intercepts are shown in Table 2. One data point for Bird 131 and one for Bird 133, both for FI 5-sec versus FI 15-sec, could not be shown on the graph.

Lines of best fit, by the method of least squares, were fitted to the data shown in Figure 1, taking each of the three sets of terminal-link conditions separately. The fitted lines are

shown in Figure 1, and the slopes, intercepts, and the percentages of variance accounted for by the fitted lines, are given in Table 2. For significance at greater than the 5% level, the variances accounted for must exceed 84% (Fisher and Yates, 1963, Table 7) for the FI 15-sec versus FI 5-sec data. Significance is reached for only one bird, because the slopes of the fitted lines were small, indicating that there was little systematic variance in the data. For the other two terminal-link conditions, all birds meet the 5% significance level (over 82% variance accounted for).

A further analysis of the data in Table 2 by a Friedman two-way analysis of variance by ranks (Siegel, 1956) showed that the slopes of the fitted lines reliably decreased from the FI 5-sec versus FI 15-sec conditions, through the FI 5-sec versus FI 5-sec conditions, to the FI 15-sec versus FI 5-sec conditions ($p < 0.01$), and that the intercept changed in the same way ($p < 0.001$).

DISCUSSION

The major problem with the present data (Figure 1) is that the lines fitted to the three different terminal-link combinations (Table 2) are not parallel. Since, in all the FI 5-sec versus FI 15-sec data except condition 18, the shorter initial-link schedule led to the longer terminal-link schedule, and in all the FI 15-sec versus FI 5-sec data except conditions 4 and 17, the shorter initial-link schedule led to the shorter terminal link, this procedural difference could have led to the different slopes found. This possibility was further checked by fitting lines by the method of least squares to the data in Figure 1, excluding those conditions that were contrary to the above suggestion. For the FI 5-sec versus FI 15-sec data, the slope of the line for the group data was 1.16 (individual range 0.93 to 1.23). For the FI 15-sec versus FI 5-sec data, the group slope was -0.21 (individual range -0.16 to 1.09, the latter for Bird 131).

This result demonstrates that there is an interaction between the durations of the initial- and terminal-link schedules. It shows that the rate of change of preference as measured by the initial-link response ratio is greater when the shorter initial-link schedule leads to the longer terminal-link schedule than when the shorter initial link leads to the shorter terminal link.

Table 2

The slope, intercept, and percentage of the variance accounted for (V) by the least squares lines fitted to the data in Figure 2. Intercept values are logarithmic.

Bird	FI 5-sec vs FI 15-sec			FI 5-sec vs FI 5-sec			FI 15-sec vs FI 5-sec		
	Slope	Intercept	V	Slope	Intercept	V	Slope	Intercept	V
131	1.19	0.84	99	0.53	0.14	90	0.73	-0.15	95
133	0.84	1.27	89	0.58	0.39	91	0.14	-0.65	69
134	0.71	0.89	92	0.36	0.17	91	0.13	-0.62	60
135	0.79	1.08	94	0.40	0.42	93	0.18	-0.18	83
136	1.12	1.27	99	1.09	0.11	96	0.19	-1.44	57
Group	0.89	1.15	93	0.51	0.24	98	0.20	-0.50	78

The performance on the initial links in the concurrent chain was biased towards key 1, as Wardlaw and Davison (1974) found for these birds. This can be shown in two ways: first, when the terminal-link schedules were equal, the fitted line had a positive intercept in all individuals (Table 2); second, if no bias was present, the intercepts of the lines fitted to the unequal terminal-link schedule data would be of the same absolute value, but opposite in sign.

The present results have important implications for theories of concurrent schedule performance. Baum (1974) discussed two major effects, bias and undermatching, often reported in this area of research. Baum stated that bias is due to unaccounted-for preference and the generalized matching law implies that, so long as the factors that produce bias are invariant, so will be the measure of bias. The term is used above in just this way. On a double-logarithmic plot of response ratios against reinforcement ratios, bias is shown by a fitted line being parallel to, but displaced from, either a theoretical line or a line fitted to control data. (cf. Baum, 1974, Figure 2). Thus, in an experiment with concurrent VI VI schedules, if the reinforcer for one response is greater than the reinforcer for the other, the animal would show a bias towards the first response if all other conditions were equal (Baum and Rachlin, 1969; Hollard and Davison, 1971). In the present experiment, invariant differences between terminal-link schedules (FI 5-sec versus FI 15-sec and *vice versa*) were arranged which should, therefore, have produced an invariant bias measure away from the equal terminal-link data. But, since the fitted lines in Figure 1 for the unequal terminal-link conditions were not parallel to those for the equal terminal-link conditions,

the bias produced by the unequal terminal-link conditions was not constant.

If bias was not constant between two different terminal FI schedules when the initial links were varied, could this also be the case when preference was changed by using unequal magnitudes of reinforcement? Investigations of previous reports (Catania, 1963; Schneider, 1973; Todorov, 1973) showed that sufficient data have not been reported to rule out such an effect. Hollard and Davison's (1971) data appear to show no such effect when preference is biased by using different types of reinforcement, but their data are not really comprehensive enough. There remains, then, the possibility that bias is not independent of the schedule on which it is measured, and that interactions between reinforcement magnitude and rate occur.

Undermatching (Baum, 1974) relates to the slope of the relation between response and reinforcement ratios on double-logarithmic coordinates. In the present experiment, the slope of the line fitted to the group FI 5-sec versus FI 5-sec terminal-link data was 0.51 (Table 2), a particularly low value compared with normal concurrent VI VI schedule performance (Baum, 1974; Lobb and Davison, 1975). This value was quite consistent between birds, except for 136 for which this slope exceeded 1.0. The reason for the low slope value is unclear. It could be due to individual variation in the animals used, or it could arise from the conditions of the experiment and be produced by delayed reinforcement, as compared to the immediate reinforcement obtained in concurrent VI VI schedules. The latter interpretation is favored by data on concurrent VI VI schedule performance by these birds collected after the present experiment. On four conditions, the slopes of fitted lines were all greater than those

from the present equal terminal-link conditions, with a group average of 0.82.

If this suggestion is correct for delayed reinforcement, it may also be true of other reinforcement parameters like magnitude of reinforcement. Again, the available data are not sufficient to test this possibility, but it is one explanation of undermatching (*cf.* Baum, 1974) that deserves investigation.

The fact that the two unequal-terminal-link fitted lines were not parallel in Figure 1 could also be explicable in terms of a different degree of undermatching in the two cases when (a) the shorter initial link leads to the shorter terminal link, and (b) when the shorter initial link leads to the longer terminal link. If this were the case more generally than in the present procedure, the measures of bias and undermatching that have previously been reported may not have been independent measures.

In conclusion, the present data showed that a constant difference in terminal-link FI schedules did not produce a constant bias away from equal terminal-link schedule data, and suggest that other constant reinforcement parameter differences should be further investigated to determine whether they do give constant bias effects. These data also indicated that the degree of undermatching may be related to delay of reinforcement, and possibly to specific types of relations between initial- and terminal-link schedules. It may be that bias and undermatching are not independent, a state of affairs that would seriously compromise their utility as derived measures of performance.

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