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A FUNCTIONAL ANALYSIS OF CHAINED FIXED-INTERVAL SCHEDULE PERFORMANCE[1]

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Three pigeons were trained on two-link chained fixed-interval fixed-interval schedules. Numbers of responses, time spent responding, and the total time spent in each component were measured. The data were analyzed according to the matching law for multiple and concurrent schedules. In most conditions, the ratio of response rates in the two links was a constant proportion of the ratio that would be predicted in a multiple schedule with the same components. Data on pauses during the interval schedules showed that, in most conditions, the pause duration was a linear function of the interval length, and greater in the initial link than in the terminal link. The experiment thus demonstrated a quantitative functional analysis of performance on a chained schedule.

A relatively simple functional relation exists between response rates and reinforcement rates in both multiple and concurrent schedules. The general relation may be written:

$$\frac{P_1}{P_2} = c\left(\frac{R_1}{R_2}\right)^a \qquad (1)$$

where P_1 and P_2 are the response rates on the two schedules and R_1 and R_2 are the reinforcement rates on these schedules. In concurrent variable-interval (VI) performance, both the parameters *c* and *a* are one (Herrnstein, 1970; Rachlin, 1971). When a fixed-interval (FI) schedule (schedule 1) is arranged concurrently with a VI schedule (Nevin, 1971; Trevett, Davison, and Williams, 1972) the values of *c* and *a* may be less than one. In concurrent FI schedule performance, both *c* and *a* are generally one (White and Davison, 1973), and in multiple VI VI and multiple FI FI schedule performance, *c* is one but *a* is less than one (Lander and Irwin, 1968; Barron and Davison, 1972). Performance on concurrent differential-reinforcement-of-low-response-rate schedules (Staddon, 1968) is also characterized by values of *c* and *a* of less than one. Finally, when qualitatively or quantitatively different reinforcers are arranged for concurrent VI VI performance, *c* is less than one if the reinforcer on key 1 is less preferred than that on key 2, and the value of *a* is also less than one (Hollard and Davison, 1971). In this analytic system, *c* describes a constant preference over all experimental conditions and is unaffected by changes in the investigated independent variable. As such, it covers all reinforcers acting in an experimental situation that are not expressly varied by the experimenter, for example, key bias (Baum and Rachlin, 1969). The value of *a* is an index of the sensitivity of the response rate ratio to changes in the ratio of the values of the independent variable under study. The effects of different values of *a* have been discussed in detail by Lander and Irwin (1968).

The present experiment was an attempt to extend this general approach to performance on a chained schedule. While there is an extensive literature on chained schedule performance (Kelleher and Gollub, 1962), an analysis in terms of Equation 1 has not previously been attempted. For the present experiment, two-component chained FI FI schedules were selected so that the results could be compared with the analysis of multiple FI FI schedule performance reported by Barron and Davison (1972).

METHOD

Subjects

Three homing pigeons, numbered 51 to 53, were maintained at 80% ± 15 g of their free-feeding body weights. They had previously

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served in studies of multiple VI VI performance.

Apparatus

The sound-attenuated experimental chamber was situated remote from conventional relay control equipment and external noise was masked by an exhaust fan. The chamber contained two response keys 2 cm in diameter, 13 cm apart and 22.5 cm from the floor. Both keys could be transilluminated by various colored lights, but only the left key was lit and operative in this experiment. Pecks on this key exceeding 0.1 N closed a microswitch behind the key and gave auditory feedback from a relay situated inside the chamber and visual feedback from a 30-msec offset of the keylight. A food magazine, situated midway between the two keys and 10 cm from the grid floor, was illuminated during reinforcement.

Procedure

As all three subjects had extensive histories of responding on multiple schedules, no keypeck or schedule training was necessary, and they were placed directly on the first experimental condition (Table 1). The number of reinforcements (3-sec access to wheat) in a session was fixed for each experimental condition to maintain a maximum session time of about 1.75 hr, and these numbers are shown in Table 1.

When the session commenced, the key was white. A single response on the key produced reinforcement, which was followed by the presentation of the key colored red, which was associated with an FI schedule of reinforcement and signalled the initial link of the chain. When the time arranged by this schedule had elapsed, a response on the red key turned the key white and the terminal link of the chain commenced. When the time arranged by the terminal-link timer had elapsed, a response produced reinforcement, followed by the reinstatement of the red initial link and associated schedule. During reinforcement, the key was blacked out and inoperative and the food magazine was lit.

Three types of experimental conditions were arranged. In the first set, the terminal-link schedule was always FI 60-sec while, in the various experimental conditions, the initial-link schedule was varied from FI 15-sec to FI 240-sec. In the second set, the initial link was always FI 60-sec and the terminal link was varied from FI 15-sec to FI 240-sec. In the last set, the schedules were chain FI x-sec FI y-sec under the restriction that $x + y = 120$ sec. Finally, two control conditions were arranged. The first of these was chain FR 1 FI 60-sec, in which the first response emitted in the presence of the red key following food reinforcement started the FI 60-sec schedule and changed the key color to white. The second control condition was multiple FI 60-sec FI 60-sec, in which reinforcement was obtained after completion of the initial-link schedule as well as the terminal-link schedule, and the same stimuli were associated with each component as in the chained schedules.

Training continued under each experimental condition until performance stabilized. The stability criterion required that the median of the proportion of initial-link responses to total responses over five sessions did not differ by more than 0.05 from the median of the previous five sessions. When this criterion had been met five, not necessarily consecutive, times by each animal, the experimental conditions were changed for all animals. In all conditions, the number of responses, the time elapsing before the first response after the start of a component, and the total time in a component were measured for each component. In order to avoid errors in the measurement of pauses in the terminal link through overrunning the first link, the timing of this pause was not affected by responses emitted up to 3 sec after the terminal link started. The initial-link schedule commenced at the beginning of reinforcement, and thus strictly the nominal values of these schedules are 3 sec less than shown in Table 1. Hence, the measured initial-link times are sometimes less than the nominal times. Cumulative records of performance were taken in each session.

RESULTS

All data (Table 1) are reported as the average of the various measures per link of the chained schedules over the final five sessions of each experimental condition. This Table shows that, in a number of experimental conditions, the animals did not complete the initial-link schedule, and thus enter the terminal link, until some time after the initial-link time had elapsed. This effect is seen in chain FI 60-

Table 1

The number of responses emitted, the time elapsing before responding, and the total time in each link of the various chained and multiple schedules. The data are the average number from each link over the final five experimental sessions. Time data are in seconds. Also shown is the number of cycles of the complete chain arranged in each session and the ratio of terminal to initial-link times both arranged and obtained.

	Responses		*Pause Time*		*Total Time*		*Time Ratio Link 2/ Link 1*	
Bird	*Link 1*	*Link 2*	*Link 1*	*Link 2*	*Link 1*	*Link 2*	*Arr.*	*Obt.*
Chain FI 120-sec FI 60-sec. 30 cycles, 19 sessions								
51	19.3	85.8	58.4	15.7	127.2	64.7	0.5	0.51
52	39.1	53.8	44.7	14.2	130.2	63.6	0.5	0.49
53	32.5	75.6	57.9	9.5	129.0	64.0	0.5	0.50
Chain FI 30-sec FI 60-sec. 40 cycles, 18 sessions								
51	8.4	83.6	16.8	12.2	29.7	63.5	2.0	2.14
52	8.0	59.3	10.8	12.5	29.8	62.2	2.0	2.09
53	16.0	72.3	9.2	8.0	29.2	62.0	2.0	2.13
Chain FI 240-sec FI 60-sec. 20 cycles, 24 sessions								
51	41.4	103.4	126.5	20.6	260.9	65.3	0.25	0.25
52	83.8	58.2	74.2	16.5	261.5	65.5	0.25	0.25
53	36.0	68.5	94.7	12.1	260.5	66.0	0.25	0.25
Chain FI 15-sec FI 60-sec. 44 cycles, 15 sessions								
51	6.2	82.8	7.8	12.0	13.9	63.0	4.0	4.54
52	3.6	63.4	9.5	12.7	17.2	65.1	4.0	3.78
53	7.2	69.2	7.8	8.9	13.6	65.3	4.0	4.81
Chain FI 60-sec FI 60-sec. 40 cycles, 23 sessions								
51	12.2	88.4	32.7	19.1	62.5	64.7	1.0	1.03
52	19.6	49.6	26.0	21.0	63.6	65.9	1.0	1.04
53	9.3	62.9	44.3	18.4	65.7	66.2	1.0	1.01
Chain FI 60-sec FI 120-sec. 30 cycles, 17 sessions								
51	10.0	138.1	41.6	27.8	66.0	130.6	2.0	1.98
52	9.2	94.4	40.4	25.8	65.4	130.9	2.0	2.00
53	7.3	107.3	47.6	21.7	66.0	131.5	2.0	1.99
Chain FI 60-sec FI 30-sec. 44 cycles, 20 sessions								
51	12.7	48.7	34.4	7.0	62.0	32.5	0.5	0.52
52	14.6	35.9	32.3	10.3	66.4	32.8	0.5	0.49
53	12.2	34.5	40.7	7.4	61.9	33.2	0.5	0.54
Chain FI 60-sec FI 240-sec.[1] 20 cycles, 15 sessions								
51	7.8	176.8	112.5	14.5	146.2	257.3	4.0	1.76
52	5.2	132.2	119.9	12.3	138.5	250.4	4.0	1.81
53	3.1	168.5	111.7	16.9	116.6	247.4	4.0	2.12
Chain FI 60-sec FI 15-sec. 44 cycles, 20 sessions								
51	13.9	40.6	32.2	5.5	62.2	16.6	0.25	0.27
52	14.7	19.2	31.0	7.4	62.1	16.7	0.25	0.27
53	21.2	27.0	35.1	3.6	61.8	16.8	0.25	0.27
Chain FI 90-sec FI 30-sec. 40 cycles, 18 sessions								
51	15.6	61.7	56.0	8.5	96.7	33.0	0.33	0.34
52	25.6	30.6	52.3	16.3	97.5	33.7	0.33	0.35
53	23.0	39.4	54.4	7.0	96.4	33.3	0.33	0.28
Chain FI 30-sec FI 90-sec. 40 cycles, 15 sessions								
51	3.5	87.0	28.0	20.4	37.7	100.3	3.0	2.67
52	2.4	55.3	39.1	41.2	43.6	99.6	3.0	2.28
53	2.9	97.7	31.3	12.8	36.0	99.7	3.0	2.77

Table 1 *continued*

Bird	*Responses* Link 1	*Responses* Link 2	*Pause Time* Link 1	*Pause Time* Link 2	*Total Time* Link 1	*Total Time* Link 2	*Time Ratio Link 2/Link 1* Arr.	*Time Ratio Link 2/Link 1* Obt.
Chain FI 105-sec FI 15-sec. 40 cycles, 18 sessions								
51	24.7	44.1	56.0	5.8	110.7	16.6	0.14	0.15
52	35.1	20.2	51.5	8.4	119.0	16.9	0.14	0.14
53	28.2	23.4	61.7	5.1	114.5	16.9	0.14	0.15
Chain FI 15-sec FI 105-sec. 40 cycles, 15 sessions								
51	1.4	95.8	24.2	17.4	25.8	114.2	7.0	4.44
52	1.2	44.6	53.7	26.5	54.3	112.3	7.0	2.07
53	1.2	97.4	39.9	15.7	41.0	115.6	7.0	2.82
Chain FR 1 FI 60-sec. 40 cycles, 14 sessions								
51	1.0	73.7	16.1	8.9	16.1	67.2	–	4.17
52	1.0	45.5	14.7	14.7	15.2	66.7	–	4.38
53	1.0	58.2	16.7	13.3	16.7	66.9	–	4.01
Multiple FI 60-sec FI 60-sec. 40 reinforcements, 15 sessions								
51	52.1	40.5	15.8	27.0	62.1	62.0	1.0	1.00
52	39.3	38.0	17.2	16.0	60.0	64.1	1.0	1.07
53	53.9	40.3	18.2	18.7	63.0	61.2	1.0	0.97

[1] All three animals failed to complete the arranged number of cycles in this condition. The smallest number completed was 88% for Bird 53.

sec FI 240-sec, chain FI 30-sec FI 90-sec, and chain FI 15-sec FI 105-sec for which the obtained ratios of times spent in the two links are very different from the arranged ratios of times (Table 1). Some cases of late completion of the initial links are shown in the cumulative records in Figure 1. These records also show that, in all cases, performance in both the initial and terminal links consisted of a pause in responding followed by a relatively constant rate of emission of responses, which terminated in either the production of the terminal link or primary reinforcement (*cf.* Schneider, 1969). The pause before responding commenced appeared to take up a larger proportion of the initial link than of the terminal link, and this result is borne out by the data in Table 1.

Figure 2 shows the duration of the pause before responding on each link as a function of the measured duration of the varied component (Table 1) averaged over the three birds. The results are shown separately for the three sets of conditions in which the initial link (Figure 2a), the terminal link (Figure 2b), or both links (Figure 2c) were varied. Straight lines were fitted by the method of least squares to all data points in Figure 2 except the three obtained from conditions in which the initial link was not completed until a considerable time after the interval had elapsed. These three points are clearly inconsistent with the body of data in Figure 2.

When the initial link was varied (Figure 2a), the duration of the pause before responding approximates a constant proportion (0.36) of the initial-link interval length. The pause in the terminal link under these conditions appears quite constant. When the terminal link was varied (Figure 2b), the pause before responding in the terminal link approximates a constant proportion (0.18) of the terminal-link interval. However, in this case, changing the terminal-link schedule clearly changes the pause in the initial link, longer terminal-link intervals giving longer initial-link pauses. In this figure, the data from chain FI 60-sec FI 240-sec, a condition in which the FI 60-sec schedule was often not completed until some time after the interval had timed, are inconsistent. The pause constitutes a much larger proportion of the initial-link time and a much smaller proportion of the terminal-link time when compared with the other data. A similar contrast effect may be seen in Figure 2c for the other two anomolous data points.

Figures 2a and 2b show that the pause in the initial link was a larger proportion of the interval than the pause in the terminal link. This is shown again in Figure 2c for the conditions in which both intervals were varied, the

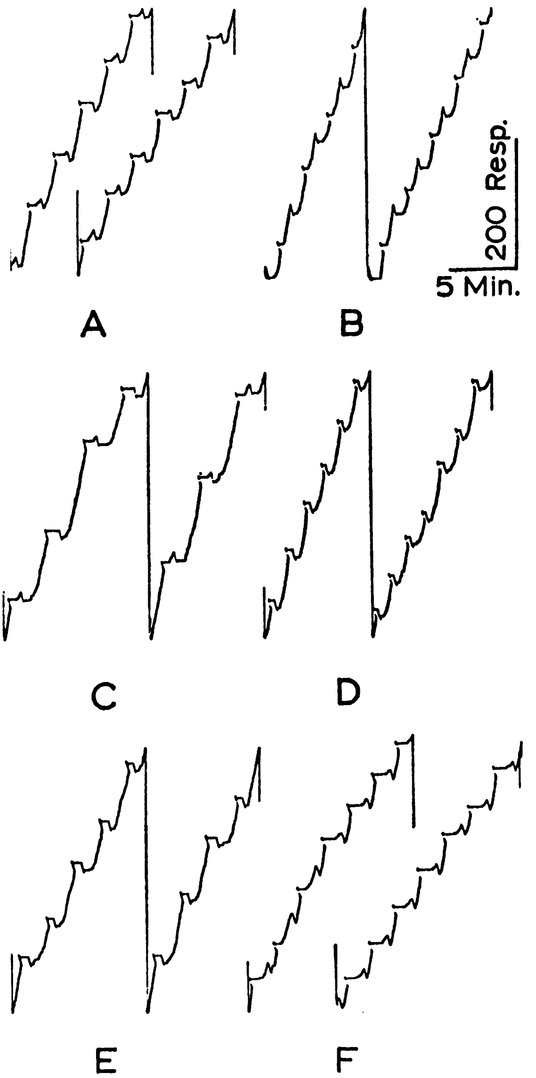

Fig. 1. Sample cumulative records of stable performance on various chained and multiple schedules. A: chain FI 60-sec FI 60-sec; B: multiple FI 60-sec FI 60-sec; C: chain FI 60-sec FI 120-sec; D: chain FR 1 FI 60-sec; E: chain FI 30-sec FI 90-sec; F: chain FI 90-sec FI 30-sec. All records are from Bird 53 in the final session of the experimental condition.

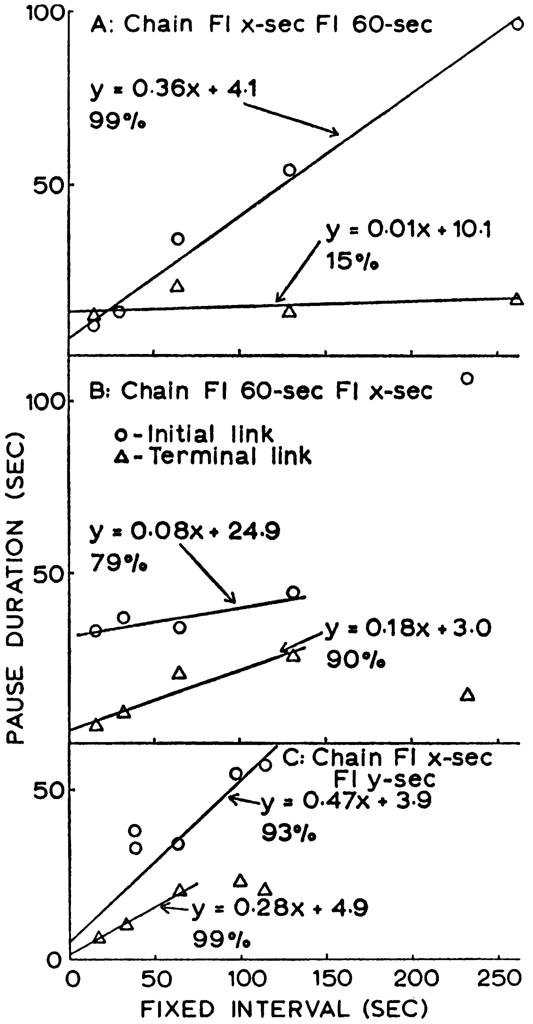

Fig. 2. The duration of the pause before responding in the initial and terminal links as a function of the size of the varied FI schedule. When both intervals were varied (graph C), the pause in both cases is shown as a function of the interval of which it was a part. The data from chain FI 60-sec FI 60-sec contribute data points to all three graphs. The equations of the best-fitting straight lines to all except deviant data are shown and, beneath them, the percentage of data variance accounted for by the equation. The group data are arithmetic averages.

proportions of times spent pausing being 0.47 and 0.28 in the two links respectively. The fact that the pause proportions in both links were higher in the conditions in which both intervals were varied is presumably due to the effects of interactions between the interval in one link and the pause in the other, especially noticeable in Figure 2c. However, the fitting of straight lines in Figure 2c may be misleading, as the interactions already shown would be likely to lead to both functions being curvilinear.

The ratio of response rates in the two links (P_1/P_2) is shown in Figure 3 as a function of the ratio of times spent in the two links (T_2/T_1) on double logarithmic coordinates. This independent variable was chosen because it is consistent with that used by Barron and Davison (1972) in their study of multiple FI FI

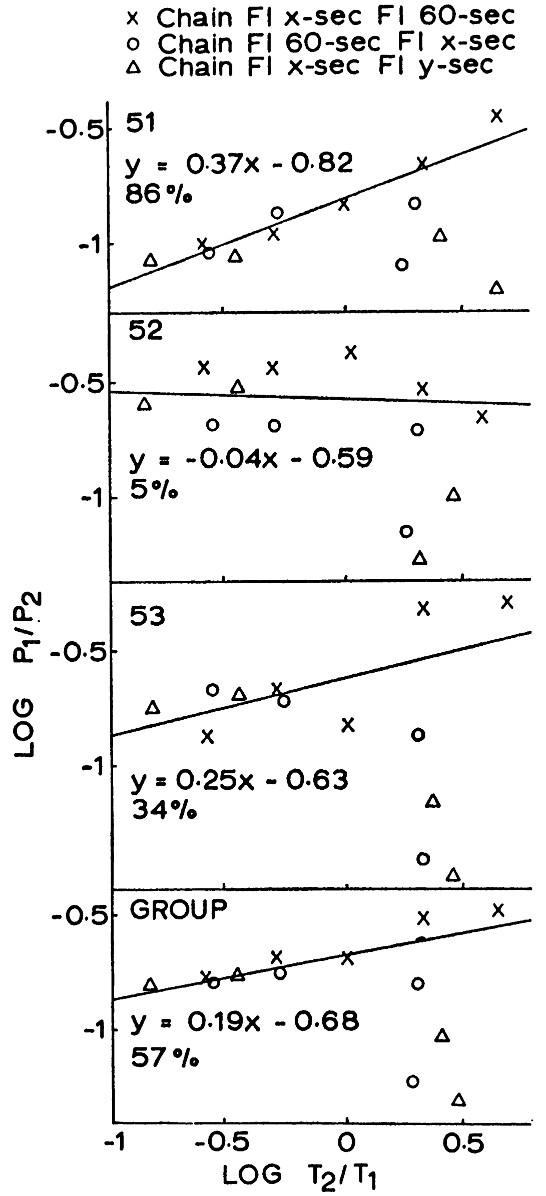

Fig. 3. The ratio of response rates in the two links (P_1/P_2) as a function of the ratio of times in the two links (T_2/T_1) on double logarithmic coordinates. Straight lines are fitted to all data save the consistently deviant points. Beneath the straight line equation is the percentage of data variance accounted for by the equation.

performance. The double logarithmic plot was used because it allows a direct assessment of the values of c and a in Equation 1. For all animals, the three previously discussed data points are again inconsistent with the other data, each showing abnormally low response rates in the initial links relative to the rates in the terminal links. Apart from these three conditions, the data from varying initial, terminal, or both intervals cannot be differentiated.

For each animal, and for the grouped data, best-fitting straight lines by the method of least squares were calculated for all response rate data save those from the inconsistent points. The adequacy of the fits of the straight lines in Figure 3 were measured by the difference between the variance of the data around the data mean and the variance of the data around the fitted lines as a percentage of the variance of the data around the data mean. This measure, the percentage of the data variance accounted for by the fitted lines, was 86% for Subject 51, but only 5% and 34% for Subjects 52 and 53 respectively. For the last two animals, the reason for the small amount of variance accounted for was simply that response rates changed little with changes in the arranged intervals, giving a smaller amount of systematic variance in the data. Thus, random fluctuation constituted a large relative, not absolute, proportion of the variance.

DISCUSSION

The data from three conditions (chain FI 60-sec FI 240-sec, chain FI 30-sec FI 90-sec, and chain FI 15-sec FI 105-sec) lacked consistency with the other data on all measures. Table 1 shows that all three conditions produced a considerably longer initial-link time than was arranged and, therefore, many examples of only a single response being emitted in the initial link. In these conditions, the ratio of response rates were all much lower than would be expected from the other data, and this result is probably caused by the increased proportion of the initial-link time, and the decreased proportion of the terminal-link time, taken up by pecking (Figures 2b and 2c). An explanation of the contrast in pausing in the two links in these three conditions is not attempted here and requires further experimentation.

Pausing

Figure 2 shows that the pause before emitting a response in the two links of the chain was a relatively constant proportion of the duration of the FI schedule in that link. These results are similar to those reported for performance in single FI schedules by Schneider

(1969). Figure 2 also shows that the pause in the initial link is a greater proportion of the initial-link interval than the pause in the terminal link is of the terminal-link interval. The reason for this difference is, presumably, that the reinforcer maintaining initial-link responding is less effective than that which maintains terminal-link responding. Figure 2 also shows that the intercept of the line fitted to pause data is greater for the initial link than for the terminal link. That is, when the first response in the initial link produces the terminal link (FI 0-sec or FR 1) and the terminal link is FI 60-sec, the fitted line in Figure 2a predicts that the animals will pause for about 4 sec in the initial link before emitting the one response that produces the terminal link. The control condition, chain FR 1 FI 60-sec, shows that such a pause occurs. In this condition (Table 1) the animals paused on the average 15.8 sec before emitting a response in the initial link. The difference between the obtained and predicted values may be another example of a contrast effect occurring between initial and terminal link pauses.

The Matching Law

In order to obtain the appropriate form of Equation 1 for the present data, we assume that the independent variable in Figure 3 (time in link 2/time in link 1) measures the ratio of the rates of reinforcement (rate in link 1/rate in link 2) as used by Barron and Davison (1972). Hence, if the present data deviate from the function reported by Barron and Davison for multiple FI FI performance, the deviation can be said to result from the magnitude of reinforcement for link 1 performance being different from the magnitude of reinforcement for link 2 performance. The appropriate values of a for the present data are simply the slopes of the fitted lines in Figure 3 (group, 0.19, range −0.04 to +0.37). For simplicity, the values of c are obtained neglecting the slightly higher response rate in the first component evident in the multiple FI 60-sec FI 60-sec schedule control. They are thus the antilogs of the logarithmic constants of the fitted lines in Figure 3 (group, 0.21, range 0.15 to 0.26). Thus, for the group, the form of Equation 1 for chain FI FI schedules is:

$$\frac{P_1}{P_2} = 0.21\left(\frac{R_1}{R_2}\right)^{0.19} \qquad (2)$$

The value of a in Equation 2 is close to that reported by Barron and Davison (1972) for multiple FI FI schedules (0.14, range 0.05 to 0.19) and to the value calculated by them for singly arranged FI schedules (0.22) from data reported by Schneider (1969). However, the value of c in Equation 2 is very different from the corresponding value (one) obtained from multiple or single schedule FI performance. Comparison of these results shows that the ratio of response rates in the initial and terminal links of a chained FI FI schedule is a constant fraction of the ratio of response rates in the components of a multiple FI FI schedule composed of the same intervals. As mentioned in the introduction, the constant fraction c describes the effects of reinforcers in the situation, which do not change with manipulations of the independent variable. Thus, c may be interpreted as the ratio of reinforcement magnitudes maintaining initial- and terminal-link responding. It is not possible, however, to go further and obtain the absolute value of reinforcement for initial-link responding by substituting a value of 3 sec for the terminal-link reinforcer. The value of c is an aggregate measure of all the reinforcers operative in the chain. Thus, while the production of the terminal-link stimulus may reinforce initial-link responding, the production of the initial-link stimulus after food reinforcement may detract from the value of food reinforcement (Barron and Davison, 1972). It may also be that the production of food reinforcement in the terminal link has some effect on initial-link responding for which there is no food reinforcement, without there being a similar effect in the opposite direction. Finally, it is not clear at present whether c should be taken as a direct measure of the reinforcement magnitude ratio or whether c is this ratio taken to some power. The latter is indicated by the finding that changes in reinforcement magnitude in multiple VI VI schedules affect response ratios in the same way as changes in reinforcement rate (Shettleworth and Nevin, 1965). All these questions may be answered by parametric investigations similar to that reported here.

It should be noted that, as the value of c is constant for all chained FI FI schedule performances, it cannot be identified with the usual measures of conditioned reinforcement, the magnitude of which is generally found to be a function of the reinforcement rate in the terminal link (Kelleher and Gollub, 1962). The difference between these approaches is in terms of measurement, traditional research on conditioned reinforcement using only initial link response measures, the present research using responses in both links. It is left for future research to determine which approach is most effective.

A similar procedure to that used here can be applied to parametric data from a heterogeneous chain VI VI schedule performance reported by Findley (1962, p. 127). Estimated average group response rates from Findley's Figures 3 and 4 give best-fitting values of $a = -0.88$ and $c = 0.014$ in Equation 1, this function accounting for 93% of the data variance. The negative value of a reflects the fact that response rates in both links of this schedule generally changed in the same direction when the reinforcement rate in the terminal link was varied. The opposite is the case with the present results and also with performance on chain VI FI schedules (Findley, 1962, p. 128). Performance on this latter schedule gives best-fitting values of $a = 0.82$ and $c = 1.43$, with 97% of the variance accounted for. The results of Findley's first experiment suggest that it may not generally be the case that the same values of a apply to both multiple and chained schedules (*cf.* Lander and Irwin, 1968), but the influence of using two different responses in the chain cannot be assessed without a control condition in which these two responses are used in the components of a multiple VI VI schedule. The present results, and those obtained from Findley (1962), do indicate that the approach taken here can be successful with chains comprising other schedule types, and hence that chained schedule performance can be incorporated into the growing body of data that can be described in terms of Equation 1.

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