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# *THE EFFECTS OF TERMINAL-LINK FIXED-INTERVAL AND VARIABLE-INTERVAL SCHEDULES ON RESPONDING UNDER CONCURRENT CHAINED SCHEDULES*[1]

DAVID MACEWEN

MARY WASHINGTON COLLEGE OF THE UNIVERSITY OF VIRGINIA

Previous work using variable-interval schedules in the terminal links of concurrent chained schedules suggested that relative choice proportion in the initial links equalled relative rate of reinforcement in the terminal links. With fixed-interval terminal-link schedules, however, matching was not obtained. The present study held pairs of fixed-interval terminal-link schedules in a constant ratio but varied absolute sizes. Relative choice for the smaller terminal-link fixed-interval schedule was a negatively accelerated, increasing function of absolute size of the fixed-interval pairs. Matching was found only with the fixed-interval pair of 5 and 10 sec. When pairs of variable-interval schedules were arranged so that the harmonic mean of the intervals equalled the fixed-interval parameter values, relative choice functions were like those for fixed-interval schedules.

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Preference for various schedules of reinforcement can be measured with two concurrent chain schedules (Autor, 1960). In the initial links of the chain schedules, the animal has the option of choosing either chain. A relative choice proportion for the terminal schedules is defined as the number of responses emitted on one key in the initial links divided by the total number of responses on both keys in the initial links.

Previous work using variable-interval (VI) schedules in the terminal links of the concurrent-chains procedure (Autor, 1960; Herrnstein, 1964*a;* and Killeen, 1968) suggested that the relative choice proportion was proportional to the relative rate of reinforcement in the terminal links. Initially, the relative rate of reinforcement was calculated by taking the reciprocal of the arithmetic mean of intervals of one terminal-link schedule divided by the sum of the reciprocals of the arithmetic means for both terminal-link schedules. Killeen (1968) later determined that a more appropriate transformation was the harmonic mean of the intervals. It appeared that pigeons' choice behavior could be described as "matching" the relative harmonic rates of reinforcement in the terminal links.

The harmonic rate of reinforcement is the average of the reciprocals of intervals from initial presentation of the terminal link until reinforcement. If these intervals, termed reinforcement immediacies (Chung and Herrnstein, 1967; Killeen, 1968), are a crucial factor affecting choice, and if matching is a general phenomenon, one should find matching of relative choice proportions to relative immediacy if fixed-interval schedules are used in the terminal links. When FI schedules were used in the terminal links (Herrnstein, 1964*b;* Killeen, 1970), however, the relative choice proportion in the initial links did not indicate matching. Rather than matching relative response rate to relative reinforcement rate, animals responded excessively on the side with the briefer fixed-interval schedule in the terminal link.

The present experiment provided additional data on terminal-link FI and VI schedules in an attempt to develop a formulation consistent with available data.

## METHOD

### *Subjects*

Four experimentally naive, male White Carneaux pigeons (M1, M3, M5, and M6) were maintained at approximately 80% of their free-feeding body weights.

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*Apparatus*

The experimental chamber was an 11.5 by 11.5 by 13.5 in. (29 by 29 by 34 cm) Masonite box. Two Gerbrands pigeon keys, separated by a distance of 4.5 in. (11 cm) from the center of one key to the other, were mounted 9 in. (22 cm) above the floor. The left key was transilluminated by either a white or a blue light and the right key by either a white or a red light, according to the particular schedule component. A response of at least 15 g (0.15N) on the lighted key resulted in auditory feedback provided by the closure of a relay mounted behind the key. The reinforcer consisted of access to mixed grain for 4 sec, with the keylights out and a 7.5-w white bulb illuminating the grain. Standard scheduling and recording equipment was located in an adjacent room.

*Procedure*

All pigeons were first magazine trained, and then key pecking was shaped in the presence of the blue and red lights. The concurrent-chains procedure was then initiated with white lights and a VI 30-sec schedule in the initial links, and equal FI 15-sec schedules associated with blue and red lights in the terminal links.

The concurrent-chains procedure is schematized in Figure 1. For Conditions I and II, presentation of the terminal links was arranged by a single VI 30-sec schedule. The particular terminal link to be presented under the VI schedule was determined by a Gellerman series. The Gellerman series assured an equal number of presentations of each terminal link with no more than three consecutive presentations on a given side (Gellerman, 1933). If presentation of the left terminal link was arranged, the pigeon had to respond on the left key to produce the terminal link, and responses on the right key were of no consequence. Conditions were reversed when a right terminal link was arranged. A response on the appropriate key in the initial link produced the terminal link for that key, illumination for the other key was removed, and the initial-link VI 30-sec schedule stopped.

For the first condition, key pecks in the terminal link produced mixed grain according to FI schedules. For the second condition, key pecks in the terminal link produced mixed grain according to VI schedules. The VI schedules were arranged so that the harmonic mean

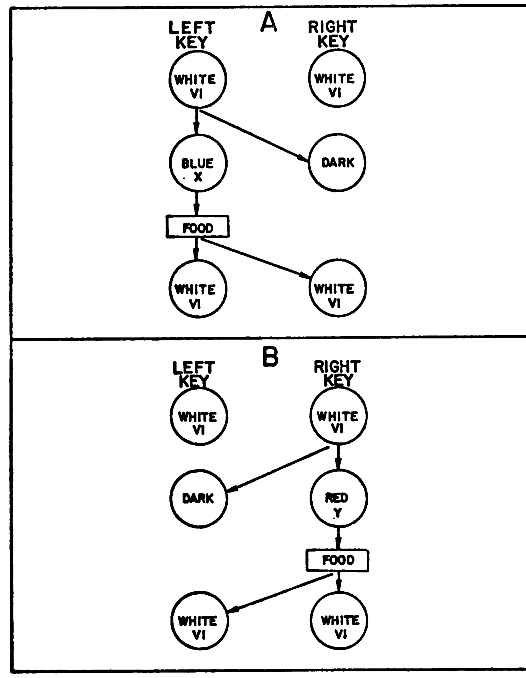


Fig. 1. Pictorial representation of the experimental procedure. Figures 1A and 1B indicate the sequence of events following responses on the left or right keys, respectively. The x and y represent the various terminal-link schedules used in the study.

of each schedule corresponded in duration to an FI schedule of the first condition. Following food in one of the terminal links, the conditions of the initial links were reinstated (Figure 1).

In Condition III, the terminal links were presented under two independent VI 60-sec schedules for the left and right keys to make conditions more comparable with conditions used in most previous work with concurrent chain schedules. If presentation of the left terminal link was arranged by the left initial-link VI schedule, the right initial-link VI schedule continued to operate. The left initial-link VI schedule continued to operate when presentation of the right terminal link was arranged by the right initial-link VI schedule. Both initial-link VI schedules stopped once a terminal link had been initiated. If the left initial-link schedule arranged presentation of the terminal link, but the pigeon first pecked and initiated a right-key terminal link, the left-key terminal link was still available after reinforcement on the right key. Similarly, if the right key arranged presentation of the terminal link, it was still available after reinforcement on the left key. Key pecks in the terminal links produced mixed grain according to VI schedules.

Each experimental session continued for 50 reinforcements. Data were collected from each bird daily, seven days a week. Each pair of terminal-link schedules remained in effect until responding in the initial links satisfied a visual criterion of stability for at least seven days. The visual criterion was reached for each terminal schedule pair in about 30 days. The order of experimental conditions and values for the left and right terminal-link schedules is given for each pigeon in Table 1. The duration of the terminal links was measured from presentation of a terminal link until the occurrence of reinforcement. All VI schedules used were equal probability schedules derived from Catania and Reynolds (1968). Terminal-link schedule durations are presented as harmonic means and initial-link schedule durations are presented as arithmetic means.

The independent variable in this study was the duration of the terminal-link schedules. Terminal schedule pairs for all three conditions were selected so that their absolute sizes varied but the ratios of their harmonic means were constant. This procedure was followed even in Condition II where, for two of the birds, some of the terminal-link schedule pairs consisted of one VI and one FI schedule. The particular FI parameters were chosen to cover a wider range than used by Chung and Herrnstein (1967), Herrnstein (1964*b*), and Killeen (1968).

## RESULTS

The data for each pigeon are presented as medians for the last five days on each pair of terminal-link schedules (Table 2). The main dependent variable was the proportion of initial-link responses occurring on the left key, the key with briefer interreinforcement intervals. Choice proportions were obtained from:

$$\frac{R_l}{R_r + R_l}$$

where $R_r$ is the total number of initial-link responses emitted on the right key, and $R_l$ is the total number of initial-link responses emitted on the left key. Choice proportions for each pigeon on all procedures are shown in Column (ii) of Table 2. Columns (iii) and (iv) of Table 2 give the absolute rates of responding (responses per minute) for each key in both the initial and terminal links. Column (v) shows the average time in seconds of initial-link presentation before the onset of a terminal link. This time was obtained by dividing the total time in the initial links by the total number of reinforcements (50). Column (vi) presents the relative proportion of time spent on the left key in the initial links. Elapsed time in seconds was recorded on a counter as soon as the pigeon pecked a given key. When the pigeon switched over and pecked the other

Table 1

Order of Experimental Conditions for Each Pigeon

| *Conditions and Schedule(s) in Initial Links* | *Schedules in Terminal Links (Left Key—Right Key)* *M1* | | *M3* | | *M5* | | *M6* | |
|---|---|---|---|---|---|---|---|---|
| Condition 1 | FI-10 | FI-20 | FI-40 | FI-80 | FI-5 | FI-10 | FI-20 | FI-40 |
| Single VI 30-sec | FI-40 | FI-80 | FI-10 | FI-20 | FI-20 | FI-40 | FI-5 | FI-10 |
| | FI-20 | FI-40 | FI-5 | FI-10 | FI-10 | FI-20 | FI-40 | FI-80 |
| | FI-5 | FI-10 | FI-20 | FI-40 | FI-40 | FI-80 | FI-10 | FI-20 |
| Condition II | VI-20 | VI-40 | VI-20 | VI-40 | VI-20 | VI-40 | VI-20 | VI-40 |
| Single VI 30-sec | VI-10 | VI-20 | VI-10 | VI-20 | VI-10 | VI-20 | VI-10 | VI-20 |
| | VI-5 | VI-10 | VI-5 | VI-10 | VI-5 | VI-10 | VI-5 | VI-10 |
| | | | FI-20 | VI-40 | FI-20 | VI-40 | | |
| Condition III | | | | | | | | |
| Two VI 60-sec | | | VI-20 | VI-40 | VI-20 | VI-40 | | |

Terminal-link schedule durations are harmonic means in seconds; initial-link schedule durations are arithmetic means in seconds.

Table 2
Data Collected for Each Pigeon for Each Condition. Data are Medians for the Last Five Days.

| | (i) | | (ii) | (iii) | | (iv) | | (v) | (vi) | (vii) | (viii) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Schedules in Terminal Links* | | | *Absolute rate of responding (responses/min) in Initial Links* | | *Absolute rate of responding (responses/min) in Terminal Links* | | *Latency of Terminal Link Entry (Initial time/no. reinforcements) Time in sec* | *Relative Time in Initial Link for Left key* | *Changeover Rate (Changeover Responses/min)* | *Mean Time (sec) Responding before Changeover (Initial Time/½ CO)* | |
| *Pigeon* | *Left Key* | *Right Key* | *Choice Proportion* | *Left Key* | *Right Key* | *Left Key* | *Right Key* | | | | *Left Key* | *Right Key* |
| M1 | FI-5 | FI-10 | 0.661 | 62.3 | 16.5 | 49.6 | 51.7 | 32.5 | 0.734 | 24.3 | 3.6 | 1.3 |
| | FI-10 | FI-20 | 0.814 | 48.2 | 11.1 | 43.8 | 24.5 | 35.8 | 0.772 | 10.9 | 8.4 | 2.4 |
| | FI-20 | FI-40 | 0.938 | 55.8 | 3.7 | 51.0 | 43.7 | 45.8 | 0.892 | 4.3 | 24.9 | 2.9 |
| | FI-40 | FI-80 | 0.950 | 56.4 | 3.5 | 94.1 | 80.4 | 47.7 | 0.909 | 3.2 | 34.0 | 3.4 |
| | VI-5 | VI-10 | 0.668 | 46.2 | 21.6 | 147.2 | 111.3 | 36.7 | 0.656 | 20.8 | 3.7 | 1.9 |
| | VI-10 | VI-20 | 0.819 | 41.8 | 11.3 | 132.7 | 95.8 | 37.0 | 0.757 | 14.2 | 6.3 | 2.0 |
| | VI-20 | VI-40 | 0.939 | 57.6 | 4.1 | 118.6 | 80.1 | 41.6 | 0.887 | 5.6 | 18.8 | 2.3 |
| M3 | FI-5 | FI-10 | 0.747 | 21.7 | 6.9 | 90.0 | 126.0 | 35.6 | 0.764 | 8.6 | 10.6 | 3.2 |
| | FI-10 | FI-20 | 0.819 | 13.8 | 3.2 | 90.3 | 125.5 | 43.0 | 0.821 | 4.5 | 21.6 | 4.7 |
| | FI-20 | FI-40 | 0.864 | 12.5 | 2.1 | 144.4 | 129.9 | 57.8 | 0.892 | 2.9 | 36.9 | 4.4 |
| | FI-40 | FI-80 | 0.915 | 12.7 | 1.4 | 62.5 | 38.3 | 55.5 | 0.881 | 2.2 | 48.0 | 6.5 |
| | VI-5 | VI-10 | 0.757 | 25.9 | 8.6 | 155.1 | 79.0 | 34.4 | 0.693 | 12.9 | 6.4 | 2.8 |
| | VI-10 | VI-20 | 0.837 | 14.6 | 2.9 | 90.5 | 45.1 | 43.6 | 0.782 | 4.7 | 18.3 | 5.1 |
| | VI-20 | VI-40 | 0.856 | 14.1 | 2.1 | 74.8 | 37.7 | 46.9 | 0.869 | 3.3 | 31.4 | 4.7 |
| | FI-20 | VI-40 | 0.857 | 15.0 | 2.1 | 103.2 | 89.0 | 56.0 | 0.867 | 3.0 | 34.7 | 5.3 |
| | VI-20 | VI-40* | 0.932 | 17.0 | 1.3 | 97.3 | 74.4 | 58.6 | 0.924 | 3.0 | 36.6 | 3.0 |
| M5 | FI-5 | FI-10 | 0.645 | 11.3 | 6.6 | 74.4 | 92.2 | 42.8 | 0.610 | 8.2 | 8.9 | 5.7 |
| | FI-10 | FI-20 | 0.719 | 12.8 | 4.7 | 62.4 | 75.8 | 46.5 | 0.780 | 5.8 | 16.7 | 4.7 |
| | FI-20 | FI-40 | 0.827 | 9.4 | 2.3 | 52.3 | 42.5 | 62.6 | 0.858 | 2.7 | 39.4 | 6.5 |
| | FI-40 | FI-80 | 0.870 | 13.3 | 1.7 | 40.1 | 31.3 | 58.3 | 0.843 | 2.5 | 41.1 | 7.7 |
| | VI-5 | VI-10 | 0.655 | 9.6 | 4.4 | 74.4 | 50.2 | 43.4 | 0.624 | 7.0 | 10.7 | 6.4 |
| | VI-10 | VI-20 | 0.732 | 7.9 | 3.5 | 31.8 | 25.7 | 47.6 | 0.717 | 4.5 | 19.2 | 7.5 |
| | VI-20 | VI-40 | 0.810 | 8.5 | 2.3 | 38.4 | 26.3 | 51.6 | 0.755 | 2.8 | 31.9 | 10.7 |
| | FI-20 | VI-40 | 0.826 | 9.9 | 2.6 | 55.4 | 38.1 | 53.0 | 0.805 | 2.8 | 33.9 | 8.1 |
| | VI-20 | VI-40* | 0.965 | 11.7 | 0.2 | 40.0 | 31.3 | 69.9 | 0.987 | 0.7 | 157.0 | 1.9 |
| M6 | FI-5 | FI-10 | 0.762 | 41.5 | 10.6 | 101.7 | 49.1 | 33.9 | 0.738 | 14.4 | 6.1 | 2.1 |
| | FI-10 | FI-20 | 0.928 | 46.7 | 3.5 | 36.4 | 74.5 | 39.4 | 0.848 | 4.5 | 22.6 | 4.0 |
| | FI-20 | FI-40 | 0.975 | 39.1 | 0.9 | 42.9 | 68.7 | 56.4 | 0.946 | 1.6 | 70.2 | 3.9 |
| | FI-40 | FI-80 | 0.962 | 26.7 | 1.2 | 69.5 | 91.4 | 51.1 | 0.887 | 1.8 | 56.8 | 7.2 |
| | VI-5 | VI-10 | 0.769 | 13.5 | 4.6 | 161.1 | 156.7 | 43.0 | 0.774 | 4.6 | 19.9 | 5.7 |
| | VI-10 | VI-20 | 0.922 | 26.7 | 2.4 | 168.0 | 74.4 | 55.8 | 0.888 | 2.7 | 38.7 | 4.8 |
| | VI-20 | VI-40 | 0.941 | 19.4 | 0.5 | 115.1 | 90.1 | 70.5 | 0.925 | 1.6 | 68.1 | 5.5 |

*Initial-link schedules were two, independent VI 60-sec schedules.

key, a second counter began recording elapsed time in seconds and the first counter stopped. When the procedure returned to the initial links after reinforcement, initial time was recorded on the key last pecked before terminal-link presentation. In this way, total separate time spent on each key was recorded. Total time spent on the left key was divided by the total separate time spent on both left and right keys to obtain relative time.

Column (vii) presents changeover response rate (responses per minute), *i.e.*, the total number of times the pigeon switched from one key to the other in the initial links divided by the total time spent in the initial links. Column (viii) presents the average time in seconds spent responding on a key in the initial links before switching to the other key. The data in Column (viii) were obtained by dividing the total time spent on a given side in the initial links by one-half of the total number of changeover responses.

Data from Columns (iv) and (ii) indicate that absolute rates of responding in the terminal links were not systematically related to choice proportions in the initial links. The effect shown in Column (iv) has been a rather general finding with the concurrent-chains procedure (Autor, 1960; Herrnstein, 1964*a*).

A comparison can be made between Columns (ii) and (vi). Column (ii) presents relative number of responses in the initial links, while Column (vi) presents relative time in the initial links. The relative proportions in each column increased as the parameter values of the terminal-link schedules increased, although their absolute values were often quite different from each other. The difference between the absolute values of these two measures was perhaps due to the birds not responding at a constant rate. If the birds had responded at a perfectly constant rate on each key for each condition, time and number of responses would be redundant. It should also be pointed out that separate time spent on each key includes time spent during the changeover responses. Catania (1961) showed that this changeover time may vary with experimental conditions. This limitation in the separate time measure would also hold with respect to Column (viii), where one-half the number of changeover responses was divided by the separate time spent on the keys.

Column (iii) shows that generally, the absolute response rate in the initial links is higher the briefer the duration of the terminal link schedule pairs. There is some correlation between Columns (iii) and (v), *i.e.*, the higher the response rate the less time spent in the initial links. The correlation would be expected, since a higher response rate would minimize the time between a scheduled terminal-link presentation and actual presentation. Column (vii) shows that the briefer the length of the terminal-link schedule pairs, the higher the rate of changeover responses. This is reflected in Column (viii), where the mean duration of responding on a given side before changing to the other side was briefer the briefer the duration of the terminal-link schedule pairs.

Column (ii) of Table 2 shows that the choice proportions for the briefer interreinforcement interval (left key) increased as the duration of the terminal-link schedule pairs increased for both VI and FI schedules. Figure 2 presents the relation more clearly. Solid line functions in Figure 2 show the choice proportions for the left key as a function of the fixed-interval terminal schedules. None of these functions is consistent with the simple matching rule derived from earlier work with VI terminal-link schedules. Instead of being constant at 0.66, the functions could be characterized as negatively accelerating as the absolute duration of the FI pairs increased. In two of the four birds, M1 and M5, the choice proportion function crossed the matching line when the FI parameters were 5 and 10 sec. That is, when FI pair 5 and 10 sec was used in the terminal links, the choice proportion in the initial links was consistent with the simple matching rule. However, as soon as the absolute durations of the terminal-link FI pairs increased, matching was not obtained.

Dashed line functions in Figure 2 show the choice proportion functions with terminal-link VI schedules. The VI schedules were arranged so that the harmonic means of the intervals corresponded to the durations of terminal-link FI schedule pairs. It can be seen that the choice proportions for the briefer reinforcement interval increased as the absolute duration of the terminal-link schedule pairs increased. The function generated with the terminal-link VI schedules was like the function for the FI schedules.

The triangles in Figure 2 for M3 and M5 show choice proportions when the terminal

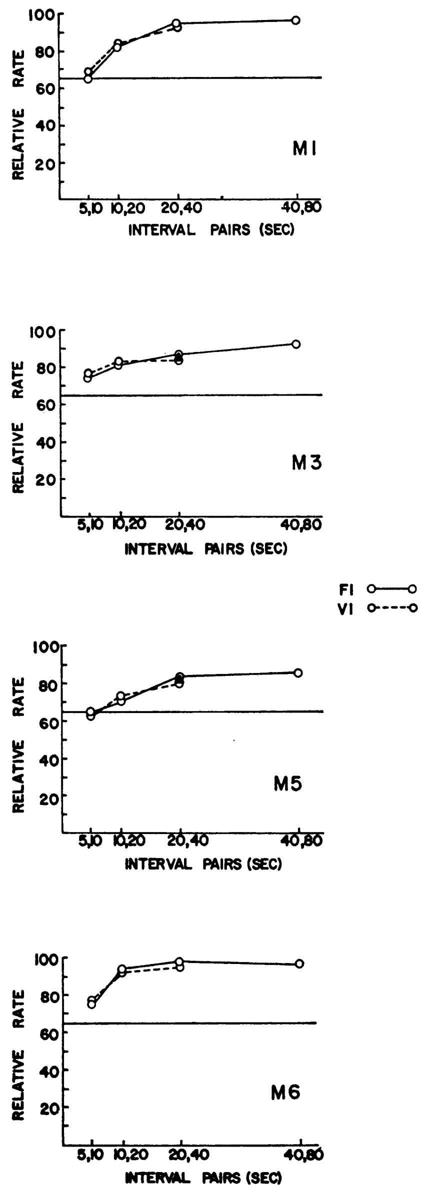


Fig. 2. Relative choice proportions in the initial links as a function of interreinforcement intervals in the terminal links. Solid line functions indicate relative choice for the shorter terminal-link schedule (left key) when the interreinforcement intervals were pairs of fixed-interval schedules of reinforcement. Dashed line functions indicate relative choice when the interreinforcement intervals in the terminal links were variable-interval schedules, arranged so that the harmonic mean of the intervals equalled the parameters of the fixed-interval schedules. Values on the abscissa are the durations in seconds of the terminal-link schedule pairs. Triangles for M3 and M5 are choice proportions when the terminal links were FI 20-sec, and a VI schedule arranged so that the harmonic mean of the intervals equalled 40 sec.

links consisted of an FI 20-sec schedule and a VI schedule arranged so that the harmonic mean of the intervals equalled 40 sec. The choice proportions in the initial links were nearly identical to the proportions when either FI pairs alone or VI pairs alone were used in the terminal links.

Table 2 also compares results of the two procedures for arranging terminal-link presentation. Conditions I and II, during which all data presented so far were collected, used a single VI 30-sec schedule in the initial links. Condition III used two independent VI 60-sec schedules for each key in the initial links. These data are presented in Table 2, indicated by an asterisk. The data, which are medians from the last five days, indicate that results were somewhat different for the two procedures. Column (ii) shows that choice proportions were higher when two independent schedules arranged terminal-link presentation than when a single schedule was used. Column (viii) shows mean time in seconds spent responding on each initial-link key before switching over to the other key. The distribution of time spent shifted such that when two independent VI schedules arranged terminal-link presentation, pigeons spent more time on the briefer interreinforcement side and less time on the longer interreinforcement side.

Additional data, not given in Table 2, showed that there was not an equal number of reinforcements with left and right terminal links during Condition III. Bird M3 showed 36 reinforcements under the left terminal-link schedule and 14 under the right. Bird M5 showed 43 reinforcements under the left terminal-link schedule and seven under the right. With the single schedule procedures, presentation of the terminal links was arranged such that there were an equal number of reinforcements, *i.e.*, 25 under the left terminal link and 25 under the right.

## DISCUSSION

Results of the present study indicate that matching is a function of the absolute duration of the FI terminal-link schedules. For two of the four birds, matching was found when the terminal links consisted of FI 5- and 10-sec schedules. The relative choice proportion was a negatively accelerating function of the absolute durations of the terminal-link FI schedule pairs. Moreover, when terminal-link VI schedules were arranged so that the harmonic mean of their intervals equalled the parameter values of the FI schedules, the relative choice proportion functions were like those for FI schedules. The close correspondence between the choice proportion functions suggested that, perhaps FI and VI terminal-link schedules could be substituted for each other, as long as the VI schedule was arranged so that the harmonic mean of the intervals equalled the duration of the FI schedule it replaced.

For equal-probability VI schedules, the harmonic mean of the intervals is considerably less than the arithmetic mean of the intervals. In previous studies, the arithmetic mean of the intervals for VI schedules has generally ranged between 30 and 120 sec. The durations in this range are convenient because they produce intervals such that for 50 or 60 reinforcements, sessions are not too long. For a schedule with an arithmetic mean of intervals falling within the above range, the harmonic mean of the intervals is much briefer and falls within the range at which matching was found in the present study with terminal-link FI schedules. The generality of the matching rule does not extend beyond a limited range, even for VI schedules, and the ranges used by Herrnstein (1964*b*) and Killeen (1968) were simply not large enough to show this inadequacy. It is most likely that what has been called "matching" is simply a point on a continuum, and as such cannot be thought of as a rule of behavior at all.

The limitations of the matching rule found in the present work do not seem to be a result of using one VI schedule during both initial links. When two concurrent and independent VI schedules were used to arrange the terminal links, the data generated were also inconsistent with the matching rule. Moreover, relative choice was greater with respect to the left key or briefer-interreinforcement side using two independent VI schedules in the initial links than with only one VI schedule. This result was probably due to two factors. A major difference between the two procedures is that when the single VI schedule arranged a given left or right terminal-link presentation, responses on the opposite key had no effect in initiating the terminal link. The result of this was that in order to receive food, the bird had to make changeover responses. With the two independent initial-link VI schedules, changeover responses were actually not necessary for reinforcement. The animal could remain on a given side and continue to initiate the terminal link and receive food on that side. In this case, actual presentations of the left and right terminal links were not necessarily equal and there would be, therefore, a greater number of reinforcements on one side than the other. These two features may have combined to increase the choice proportions.

The present study indicated that the transformation function most appropriate for a correspondence between terminal-link VI and FI schedules seemed to be the harmonic mean of the intervals. When harmonic means are equated for the two schedules, they may be interchanged in the terminal links, and initial-link performance is unaffected. The behavioral significance of the harmonic mean of the reinforcement interval has been described elsewhere (Killeen, 1968).

A study by Fantino (1969) showed that choice proportions do not follow a simple matching rule when the length of the initial-link VI schedule is varied over a large range. Fantino was able to make suitable predictions of choice proportions with a model that took into account the total time to reinforcement from the onset of the initial links. Table 3 shows that Fantino's formulation correctly describes the direction of choice proportions in the present study, but, in general, the Fantino formulation predicts choice proportions to be lower than they actually are.

The fact that the relative choice proportion functions for the FI and VI terminal-link schedules were so similar at every point strongly suggests an analysis of relative response rate in terms that can be extended to both types of schedules. Just what these terms may be is at this point unclear. Other investigators (Killeen, 1968; Davison, 1969) have described preference using a power function of the terminal-link interreinforcement intervals in a VI schedule. Killeen (1968) found that relative rate could be determined from the relative ratio of the power functions for each terminal VI schedule. The present study has shown, however, that this relation holds only for rather short terminal-link schedules.

Davison (1969) found that for N equal to 2, relative rate could be accounted for with r equal to $-3$ in Killeen's (1968) equation. In

Table 3

Choice proportions predicted from the formulation by Fantino (1969) compared with data from the present experiment.

| Pigeon | Schedule | Choice Proportion Predicted | Choice Proportion Obtained | Predicted minus Obtained |
|---|---|---|---|---|
| M1 | FI 5-10 | 0.54 | 0.66 | −0.12 |
| M3 | FI 5-10 | 0.54 | 0.74 | −0.20 |
| M5 | FI 5-10 | 0.54 | 0.64 | −0.10 |
| M6 | FI 5-10 | 0.54 | 0.76 | −0.22 |
| mean | FI 5-10 | 0.54 | 0.70 | −0.16 |
| M1 | FI 10-20 | 0.58 | 0.81 | −0.23 |
| M3 | FI 10-20 | 0.58 | 0.81 | −0.23 |
| M5 | FI 10-20 | 0.58 | 0.71 | −0.13 |
| M6 | FI 10-20 | 0.58 | 0.92 | −0.34 |
| mean | FI 10-20 | 0.58 | 0.81 | −0.23 |
| M1 | FI 20-40 | 0.66 | 0.93 | −0.27 |
| M3 | FI 20-40 | 0.66 | 0.86 | −0.20 |
| M5 | FI 20-40 | 0.66 | 0.82 | −0.16 |
| M6 | FI 20-40 | 0.66 | 0.97 | −0.31 |
| mean | FI 20-40 | 0.66 | 0.89 | −0.23 |
| M1 | FI 40-80 | 0.83 | 0.95 | −0.12 |
| M3 | FI 40-80 | 0.83 | 0.91 | −0.08 |
| M5 | FI 40-80 | 0.83 | 0.87 | −0.05 |
| M6 | FI 40-80 | 0.83 | 0.96 | −0.13 |
| mean | FI 40-80 | 0.83 | 0.92 | −0.09 |
| M1 | VI 5-10 | 0.60 | 0.68 | −0.08 |
| M3 | VI 5-10 | 0.60 | 0.75 | −0.15 |
| M5 | VI 5-10 | 0.60 | 0.65 | −0.05 |
| M6 | VI 5-10 | 0.60 | 0.76 | −0.16 |
| mean | VI 5-10 | 0.60 | 0.71 | −0.11 |
| M1 | VI 10-20 | 0.74 | 0.81 | −0.07 |
| M3 | VI 10-20 | 0.74 | 0.83 | −0.09 |
| M5 | VI 10-20 | 0.74 | 0.73 | +0.01 |
| M6 | VI 10-20 | 0.74 | 0.92 | −0.18 |
| mean | VI 10-20 | 0.74 | 0.82 | −0.08 |
| M1 | VI 20-40 | 0.97 | 0.93 | +0.04 |
| M3 | VI 20-40 | 0.97 | 0.85 | +0.12 |
| M5 | VI 20-40 | 0.97 | 0.81 | +0.16 |
| M6 | VI 20-40 | 0.97 | 0.94 | +0.03 |
| mean | VI 20-40 | 0.97 | 0.88 | +0.09 |
| M3 | VI 20-40* | 0.97 | 0.93 | +0.04 |
| M5 | VI 20-40* | 0.97 | 0.96 | +0.01 |
| mean | VI 20-40* | 0.97 | 0.94 | +0.03 |

*Initial-link schedules were two, independent VI 1-min schedules.

the present study, Killeen's equation cannot account for the variation in relative choice as a function of the absolute duration of the terminal-link schedules. Regardless of the value assigned to r, the formulation yields constant relative choice when the durations of the terminal link schedules remain at a two-to-one ratio.

In Conditions I and II of the present study, relative rate of reinforcement was held constant for the two keys. The explicit independent variable was the absolute duration of the terminal-link schedules and relative choice seemed to vary as a function of this variable. It is possible that the critical variable was the difference in duration of the interreinforcement intervals between the two terminal-link schedules. The larger this difference, the easier it should be to discriminate between the terminal-link schedules and the smaller the difference, the more difficult would be a discrimination. Utilizing the present procedure, relative choice might be considered to be the result of a discrimination between the interreinforcement intervals for the two terminal-link schedules. When the interreinforcement intervals for the two terminal-link schedules are held at an overall two-to-one ratio, it should be easier to discriminate between a schedule with a harmonic mean of 20 sec and one of 40 sec than between a schedule with a harmonic mean of 5 sec and one of 10 sec. Thus, the relative choice proportion for the shorter terminal-link schedule should increase as the absolute lengths of the terminal-link schedule pairs increase.

On the other hand, it should be easier to discriminate between a schedule with a harmonic mean of 5 sec and one of 10 sec than between a schedule with a harmonic mean of 35 sec and one of 40 sec. In the latter case, not tested in the present study, one might predict that the relative choice proportion for the briefer terminal-link schedule would be greater for the 5-sec and 10-sec terminal-link schedule pair than for the 35-sec and 40-sec pair.

In considering general formulations to predict choice behavior in the concurrent-chains procedure, studies (Herrnstein, 1964*a;* Killeen, 1968; Fantino, 1969; Duncan and Fantino, 1970; and the present study) have enumerated several apparently important variables. These are: relative harmonic rate of primary reinforcement; the duration of the initial-link VI schedule; reductions in the expected time to reinforcement for each key; and the absolute duration of the terminal schedule pairs. The last variable is important because it possibly affects the discriminability between the two terminal-link schedules. It would appear that any successful attempt to predict choice behavior would have to consider all of these variables in the resulting formulation.

## REFERENCES

Autor, S. M. *The strength of conditioned reinforcers as a function of frequency and probability of reinforcement.* Unpublished doctoral dissertation, Harvard University, 1960.

Catania, A. C. Behavioral contrast in a multiple and concurrent schedule of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1961, **4,** 335-342.

Catania, A. C. and Reynolds, G. S. A quantitative analysis of responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 327-383.

Chung, S-. H. and Herrnstein, R. J. Choice and delay of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1967, **10,** 67-74.

Davison, M. C. Preference for mixed-interval versus fixed-interval schedules. *Journal of the Experimental Analysis of Behavior,* 1969, **12,** 247-252.

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.

Gellerman, L. W. Chance orders of alternating stimuli in visual discrimination experiments. *Journal of Genetic Psychology,* 1933, **42,** 206-208.

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.

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

Herrnstein, R. J. Aperiodicity as a factor in choice. *Journal of the Experimental Analysis of Behavior,* 1964, **7,** 179-182. (*b*)

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.

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