

*PREFERENCE FOR MIXED-INTERVAL VERSUS
FIXED-INTERVAL SCHEDULES*¹

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Pigeons were trained on a two-link concurrent chain schedule in which responses on two keys were reinforced according to independent variable-interval schedules by the production of a change in key color. Further responses on the key on which the stimulus change had been produced gave a single food reinforcement and a return to concurrent variable-interval conditions. On one key the terminal link was a two-valued mixed-interval schedule, while on the other, the terminal link was a fixed-interval schedule. When the mixed-interval values were kept constant and the fixed-interval values varied, relative response rates in the initial concurrent links matched relative reinforcement rates in the terminal links when these were computed from cubic transformations of the reciprocals of the intervals comprising the terminal link schedules.

Concurrent chain schedules (Autor, 1960) are widely used in the study of preference. In these procedures, responses on two keys occasionally produce a stimulus on either key during which the animal may produce primary reinforcement according to some schedule. While one terminal link schedule is available on one key, the other key is darkened, and responses on it have no scheduled consequence. Preference for the schedules of primary reinforcement in the terminal links is measured by the relative rate of responding on one key (responses on that key/total responses) during the concurrent initial links.

Initial research (Autor, 1960; Herrnstein, 1964a) indicated that preference for stimuli associated with various values of variable-interval (VI) and variable-ratio (VR) schedules of primary reinforcement in the terminal links of concurrent chain schedules was controlled by the relative reinforcement rates in the terminal links (reinforcements per hour on one key/total reinforcements per hour). In these studies, relative reinforcement rates were computed from the arithmetic means of the component intervals. However, Herrnstein (1964b) found that arithmetic reinforcement rates computed in this way did not predict the relative preference for fixed- *versus* variable-

interval schedules. It was clear that, if relative response rates were controlled by relative reinforcement rates, the animals were not averaging the component intervals arithmetically. No specific transformation was suggested. In the choice between fixed- and mixed-ratio schedules, Fantino (1967) found that relative preference could be predicted from relative reinforcement rates computed from the geometric means of the reinforcement rates provided by the component ratios.

Killeen (1968) further investigated the relative preference for fixed- *versus* variable-interval schedules in the terminal links of concurrent chain schedules. He showed that this preference could be predicted from the relative reinforcement rates computed from the harmonic mean of the component intervals. This measure is obtained by taking the average of the reciprocals of the intervals comprising the VI schedule rather than, in the case of arithmetic reinforcement rates, the reciprocal of the average of the component intervals. Thus, if R_a and R_b are the initial link response rates to the FI and VI keys respectively, x is the value of the terminal link fixed interval, y_i is the value of the i^{th} interval in the terminal link VI schedule, and N is the number of intervals comprising the VI schedule, $r = -1$ in the equation:

$$\frac{R_a}{R_a + R_b} = \frac{x^r}{x^r + \frac{1}{N} \sum_{i=1}^N y_i^r} \quad (1)$$

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The measurement of reinforcement rate using this transformation also leads to matching of relative response and relative reinforcement rates in Herrnstein's (1964*b*) data.

The present study investigated preference for fixed- and mixed-interval (FI, MI) schedules. The mixed-interval schedule was constant throughout the experiment, and consisted of two intervals which were randomized in order and occurred equally often. Experimental conditions consisted of varying the fixed-interval values and determining the resultant relative response rates in the initial links.

METHOD

Subjects

Five adult White Carneaux pigeons served. They had extensive experimental histories, including concurrent chain schedules (Davison, 1968, and similar procedures). After each experimental session they were fed to 80% of their free-feeding body weights.

Apparatus

The experimental chamber (Grason-Stadler, E1184JA) contained two response keys which could be transilluminated with various colors of light by lamps placed behind them. No other illumination was provided. Feedback was given for each response emitted on either of the two keys (when illuminated) in the form of the click of a relay situated behind the center of the panel. Reinforcement consisted of 3-sec access to a hopper containing mixed grain; experimental sessions, which were conducted six days per week, were terminated after the delivery of 60 reinforcements.

Experimental contingencies were controlled by Grason-Stadler electromechanical apparatus remote from the soundproofed and ventilated box containing the experimental chamber.

Procedure

Since the animals had previously worked on concurrent chain schedules, no key-peck or schedule training was necessary. The animals were placed directly under the first experimental condition.

A diagram of the procedure (Herrnstein, 1964*a*) is shown in Fig. 1. Each session commenced with both keys illuminated by red light. Responses on the two keys were rein-

forced according to two independent VI 1-min schedules by the production of a green key color. When green had been produced on either key, the light behind the other key was turned off. When the left key was green, one primary reinforcement could be produced according to an MI reinforcement schedule. This schedule was composed of two interval values, 15 sec and 45 sec, which were scheduled with equal probability and were randomized in order, with the restriction that not more than three intervals of the same value could occur in succession. When the right key was green, one primary reinforcement could be produced according to an FI schedule. During green conditions on either key, the VI programmers associated with both keys were stopped. Immediately after primary reinforcement was produced on either key, the conditions reverted to concurrent VI 1-min VI 1-min under the red keys.

During the concurrent VI links, a change-over delay (Herrnstein, 1961) was in effect. A response on either key could not initiate the terminal links until at least 0.5 sec had elapsed from the time at which the animal had commenced responding on a key after responding on the other key.

The experimental conditions consisted of varying the FI values in the terminal link on

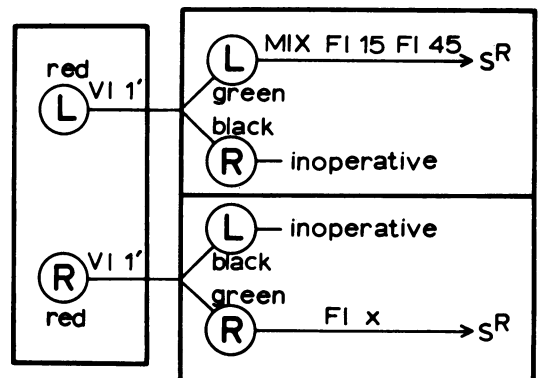


Fig. 1. Diagram of the procedure. Responding on two red keys was reinforced on two independent VI 1-min schedules by a change to a green key color and the darkening of the other key. When the left key was green, food reinforcement was available on a mixed FI 15-sec FI 45-sec schedule on that key and responses to the right key had no consequence. When the right key was green, food reinforcement was available on a fixed-interval schedule and responses to the left key had no consequence. After food reinforcement on either key, the conditions reverted to concurrent variable-interval schedules under the red keys.

the right key in the following order for all animals: 30, 10, 20, 15, and 25 sec. Training was given on one FI value until the performance was stable according to the following criterion. Each pigeon's performance was assumed to be stable if the median relative response rates in the initial link to the MI key over five sessions was less than 5% different from the median relative rate for the previous five sessions at the same FI value. The FI value was changed for all animals (as a group) when each had individually satisfied this criterion. The number of training sessions given under each condition ranged from 21 to 30.

RESULTS

Data shown here for individual animals are, in all cases, median values from the final five training sessions. Group data are reported as the median of these individual values.

Absolute response rates in both links of the chains on the two keys in the various condi-

tions of the experiment are shown in Table 1. Also shown in this table are the median number of entries into the terminal link on the MI key. These varied as a function of the interval value on the FI key, but were not sufficient to account for the variations in relative initial link response rates.

Figure 2 shows the relative response rates in the initial links on the MI key as a function of the value of the terminal link interval on the FI key for the five animals. The points lie close to a straight line over the range of intervals studied, which suggests that initial link responding would cease on the MI key at FI values below 6 sec. The same data, plotted as a function of relative arithmetic reinforcement rates (Herrnstein, 1964a), geometric reinforcement rates (Fantino, 1967), and harmonic reinforcement rates (Killeen, 1968) are shown in Fig. 3. The diagonal line shows the expected relation between relative response and reinforcement rates if any of these three transformations are satisfactory. For all transformations, the data deviate from the diagonal,

Table 1

Responses per minute in the initial and terminal links on the two keys and the number of entries per session into the terminal link of the MI chain. All data are median values for the final five sessions.

Bird	FI	Initial (concurrent) Links		Terminal Links		MI Terminal Link Entries/Sess
		MI	FI	MI	FI	
C	10	14.7	42.0	108.0	157.7	26
	15	30.8	22.9	107.2	124.1	30
	20	34.6	23.0	86.3	110.0	31
	25	35.4	10.0	82.7	114.3	36
	30	43.0	6.1	95.0	110.1	40
E	10	5.3	72.4	155.6	162.1	22
	15	34.0	54.3	119.2	130.8	29
	20	20.0	58.5	143.0	118.8	28
	25	44.3	38.7	41.4	85.4	31
	30	51.1	16.3	166.0	141.3	33
F	10	11.6	93.3	65.7	51.0	24
	15	13.6	78.4	72.8	46.2	26
	20	23.9	69.4	67.4	54.7	27
	25	28.9	38.7	72.8	61.4	29
	30	69.4	8.8	103.1	77.6	35
G	10	7.6	76.0	50.2	97.8	24
	15	28.3	40.5	41.5	54.3	29
	20	29.6	33.4	38.6	41.4	29
	25	41.9	20.2	38.1	40.0	32
	30	79.4	5.9	44.0	44.3	41
H	10	20.6	61.2	81.6	112.1	27
	15	40.5	66.1	49.2	39.3	29
	20	41.0	42.1	61.4	76.2	30
	25	70.0	25.6	51.4	47.8	31
	30	128.3	2.5	88.7	35.4	51

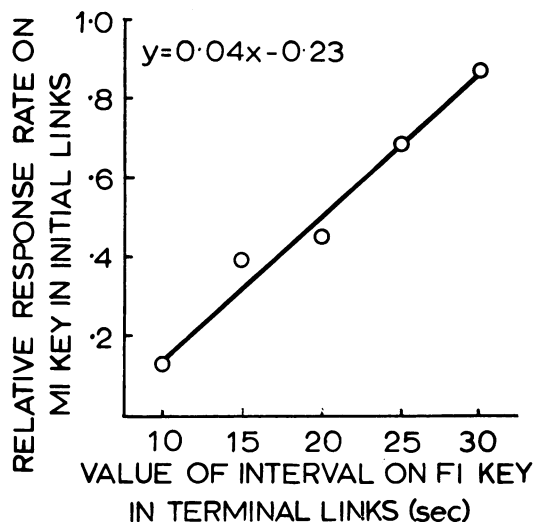


Fig. 2. Relative response rates to the MI key in the initial concurrent links of the chain schedule as a function of the interval value on the FI key in the terminal links. Median data from the group of five birds are shown. The best fitting straight line (by the method of least squares) is drawn through the data points.

showing that if relative response rates in the initial links are controlled by relative reinforcement rates in the terminal links, the component terminal link intervals in the present procedure are not averaged according to any of these transformations.

Since the MI schedule used in the present experiment is a special case of a VI schedule ($N = 2$ in equation 1), the data were examined in relation to the series of power functions investigated by Killeen.

The data were pooled and the median values for the relative response rates to the MI key in the initial links for the FI values scheduled in the terminal links were determined. Transformations of $r = -1$ to $r = -4$ were carried out according to equation 1. Visual inspection of the fit between predicted and obtained relative response rates showed that this was best at approximately $r = -3$. Predicted values of relative response rates were then calculated for $r = -2.5$ to $r = -3.5$ in steps of 0.1. By the method of least squares, the best fit was found to occur when r was between -3.0 and -3.1 . Figure 4 shows the relation between relative initial link response rates and relative reinforcement rates calculated according to a cubic transformation of the reciprocals of the component intervals for

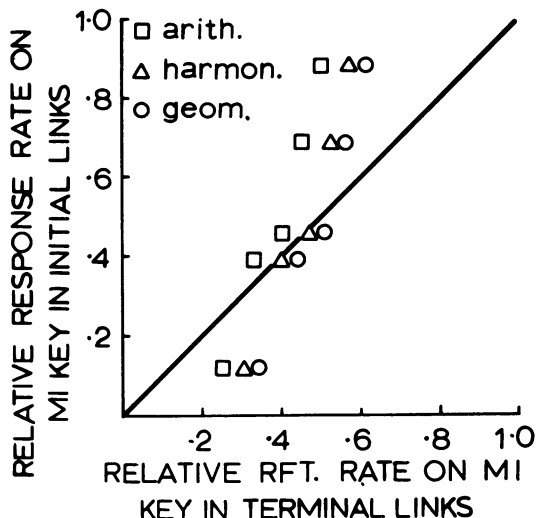


Fig. 3. Relative response rates to the MI key in the initial concurrent links of the chain schedule as a function of the relative rates of reinforcement in the terminal links. Reinforcement rates were calculated by three methods: arithmetically (reciprocal of the average interval in the terminal link schedule); harmonically (average of the reciprocals of the terminal link intervals); and geometrically (geometric mean of the reinforcement rates provided by the intervals comprising each terminal link schedule). The diagonal line is the predicted relation if relative response rates in the initial links are controlled by relative reinforcement rates in the terminal links, calculated by one of these methods.

the individual animals and the grouped data. Best fitting straight lines are drawn through the data points and in most cases these fall close to the diagonal, the predicted relation if the reciprocals of the component intervals (or the component rates) are transformed cubically.

Figure 5 shows that relative response rates in the concurrent VI links were not a function of relative response rates in the terminal links. Neither was concurrent VI performance a function of the relative absolute numbers of responses emitted in the MI and FI links.

DISCUSSION

Killeen (1968) found that when pigeons chose between fixed- and variable-interval schedules in the concurrent chain procedure, the interreinforcement intervals in the second links were averaged according to the harmonic mean ($r = -1$ in equation 1). The present experiment showed that when choice is be-

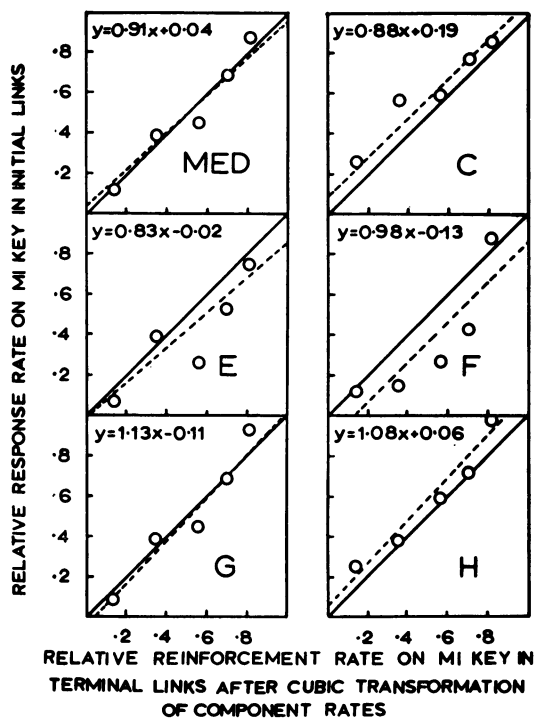


Fig. 4. Relative response rates to the MI key in the concurrent initial links as a function of the relative reinforcement rates on the MI key in the terminal links. The relative reinforcement rates were determined after a cubic transformation of the reciprocals of the component intervals. Solid diagonal lines show the predicted relation, dashed lines the best fitting linear functions. The median values for the group of animals is shown at the top left.

tween a fixed-interval schedule and a two-valued mixed-interval schedule, the pigeon averages the interreinforcement intervals according to the exponent $r = -3$ in equation 1. Short interreinforcement intervals are weighted more heavily under the present conditions than they are in the choice studied by Killeen.

Previous studies have reported that entries into the two terminal link schedules were equal (Fantino, 1967) or virtually equal (Herrnstein, 1964a), though Killeen gives no data on this aspect of performance. The inconsistency of the present results with previous data is probably caused by the use of a changeover delay in this experiment. Changeover delays have not typically been used in concurrent chain schedules, it being assumed that the delays of primary reinforcement for initial link responding already inherent in the concurrent chain procedure are sufficient to pre-

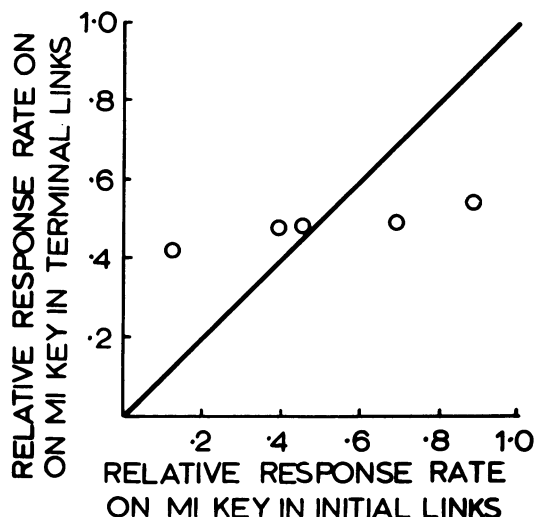


Fig. 5. Median relative response rates to the MI key in the terminal links of the concurrent chain schedule as a function of the relative response rates in the initial links on the MI key.

vent the occurrence of concurrent superstitions (Catania, 1966). No experimental data are available to support this notion. The use of short fixed-intervals in the terminal links by Killeen and in the present experiment, and the consequent production of potent conditioned reinforcement for initial link responding, increases the probability of concurrent superstitions. A changeover delay was used in the present experiment to insure against any undesired interactions of this type. The short duration of the changeover delay used would not be expected to introduce any further interactions of the type described by Shull and Pliskoff (1967).

A second difference between the present and previous concurrent chain procedures is in the use of the same stimulus conditions (green keys) for both the terminal link schedules. The difference in exponent values found by Killeen and in the present study cannot be explained by stimulus generalization of the conditioned reinforcing effects of the two terminal link schedules. If an interaction of this type occurred, the conditioned reinforcing effects of the stimuli associated with the terminal link schedules would be expected to be more similar than was found by Killeen. Relative response rates should lie closer to 0.50 over the range of experimental conditions. The data in Fig. 3 show that the differences were greater than those found by Killeen. In general, in the

concurrent chain procedure, it does not seem likely that relative initial link response rates are controlled by stimulus similarity in the terminal links.

The major difference between the present experiment and that reported by Killeen is in the number of different intervals presented in the VI and MI schedules. The difference in exponent values found in these studies may be due to either this variable or to differences in the range of intervals used. The VI schedules studied by Killeen were formed by both arithmetic and geometric progressions, and mean values of 23 to 54 sec were used in his Experiment 1. Fixed-interval values with the VI 31-sec schedule were 10, 15, 20, and 25 sec. The values for both terminal link schedules are therefore similar to those used in the present experiment. The range of intervals comprising the VI 31-sec schedule is from 4.3 to 56.7 sec, larger than in the MI schedule used in the present experiment. However, it is clear from Killeen's data that there are no range effects, since both arithmetic and geometric VI schedules with similar arithmetically determined mean reinforcement rates give the same exponent, though the latter have considerably larger ranges. It is therefore likely that the difference in exponents is due to the number of intervals comprising the VI and MI schedules. The present experiment used only two, whereas Killeen used 10 in his Experiment 1 and 12 in his Experiment 2.

The second experiment to which the present results may be related is that reported by Fantino (1967) who examined the choice between fixed-ratio and mixed-ratio schedules. Fantino found that the relative reinforcement rates in the terminal links predicted relative response rates in the initial links only when the reinforcement rate contribution of the MR schedule was determined from the geometric mean of the component reinforcement rates. Fantino's results agree with those of Herrnstein (1964b), Killeen (1968), and the present study in that variable scheduling in the terminal links of concurrent chain schedules is preferred over fixed scheduling, given equal arithmetic reinforcement rates. Although Killeen is able to account for Herrnstein's (1964b) results, these studies taken together suggest that

the problem of specifying an appropriate measure of reinforcement rate in the terminal links of concurrent chain schedules has not yet been solved. The measure of central tendency that does lead to matching of relative response and relative reinforcement rates varies with the type of scheduling of reinforcement in the terminal links. This difference is not only one of variable *versus* fixed scheduling, since mixed- *versus* fixed-ratio schedule choice requires a measure of reinforcement rate different from that required to predict mixed- *versus* fixed-interval schedule choice. Further research should aim either to determine an unambiguous method for predicting the appropriate measure of reinforcement rate for various terminal link schedule combinations, or to provide a general method of predicting relative choice from some variable other than relative reinforcement rate.

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