

## PERFORMANCE IN CONCURRENT INTERVAL SCHEDULES: A SYSTEMATIC REPLICATION<sup>1</sup>

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Five pigeons were trained on a variety of concurrent interval schedules that arranged reinforcements at either fixed or variable times after the last reinforcement. Two measures were obtained: the number of responses on each schedule, and the time spent responding on each schedule. Ratios of response rates on the two schedules did not equal ratios of reinforcement rates when both schedules were variable nor when one was variable and the other fixed. Ratios of times spent responding approximately equalled ratios of reinforcement rates when both schedules were variable, but did not do so when one was fixed.

*Key words:* concurrent schedules, VI schedules, FI schedules, response allocation, time allocation, pecking, pigeons

Reliable functional relations between performance and reinforcement parameters on concurrent interval schedules have been summarized by the matching principle (Herrnstein, 1970; Rachlin, 1971), which states that the ratio of response rates or times allocated to responding on each schedule is a function of the ratio of reinforcement rates on each schedule. The general relation (White and Davison, 1973) may be expressed:

$$\frac{P_1}{P_2} \text{ or } \frac{T_1}{T_2} = c \left( \frac{R_1}{R_2} \right)^a, \quad (1)$$

where  $P_1$  and  $P_2$  are the number of responses on the two schedules,  $T_1$  and  $T_2$  are the times allocated to the two schedules, and  $R_1$  and  $R_2$  are the numbers of reinforcements obtained on the two schedules in a session. For concurrent variable-interval variable-interval (*conc* VI VI) schedules (Baum and Rachlin, 1969), and concurrent fixed-interval fixed-interval (*conc* FI FI) schedules in which typical FI or VI response patterns are maintained on both schedules (White and Davison, 1973), both  $c$  and  $a$  are close to 1.0. For *conc* FI VI schedules (Nevin, 1971; Trevett, Davison, and Williams, 1972),  $c$  (and possibly  $a$ ) are less than 1.0 when

schedule 1 is the FI schedule. White and Davison (1973) also found that where typical FI or VI-like response patterns were not maintained on both components of *conc* FI FI schedules,  $c$  and  $a$  were again less than 1.0.

Trevett *et al.* obtained a constant proportional preference for the VI schedule over the FI schedule when these were arranged concurrently. The value of  $a$  was the same for both the *conc* FI VI data and *conc* VI VI control conditions, but the value of  $c$  was different by a constant amount between experimental and control conditions.

The present experiment systematically replicated the two previous experiments on *conc* FI VI performance (Nevin, 1971; Trevett *et al.*, 1972). It differed from these experiments in that the concurrent schedules were arranged according to the switching procedure (Findley, 1958), rather than the two-key procedure.

### METHOD

#### *Subjects*

Five homing pigeons, numbered 21, 23, 24, 25, and 26, were maintained at  $80\% \pm 15$  g of their free-feeding weights. The birds had previously been trained on *conc* FI FI schedules (White and Davison, 1973).

#### *Apparatus*

The experimental chamber, situated remote from conventional relay control equipment, was sound-attenuated and external noise was masked by an exhaust fan. A food hopper was situated 10 cm from the grid floor, midway between two translucent response keys 2 cm in

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diameter, 13 cm apart, and 22.5 cm from the floor. Both keys could be transilluminated by colored lights. Pecks on lighted keys exceeding about 0.1 N closed a microswitch behind the keys and provided auditory feedback from a relay inside the chamber. The equipment was that used by White and Davison (1973).

### Procedure

As all subjects had extensive histories of training on concurrent schedules, no key-peck or schedule training was necessary. The animals were placed directly onto the first experimental condition (Table 1).

Concurrent schedules were arranged according to the changeover method (Findley, 1958) in which a response on the left-hand (white) key alternated schedules and their associated (red or green) stimuli on the right-hand key. The two keys are known as the changeover and main keys respectively. The schedules arranged on the main key in the various parts of the experiment are shown in Table 1. In all conditions, the concurrent schedules were mutually independent and were operative simultaneously, so that the animals had continuous access via the changeover key to both schedules and their associated main-key stimuli. Bursts of responding on the changeover key were discouraged by arranging that changeover responses were effective only after at least one response on the main key following a changeover key peck. A changeover delay (Herrnstein, 1961) specified that a response on the main key could not be reinforced, even if a reinforcement had been arranged by the schedule, until 3 sec had elapsed after any response to the changeover key.

The number of reinforcements per session was varied in the different experimental conditions to maintain a session time of not more than 50 min (Table 1). Supplementary feed of mixed grain was given, when necessary, immediately after daily training sessions. During reinforcement, which consisted of 3-sec access to wheat, the magazine was illuminated and the keys were dark and inoperative.

All VI schedules used were derived from arithmetic progressions of the form  $a$ ,  $a + d$ ,  $a + 2d$ , etc., and were composed of 12 randomized intervals. In all conditions, the value of the shortest interval was 10 sec.

For all conditions, the number of responses, the time spent responding, the number of re-

inforcements obtained on each schedule, and the number of effective changeovers, were recorded. Daily response data were calculated as the relative number of responses to the red main key (responses on the red main key divided by total responses to the main key). Conditions were changed when all animals had reached a stability criterion five, not necessarily consecutive, times. To satisfy the criterion, it was necessary that the median relative number of responses for five sessions did not differ by more than 0.05 from the median of the previous five sessions.

### RESULTS

All measures of response allocation, time allocation, number of reinforcements, and number of changeovers between the schedules were obtained from the final five sessions of each experimental condition. These data are shown as single-session means in Table 1.

Ratios of numbers of responses to the two schedules are shown in Figure 1 for both the individual animals and the group as a function of the ratio of obtained reinforcement rates on the two schedules. Both coordinates are logarithmic (Baum and Rachlin, 1969), and the data from *conc* FI VI and *conc* VI VI schedules are shown separately. Straight lines were fitted to the logarithmic data by the method of least squares, and the equations of the best-fitting lines are shown in the figure. If the ratio of response rates on the two schedules equalled the ratio of reinforcement rates on the two schedules ( $c = a = 1.0$  in Equation 1), the fitted line would have a slope of 1.0 and a logarithmic intercept of 0.0. Neither set of data from this experiment is close to this equality. In analyzing the present results, Sign Tests (Siegel, 1956) were used to determine whether differences in slopes or intercepts were significant. The Sign Test requires that all five comparisons of individual animal data be in the same direction for significance at  $p = 0.05$ . On this criterion, the slopes of the fitted lines (and thus the value of  $a$  required in Equation 1) were significantly less than 1.0. Further, the slopes of the fitted lines to the *conc* FI VI data were significantly smaller than those fitted to the *conc* VI VI data. Analysis of the size of the intercepts to the fitted lines (the logarithm of  $c$  in Equation 1) shows that they were significantly smaller for the *conc* FI VI data than for the *conc* VI VI data. All comparisons not spe-

Table 1

Sequence of experimental conditions, number of sessions training, number of responses emitted and time allocated, number of changeovers, and number of reinforcements obtained on the two concurrent schedules. All these data are averaged over the last five sessions of training for the five birds. All time data are in seconds.

Main Key Schedules		No. of Sessions	Responses		Times		Reinforcements		Changeovers
Red	Green		Red	Green	Red	Green	Red	Green	
FI 120	VI 120	26	1419	2240	1121	1430	21.9	23.1	68
FI 120	VI 30	19	230	1264	193	784	8.5	41.5	51
FI 120	VI 240	23	1860	1405	1375	963	22.3	10.7	86
FI 120	VI 60	21	738	1570	432	1009	12.8	27.2	79
FI 120	VI 480	25	2200	1103	1677	810	24.0	6.0	71
VI 240	VI 60	17	804	2351	389	1753	9.4	40.6	78
VI 60	VI 240	18	2173	773	1677	426	40.4	9.6	76
FI 300	VI 75	20	545	1931	285	1509	6.8	28.2	59
FI 75	VI 300	27	1405	990	1026	754	27.9	7.1	65
VI 300	VI 75	21	363	1676	184	1337	5.6	29.5	37
VI 75	VI 300	23	1681	487	1243	268	29.6	5.4	48
VI 120	VI 30	18	433	1118	232	850	9.5	40.5	53
VI 120	VI 480	25	2322	622	2668	411	24.0	6.0	62
VI 120	VI 60	20	693	1467	387	1071	13.1	26.9	74
VI 120	VI 240	22	2033	1118	1477	682	22.4	10.6	89
VI 180	VI 90	22	823	1758	496	1381	11.4	23.6	71
VI 90	VI 180	20	1638	813	1300	562	23.9	11.1	65
FI 180	VI 90	21	876	1603	546	1319	11.3	23.7	81
FI 90	VI 180	20	1315	1109	926	860	23.5	11.5	93

cifically mentioned are not significant according to the Sign Test.

The data on time spent responding on the two schedules were analyzed in the same way as the response data, and the ratio of times allocated as a function of the ratio of obtained reinforcement rates on logarithmic coordinates is shown in Figure 2. Again, straight lines were fitted to the data by the method of least squares. For the time-allocation measures, the slopes of the lines fitted to the *conc* VI VI data are close to, but significantly greater than 1.0; those fitted to the *conc* FI VI data are significantly smaller than 1.0 (Sign Tests). Hence, the difference between the slopes of the lines fitted to these data (*conc* VI VI and *conc* FI VI) is also significant. As for the response data, the size of the intercept to the fitted lines was significantly smaller for the *conc* FI VI data than for the *conc* VI VI data.

The slopes of the lines fitted to the time-allocation data were significantly steeper than those fitted to the response-allocation data for both types of concurrent schedules, although there was no significant difference in the values of the intercepts obtained from time and response measures.

## DISCUSSION

The present results on performance in *conc* FI VI schedules, as compared to performance in *conc* VI VI schedules, broadly replicate previous results on response and time allocation (Nevin, 1971; Trevett *et al.*, 1972), even though the procedure for concurrent scheduling used here was different from those used previously. But certain important details of the results are different. The slopes of the functions relating log response-rate ratios to log reinforcement-rate ratios for *conc* FI VI performance, and thus the required value of *a* in Equation 1, were found by Nevin (1971) to be about 0.5, by Trevett *et al.* to be about 0.62, and in the present experiment to be about 0.68. We shall take these data as estimates of an exponent, *a*, for *conc* FI VI performance of 0.63, the mean value of 11 animals in these experiments. Trevett *et al.* reported that the functions relating log response-rate ratios to log reinforcement-rate ratios were displaced below the origin (0,0). For example, when FI and VI schedules with the same mean interval were concurrently arranged, the animals responded more on the VI schedule than on the FI schedule. Such a result gives a value of *c* in Equa-

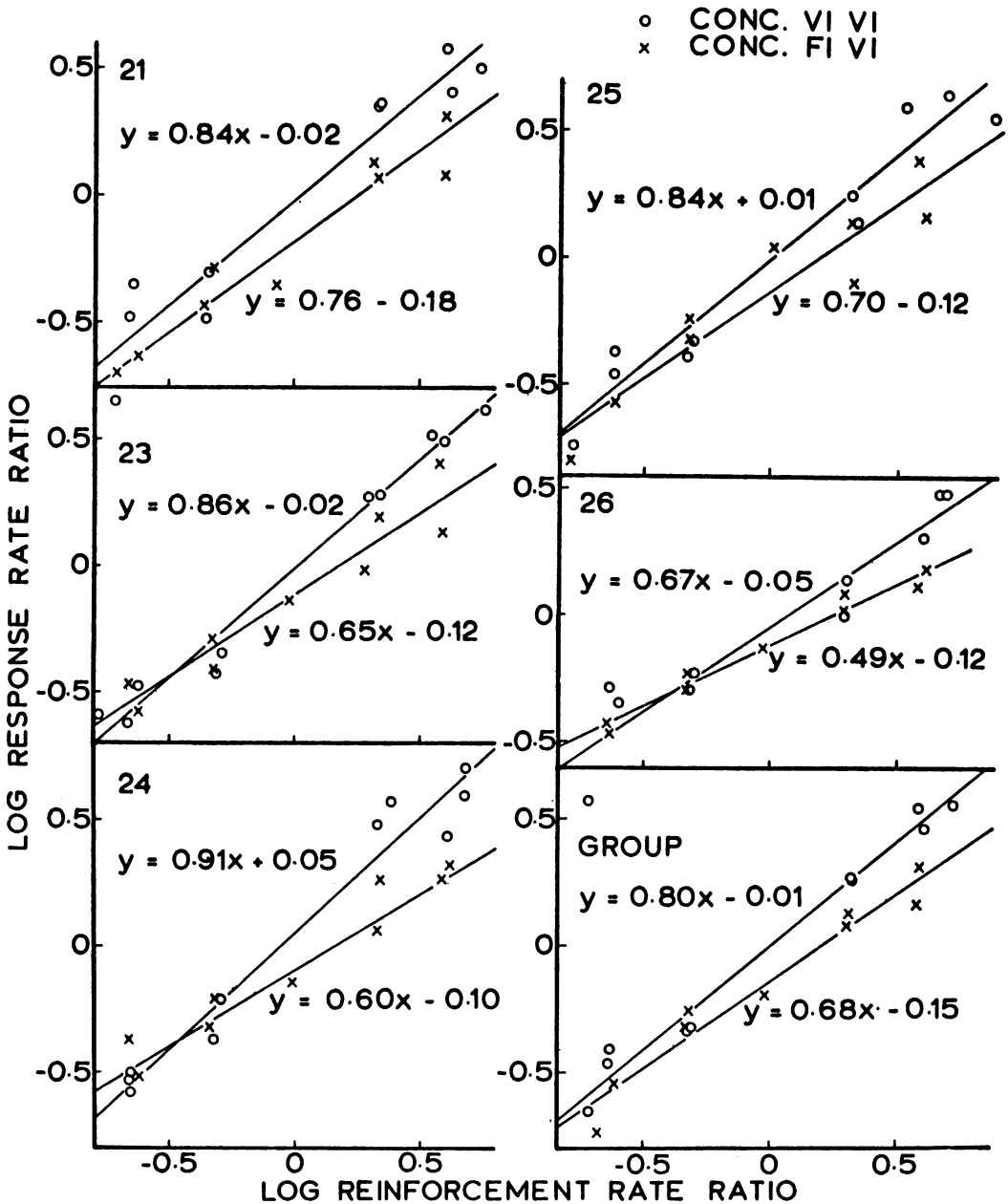


Fig. 1. The logarithm of the ratio of response rates on each schedule as a function of the logarithm of the ratio of the reinforcement rates obtained on each schedule. Data for *conc* FI VI schedules and *conc* VI VI schedules are shown separately, and straight lines were fitted to each by the method of least squares. The equation of these lines, in logarithmic terms, is shown by each.

tion 1 of less than 1.0 when schedule 1 is the FI schedule. Nevin found such a displacement for only one bird, and a displacement in the other direction for one of the other two birds. On this point, the present data strongly support Trevett *et al.*'s results, the logarithmic intercepts for each bird being negative. The ab-

solute size of the obtained intercept may be influenced by a bias toward one or other key or key color (Baum and Rachlin, 1969), and the amount of bias may be obtained from the intercept of the line fitted to the response data for the *conc* VI VI conditions (Figure 1). For the present data, this bias was very small, hav-

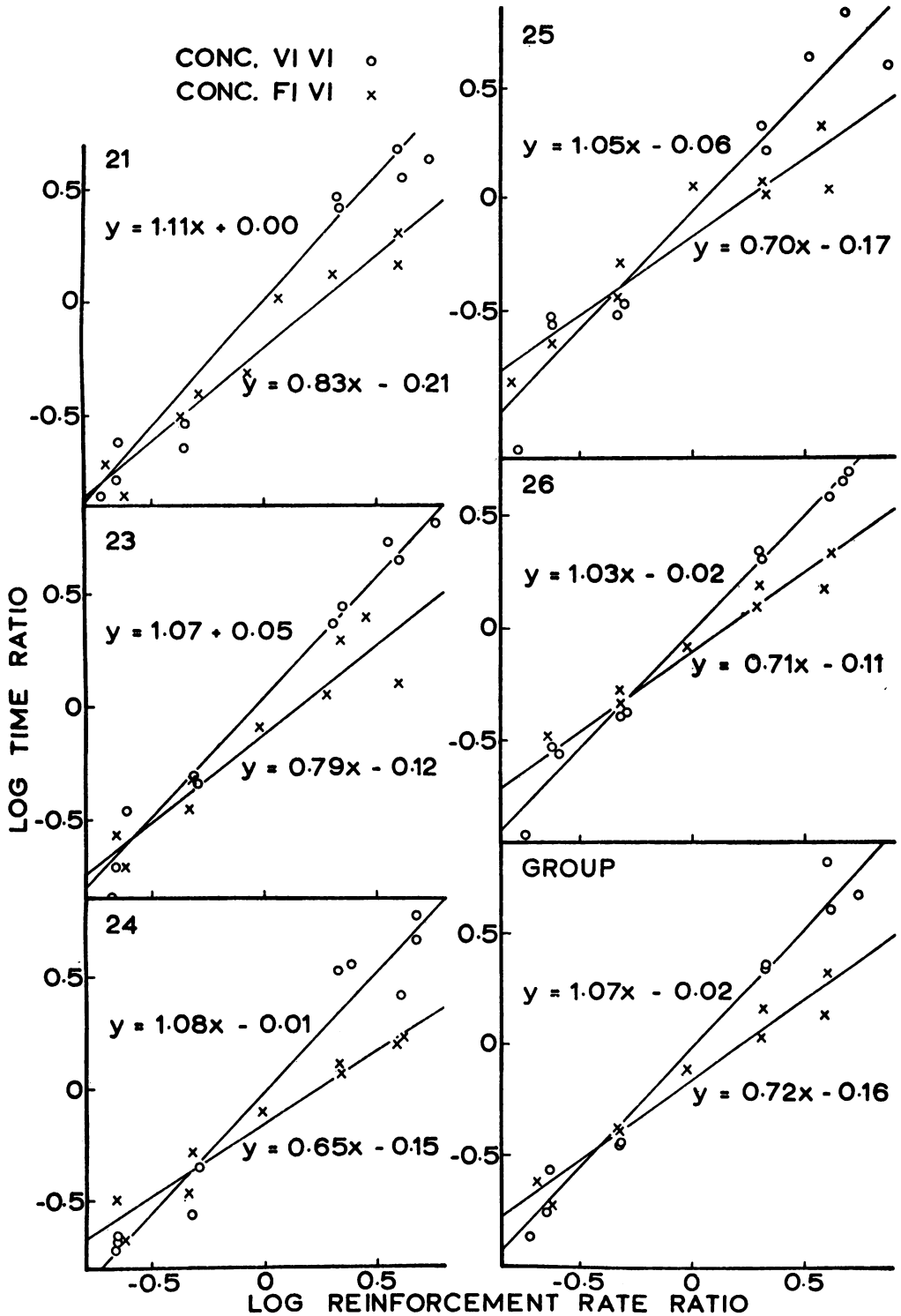


Fig. 2. The logarithm of the ratio of times allocated to responding to each schedule as a function of the logarithm of the ratio of reinforcement rates obtained on each schedule. Data for *conc* FI VI schedules and *conc* VI VI schedules are shown separately, and straight lines were fitted to each by the method of least squares. The equation of these lines, in logarithmic terms, is shown by each.

ing a logarithmic value of  $-0.01$ . The negative sign shows that the bias was toward the green key color. Thus, the true intercept of the fitted line to the *conc* FI VI response data is  $(-0.15 - (-0.01))$ , which equals  $-0.14$ , showing that the negative intercept found for the present data is not a result of stimulus bias. For Trevett *et al.*'s data, a similar calculation gives a value of  $-0.15$ . The agreement between these two results is excellent, but both seem incompatible with those reported by Nevin. We can only suggest that Nevin's results were affected by an unmeasured key bias.

On the basis of these results, it seems that *conc* FI VI schedule response allocation may be characterized by the following form of Equation 1:

$$\frac{P_1}{P_2} = 0.72 \left( \frac{R_1}{R_2} \right)^{0.63} \quad (2)$$

The value of  $c = 0.72$  is the antilog of the logarithmic intercepts found here and by Trevett *et al.*

Trevett *et al.* reported that straight lines fitted to the logarithmic response and reinforcement rate ratios for *conc* VI VI schedules did not have the expected slope of 1.0 ( $a = 1.0$  in Equation 1). Schneider (1973) also obtained a slope of less than 1.0 in *conc* VI VI schedules. The same was found in the present results, although the slope was nearer 1.0 than was found by Trevett *et al.* (0.82 versus 0.69) or Schneider (0.6). Like Trevett *et al.*, we are unable to explain why the slope was not 1.0, as would be expected from many previous reports. Schneider noted that procedural differences do not appear to account for the discrepancy. We would like to point out, however, that response allocation slopes of less than 1.0 may be the rule rather than the exception. An analysis of previously reported data on *conc* VI VI response allocation (Catania, 1963; Herrnstein, 1961; Hollard and Davison, 1971; Schneider, 1973; Shull and Pliskoff, 1967; Silberberg and Fantino, 1970; and Trevett *et al.*, 1972) showed that 22 of the 26 individual animals used in these experiments gave a value of  $a$  in Equation 1 of less than 1.0. The other four showed values close to, or somewhat above, 1.0. This clearly shows that the normally reported equality between response ratios and reinforcement-rate ratios (Herrnstein, 1961; 1970) is incorrect, and is due mainly to a reliance on graphs in which relative measures

(responses or reinforcements on a key divided by total responses or reinforcements) are shown. A slight ogival deviation on such graphs may represent a considerable deviation from unit slope on more sensitive log ratio coordinates (*cf.*, Baum, 1974).

It is of interest to examine how overall response rates on each key changed between the *conc* FI VI and the *conc* VI VI conditions. Previous research with single schedules (Schneider, 1969) showed that overall rates are lower for FI schedules, as compared with VI schedules providing the same overall reinforcement rate. Such an effect is not found in the present data. Figure 3 shows the overall response rates (number of responses divided by total session time) on each schedule for all conditions in which the first schedule was either FI 120-sec or VI 120-sec. As would be expected (Catania, 1963), the response rate on each schedule is a direct function of the reinforcement rate on that schedule, and an inverse function of the reinforcement rate on the alternate, concurrent schedule. Figure 3 shows that the response rate on the FI 120-sec schedules was similar to that on the VI 120-sec schedules when these were concurrent with various VI schedules. However, the response rate on the concurrent VI schedule in which the reinforcement rate was varied was higher when the alternate schedule

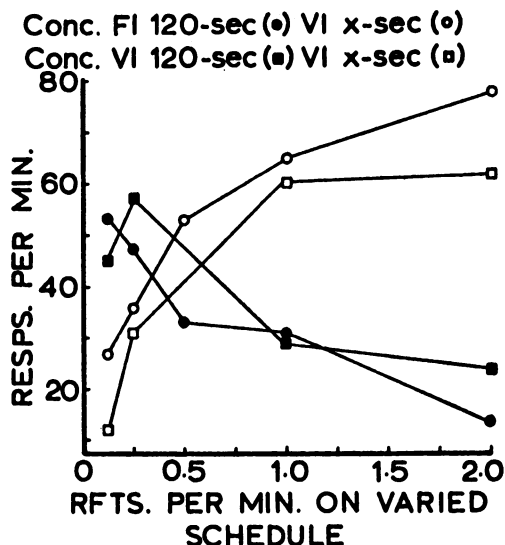


Fig. 3. The overall response rate on each schedule (number of responses divided by total session time) as a function of the reinforcement rate on the varied schedule. The data used were those obtained when one schedule was either VI 120-sec or FI 120-sec, and the concurrently arranged VI schedule was varied.

was an FI than when it was a VI schedule. In other words, response ratios on *conc* VI VI schedules differ from those on *conc* FI VI schedules because, in the latter case, animals respond more on the VI schedule, rather than less on the FI schedule, in comparison with the former case.

The present data on time allocation in *conc* FI VI schedules also replicate in general the results of Trevett *et al.* The slope of the function relating log time-allocation ratios to log reinforcement-rate ratios (Figure 2) is 0.72, compared with the value of 0.66 reported by Trevett *et al.* The log intercepts of the best-fitting lines are less than zero in both experiments,  $-0.28$  for Trevett *et al.* and  $-0.16$  for the present data. Taking the mean values for the nine birds in these two experiments, we obtain the following form of Equation 1:

$$\frac{T_1}{T_2} = 0.59 \left( \frac{R_1}{R_2} \right)^{0.69} \quad (3)$$

Comparison of Equations (2) and (3), which are averages across experiments, suggests that response and time measures in *conc* FI VI performance may be (1) equivalent with respect to the value of  $a$ , but (2) not so with respect to the value of  $c$ . But, since neither of these conclusions is supported by the present data, we will take both response and time measures of *conc* FI VI performance as giving an equally accurate estimate of both  $a$  and  $c$ .

The functions relating log time-allocation ratios to log reinforcement-rate ratios for the *conc* VI VI data gave a slope slightly greater than 1.0, and greater than the slope found for the *conc* FI VI data. Again, investigation of data previously reported on time allocation in *conc* VI VI schedules showed that slopes greater than 1.0 often occurred.

The present data do not support the conclusion that *conc* FI VI performance differs from *conc* VI VI performance only in that  $c \neq 1.0$  in the former case (Trevett *et al.*, 1972). The value of  $a$  in Equation 1, which may be interpreted as a measure of sensitivity of the dependent variable to the independent variable, is larger for *conc* VI VI performance. The value of  $a$  is also greater for time-allocation measures than response-allocation measures, both here and in many previous studies (Catania, 1963; Hollard and Davison, 1971; Shull and Pliskoff, 1967; Silberberg and Fantino, 1970; Trevett *et al.*, 1972). In view of the use to

which the simple matching law (response ratio equals reinforcement ratio) has been put, for instance as a yardstick for concurrent-chains research, it is clear that more detailed research is needed on concurrent interval schedule performance.

## REFERENCES

- Baum, W. M. On two types of deviation from the matching law: bias and undermatching. *Journal of the Experimental Analysis of Behavior*, 1974, **22**, 231-242.
- Baum, W. M. and Rachlin, H. C. Choice as time allocation. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 861-874.
- Catania, A. C. Concurrent performances: reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 253-263.
- Findley, J. D. Preference and switching under concurrent scheduling. *Journal of the Experimental Analysis of Behavior*, 1958, **1**, 123-144.
- 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. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 243-266.
- Hollard, V. D. and Davison, M. C. Preference for qualitatively different reinforcers. *Journal of the Experimental Analysis of Behavior*, 1971, **16**, 375-380.
- Nevin, J. A. Rates and patterns of responding with concurrent fixed-interval and variable-interval reinforcement. *Journal of the Experimental Analysis of Behavior*, 1971, **16**, 241-247.
- Rachlin, H. C. On the tautology of the matching law. *Journal of the Experimental Analysis of Behavior*, 1971, **15**, 249-251.
- Schneider, B. A. A two-state analysis of fixed-interval responding in the pigeon. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 677-687.
- Schneider, J. W. Reinforcer effectiveness as a function of reinforcer rate and magnitude: a comparison of concurrent performances. *Journal of the Experimental Analysis of Behavior*, 1973, **20**, 461-471.
- Shull, R. L. and Pliskoff, S. S. Changeover delay and concurrent schedules: some effects on relative performance measures. *Journal of the Experimental Analysis of Behavior*, 1967, **10**, 517-527.
- Siegel, S. *Nonparametric statistics for the behavioral sciences*. New York: McGraw-Hill, 1956.
- Silberberg, A. and Fantino, E. Choice, rate of reinforcement, and the changeover delay. *Journal of the Experimental Analysis of Behavior*, 1970, **13**, 187-197.
- Trevett, A. J., Davison, M. C., and Williams, R. J. Performance in concurrent interval schedules. *Journal of the Experimental Analysis of Behavior*, 1972, **17**, 369-374.
- White, A. J. and Davison, M. C. Performance in concurrent fixed-interval schedules. *Journal of the Experimental Analysis of Behavior*, 1973, **19**, 147-153.

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