

*PERFORMANCE IN CONCURRENT  
INTERVAL SCHEDULES<sup>1</sup>*

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Four pigeons were trained under concurrent variable-interval variable-interval and fixed-interval variable-interval schedules in a two-key situation. Both response allocation and time allocation to the two schedules were measured when various reinforcement rates were arranged on each key. All animals showed an approximately constant proportional preference for the variable-interval schedule over the fixed-interval schedule. These results support Schneider's (1969) analysis of fixed-interval schedule performance.

In a variable-interval (VI) schedule, responses are reinforced when varying periods of time have elapsed since the previous reinforcement. When two such VI schedules are simultaneously made available to an animal (concurrent VI VI schedules), the following functional relations between reinforcement parameters and response or time allocation have been shown to hold (Catania, 1966; Baum and Rachlin, 1969; Herrnstein, 1970):

$$\frac{P_1}{P_2} = \frac{R_1}{R_2} \dots\dots (1)$$

$$\frac{T_1}{T_2} = \frac{R_1}{R_2}$$

where  $P_1$  and  $P_2$  are the numbers of responses,  $T_1$  and  $T_2$  are the times spent responding, and  $R_1$  and  $R_2$  are the numbers of reinforcements on keys 1 and 2 respectively during a session. The fact that the time in which all these measures occur is the same (either response may be emitted at any time) has led to the interpretation of the Ps and Rs of the above relations as rates of responding and reinforcement (Catania, 1966).

These relations have been well documented for concurrent VI VI schedules, but at the pres-

ent time it is not clear whether these relations also apply to other types of concurrent interval schedules, for example when a fixed-interval (FI) schedule is arranged concurrently with a VI schedule. A small amount of data has been reported on performance under such schedules (Ferster and Skinner, 1957; Catania, 1962), but these data do not allow a quantitative analysis. In view of recent experiments on preference in concurrent chain schedules (Killeen, 1968), which have shown that pigeons prefer a VI schedule to an FI schedule giving the same reinforcement rate, a further analysis of performance under concurrent interval schedules is in order.

The present experiment investigated performance in concurrent FI VI schedules providing various reinforcement rates.

METHOD

*Subjects*

Four homing pigeons, numbered 101, 102, 105, and 106, were maintained at  $80\% \pm 15$  g of their free-feeding body weights. Since all had previously served in experiments on concurrent schedule performance, no magazine, key-peck, or schedule training was considered necessary.

*Apparatus*

During the experiment, the pigeons were placed in a two-key experimental chamber as described by Davison (1972). All experimental contingencies were scheduled by remotely placed electromechanical equipment, and data were recorded on impulse counters.

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### Procedure

The reinforcer consisted of 3-sec access to a hopper containing wheat, and daily sessions were terminated in blackout after 50 reinforcements. Supplementary feed of maize was given, when necessary, immediately after the training sessions.

Both response keys were illuminated white at all times except during reinforcement, when both were extinguished. Feedback was given for responses to illuminated keys in the form of a relay click. Reinforcement for responses on the two keys occurred according to the independent interval schedules shown in Table 1. The stability criterion described by Davison (1972) was used, and experimental conditions were not changed until all animals had reached this criterion.

All VI schedules, except those in Conditions 11 and 12, were derived from arithmetic progressions of the form  $a$ ,  $a + b$ ,  $a + 2b$ , *etc.*, and were composed of 12 randomized intervals. The values of  $a$ , the shortest intervals in the schedules, were for Conditions 1 to 7: VI 75-sec, 6.25-sec; VI 90-sec, 7.5-sec; VI 120-sec, 10-sec; VI 180-sec, 15-sec; and VI 300-sec, 25-sec. In conditions 8 to 11, the value of  $a$  was 7.5 sec for all VI schedules. In Conditions 11 and 12, the VI schedules consisted of 14 randomized intervals from the progression given by Fleshler and Hoffman (1962). The intervals comprising the schedules were: VI 60-sec: 217, 37, 83, 17, 68, 30, 23, 135, 5, 46, 104, 56, 12, 7; and VI 240-sec: 877, 150, 334, 69, 273, 120, 93, 541, 5, 184, 415, 225, 47, 27.

In all conditions, a changeover delay of 3 sec (Herrnstein, 1961) was in effect to minimize adventitious reinforcement of responses on one key by reinforcements arranged for the other. The changeover delay specifies that reinforcement may not occur for responses on one key, even if arranged by the interval timer, until 3 sec elapse from the first response on that key after any responses on the other key.

Responses on the two keys, the time allocated to responding on the two keys (from the first peck on one key to the first peck on the other) and reinforcements on the two keys were recorded.

### RESULTS

All data are reported as the sum of the various measures over the final five days of

each experimental condition. Data shown in the figure are derived from these sums.

Table 1 shows the schedules, the number of responses emitted on each key, the time spent responding on each key, and the number of reinforcements for each key over all experimental conditions. These data are plotted in Figure 1 as the logarithm of the ratio of responses emitted and times spent responding as a function of the logarithm of the ratio of the reinforcements for each key. Data from concurrent VI VI and FI VI schedules are shown separately. In this figure, the major diagonal shows the relation of Equation (1), that is matching between the ratio of response rates (or times spent responding), and the ratio of obtained reinforcements. Straight lines were fitted to the concurrent VI VI and FI VI data separately by the method of least squares.

It is immediately clear that the concurrent VI VI data do not conform to Equation (1), but are fitted by lines of somewhat less than unit slope. The concurrent FI VI data appear to be fitted by straight lines of similar slopes to those found for concurrent VI VI performance, but the fitted lines are displaced downwards in each case. Each animal thus shows a consistent preference for the VI schedule over the FI schedule, which is over and above preferences caused by reinforcement rate differences (Equation 1). In all cases, the time data were similar to the response data (Table 1), and only the grouped time data are shown in Figure 1.

The data for concurrent VI VI performance demonstrate, overall, a slight key bias towards key 2 and three of the animals taken individually also show a bias in the same direction. This bias is shown by the fitted lines for these data falling below the origin (0,0) in Figure 1. The value of the bias is given, in logarithmic terms, by the constant term in the fitted equations. In no case is the key bias shown in concurrent VI VI performance sufficient to account for the preference for the VI schedule in concurrent FI VI performance.

In absolute terms, the preference for the variable schedule in concurrent FI VI performance was greater for time measures than for response measures (Figure 1).

Occasionally during the experiment, event records were taken of stable performance. These confirmed the findings of Ferster and

Table 1

Sequence of experimental conditions, number of responses, and time allocated to the schedules and number of reinforcements obtained. All data are the sum of the final five experimental sessions.

Condition	Schedules (sec)		Sessions	Animal	Responses		Time (sec)		Reinforcements	
	Key 1	Key 2			Key 1	Key 2	Key 1	Key 2	Key 1	Key 2
1	FI 120	VI 120	20	101	8819	11159	4465	8407	119	131
				102	7110	15957	2856	10085	119	131
				105	7358	18943	4177	8639	122	128
				106	9980	12023	3358	9459	123	127
2	FI 75	VI 300	20	101	9666	8660	6656	5893	201	49
				102	11447	10815	4724	7747	199	51
				105	10301	10544	6903	5058	203	47
				106	13741	6914	6081	6310	205	45
3	FI 180	VI 90	16	101	5723	12894	3389	9079	80	170
				102	4028	16310	1506	11329	73	177
				105	5845	20939	2738	9526	81	169
				106	6207	12713	2353	10240	77	173
4	FI 90	VI 180	26	101	5836	8435	4619	7647	165	85
				102	9575	12445	4267	8675	165	85
				105	8867	11452	4240	7683	165	85
				106	10525	7811	5401	7089	173	77
5	FI 300	VI 75	17	101	4214	12558	2210	10115	47	203
				102	3222	15796	1236	10999	44	206
				105	3134	20623	1818	10398	47	203
				106	3227	14659	1626	10663	46	204
6	VI 90	VI 90	21	101	7651	6483	4481	4699	126	124
				102	5798	10561	2863	5330	120	130
				105	8531	10266	4587	4634	123	127
				106	8121	7748	4802	4355	127	123
7	VI 75	VI 180	39	101	9096	6334	6434	4665	184	66
				102	12404	5526	8670	2349	178	72
				105	9986	10079	6849	4203	179	71
				106	9681	6527	7633	4101	179	71
8	FI 75	VI 283	27	101	6479	6955	6416	5403	196	54
				102	10346	6563	7595	4137	202	48
				105	12465	9426	6116	5673	201	49
				106	10561	4757	7712	4119	202	48
9	FI 300	VI 75	21	101	3325	9494	2700	9773	47	203
				102	3002	15746	1309	10852	42	208
				105	4020	22179	1760	10120	45	205
				106	2675	15090	1313	11196	41	209
10	FI 90	VI 180	24	101	6965	8335	5543	6653	167	83
				102	7282	11684	3466	9465	160	90
				105	11338	12572	5636	6352	165	85
				106	8905	8882	5453	6815	168	82
11	VI 240	VI 60	17	101	3563	7294	3053	6987	48	202
				102	1013	11261	802	9206	28	222
				105	4021	16317	1881	7777	46	204
				106	3617	12019	1450	8126	47	203
12	VI 60	VI 240	20	101	9492	3675	6997	2316	205	45
				102	12703	4123	7669	2049	207	43
				105	14181	7898	6306	3315	202	48
				106	10554	3678	7296	2151	203	47

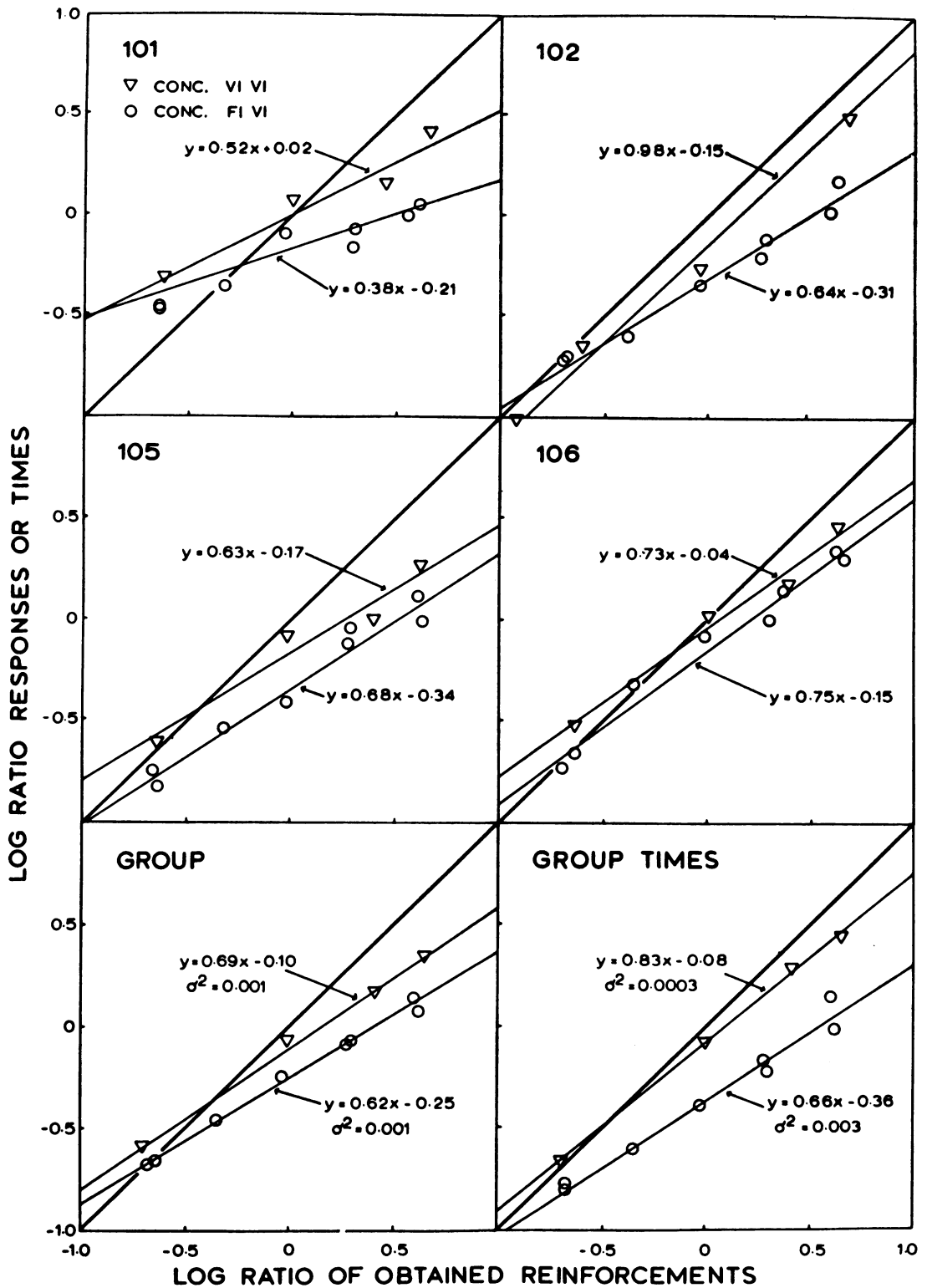


Fig. 1. The logarithm of the ratio responses emitted and times responding as a function of the logarithm of the ratio of reinforcements observed. The heavy line shows the relation expected from Equation (1), and data are shown separately for concurrent VI VI and concurrent FI VI schedule performances. The equation of the best-fitting straight line is shown for each set of data, and for the group data the mean square deviation of the data from the fitted line is also shown. All data are for response measures except for group time data.

Skinner (1957) and Catania (1962) that under concurrent FI VI schedules the VI performance consisted of a relatively constant response rate between reinforcements while the FI performance showed the usual pause after reinforcement followed by an acceleration to high response rates.

### DISCUSSION

For the concurrent VI VI data, the ratio of responses and times spent responding did not equal the ratio of obtained reinforcements as normally reported (Stubbs and Pliskoff, 1969). The reason for this is not clear, and speculation on this finding is probably unprofitable. We note, however, with Rachlin (1971), that this finding does not in any way disprove the matching law.

This research showed that, in terms of responses emitted and times spent responding, VI schedules were uniformly preferred to FI schedules, and that this preference was approximately a constant proportion, as shown by the fitted lines in Figure 1 being parallel. The following relation, analogous to Equation 1, describes this result:

$$\frac{P_1}{P_2} = c \frac{R_1}{R_2} \quad \dots \dots (2)$$

where  $c$  is a measure of this constant proportional preference. The relation is different from that describing preference for FI *versus* VI schedules in concurrent chain choice (Killeen, 1968). In the latter, such a constant proportional preference for the VI schedule was not found.

These results also differ substantially from those reported by Nevin (1971). Studying concurrent FI VI performance in a similar two-key concurrent schedule, but with a 2-sec changeover delay, Nevin found a power law relation between the ratio of responses and reinforcements.

$$\frac{P_1}{P_2} = \frac{R_1^{0.5}}{R_2^{0.5}} \quad \dots \dots (3)$$

Nevin, however, did not include concurrent VI VI controls in his experiment, which, in view of the present findings, seems to make his conclusion equivocal. If, for the purposes of argument, we accept the assumption made by Nevin, that the animals' performance would conform to Equation (1) under concurrent VI

VI schedules, we must conclude that performance in concurrent FI VI schedules is more complex than found in either Nevin's or the present experiment. In particular, the results would suggest some control over this performance by the overall reinforcement rate, because this was considerably more variable in Nevin's experiment than in the present experiment. Future research will no doubt clarify this point.

The explanation of the present result seems quite simple. Schneider (1969) suggested that FI schedules could be divided into a period of extinction after reinforcement followed by a period of reinforcement equivalent to a VI schedule. He found that, on the average, the proportion of the fixed interval spent not responding was constant for a wide range of interval values. If the animals in the present experiment spent a constant proportion of the time not responding to the FI key, and thus responding only to the VI key, a relation identical to Equation (2) would be expected. The constant,  $c$ , is then a measure of the average duration of responding on the FI schedule following the pause after reinforcement if subscript 1 indicates the FI key and subscript 2, the VI key. The constant is the proportion of the time on the FI schedule the animal spends responding concurrently with the VI schedule. This analysis assumes that when responding on the FI schedule occurs it is at the same local rate as responding to the VI schedule. Although this is not the case for these two schedules in isolation (Schneider, 1969), it may occur in the present case when most responses are emitted during a changeover delay period. Notwithstanding this, Equation (2) would also follow if local response rates on VI schedules were a constant proportion of local rates on FI schedules, which does appear to be the case for these schedules in isolation (Schneider, 1969).

The value of  $c$ , taking this as the proportion of the time in the FI that the animal responds, can be obtained directly from the fitted lines in Figure 1: it is the antilogarithm of the constant of the lines fitted to the concurrent FI VI data. Alternatively, a more accurate estimate may be made after eliminating key bias by subtracting the constants from the equations for the concurrent VI VI data from the constants for the concurrent FI VI data. Using the latter method, the proportions of

the intervals spent responding for the present data are: 101, 0.17; 102, 0.14; 105, 0.15; 106, 0.13; for group responses, 0.14; and for group times, 0.19. These values are smaller than those reported by Schneider (1969), possibly reflecting a lengthening of the FI pause after reinforcement when another response is concurrently reinforced.

In conclusion, Schneider's (1969) analysis of FI performance explained the finding of a constant proportional preference for VI schedules over FI schedules in terms of responses emitted or times spent responding when these schedules are arranged concurrently. This does not, however, explain why matching according to Equation (1) was not found for concurrent VI VI performance.

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