RATES AND PATTERNS OF RESPONDING WITH CONCURRENT FIXED-INTERVAL AND VARIABLE-INTERVAL REINFORCEMENT¹

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Pigeons were exposed to concurrent fixed-interval and variable-interval schedules of food reinforcement on two keys. The times between reinforcement were varied systematically on both keys. The overall relative frequency of responding on the fixed-interval key depended on the relative frequency of reinforcement, but did not match it. Instead, the ratio of responses on the fixed-interval key to responses on the variable-interval key was a power function of the ratio of reinforcements, with an exponent of 0.5. Patterns of responding between reinforcements on the fixed-interval key depended on both relative and absolute values of the reinforcement schedules. Similar overall relative responding was obtained at different absolute schedule values with equal relative reinforcement, despite some differences in patterns of responding.

Catania (1962) demonstrated that the characteristic pattern of responding on fixed-interval reinforcement schedules was maintained when reinforcement was available concurrently at variable intervals for responding on a second key, while the rate of responding on the variable-interval key remained roughly constant throughout each fixed interval. These results were obtained only when a brief changeover delay (COD) prevented immediate reinforcement for switching from one key to the other.

Further data on patterns and average rates of responding with concurrent fixed- and variable-interval reinforcement are reported here. These data bear on the well-known finding that the relative frequency of responses matches the relative frequency of reinforcements when two variable-interval schedules are arranged concurrently with a COD (see Herrnstein, 1970, for a comprehensive review). With variable-interval schedules, response rates on both keys are roughly uniform throughout periods between reinforcements (see Catania, 1966, for examples). Herrnstein

(1970) suggested that the overall matching relation may be independent of the local characteristics of responding. Concurrent fixed-interval and variable-interval schedules, which control different patterns of responding between reinforcements, would appear to provide an interesting test of Herrnstein's suggestion.

METHOD

Subjects

Three male white Carneaux pigeons, which had previously served as subjects in a study reported by Nevin (1969), were maintained at 80% of their free-feeding weights.

Apparatus

The experiment was conducted in a two-key Lehigh Valley pigeon chamber equipped with centrally mounted houselight and grain magazine. Masking noise was continuously present.

Procedure

During each session, the left key was lighted blue and was associated with a fixed-interval (FI) schedule; the right-hand key was red and associated with a variable-interval (VI) schedule, or extinction.

Sessions began with the initiation of the FI on the left key, while the VI tape that arranged reinforcement on the right key was positioned randomly. When either schedule made reinforcement available, its timer stopped un-

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Table 1

Sequence of experimental conditions, number of sessions per condition, and average response rates to the FI and VI keys for the final three sessions of exposure to each condition for each subject.

Condition				#58		#59		#60	
FI (sec)	VIC (sec)	Sessions		FI	VI	FI	VI	FI	VI
1.	200	Ext	13	41.8	8.2	69.0	1.8	29.0	1.7
2.	200	360	7	31.6	33.6	46.5	19.2	28.9	18.5
3.	200	180	7	18.9	56.1	36.2	22.6	19.7	21.2
4.	100	Ext	18	39.4	4.6	62.0	2.8	37.8	1.3
5.	100	360	7	27.0	19.7	60.9	16.1	31.1	10.8
6.	100	180	7	22.4	43.5	59.3	24.9	24.9	21.5
7.	100	90	7	31.1	47.4	59.4	34.7	28.0	34.0
8.	50	Ext	11	41.2	3.3	90.7	3.0	35.0	3.2
9.	50	360	7	28.8	33.4	74.7	22.8	36.4	17.0
10.	50	180	7	35.1	31.2	72.0	31.5	33.5	23.3
11.	50	90	7	38.3	46.7	68.6	33.5	35.3	25.7
12.	200	Ext	15	36.2	9.4	92.3	5.7	33.0	1.6
13.	200	360	7	38.8	28.3	73.4	39.5	37.8	25.3
14.	200	180	7	29.5	57.9	48.1	44.9	29.8	34.6
15.	200	90	7	23.4	65.7	45.3	54.8	23.6	40.8

til that reinforcement occurred. A reinforced key peck produced 4-sec access to grain. Only the key that was pecked to produce a reinforcer was darkened during grain presentations. The timers for both schedules stopped during grain presentations arranged by either schedule. Rate calculations are based on time when both keys were lighted. A 2-sec COD requirement, timed from the initial peck on a key following a peck on the other key, was in force throughout the experiment. This COD requirement insured that reinforcement would follow at least two consecutive pecks on a key, and would follow the last peck on the other key by at least 2 sec. Sessions terminated after 18 or 36 reinforcers were obtained on the FI key. This number was chosen to keep the subjects near their 80% weights.

Systematic experimentation began after 30 sessions of pretraining with *conc* FI 200-sec VI 240-sec, during which time the parameters of the experiment were selected. The sequence of FI and VI schedule values employed during the experiment is given in Table 1, together with numbers of sessions on each pair of schedules.

RESULTS

Overall rates of responding stabilized rapidly in this study. Except for the extinction condition, which typically required six to eight sessions before reasonable stability was

achieved, visual inspection revealed no systematic changes in the average rates of responding on each key after three sessions of training on each pair of FI and VI schedules. An illustration of the rapid stabilization of performance is given in Fig. 1.

Note the immediate increase in rate on the VI key and the concomitant decrease on the FI key when VI reinforcement was introduced. Also, note the absence of systematic changes in

Fig. 1. Average rates of responding on the FI and VI keys during the last five sessions of training with concurrent FI 100-sec Extinction, and the immediately following seven sessions with concurrent FI 100-sec VI 360-sec.

response rate on either key during the seven sessions of concurrent FI VI training. This condition was selected arbitrarily and is representative of the other conditions studied.

The overall rates of responding on the FI and VI keys, averaged for the last three sessions on each pair of schedules, are summarized in Table 1. Reinforcement rates were always close to their scheduled values. Inspection of the table indicates that at each FI value, VI response rates increased systematically as the average interval between VI reinforcements decreased, while FI response rates generally decreased. There was no systematic relation between FI response rates and the length of the FI schedule, perhaps because of a tendency for rates to increase over the course of the study.

Relative frequency of responding on the FI key is related to relative frequency of reinforcement on the FI key in Fig. 2.

Schedule pairs that were equal in terms of relative reinforcement generally produced about the same values of relative responding. This may be seen in Fig. 2 by noting the tight clustering of the data points coded for the three different FI schedule values over a relative reinforcement value of 0.64, for Birds 59 and 60. The four data points represent performances on concurrent FI 200-sec VI 360-sec; FI 100-sec VI 180-sec; FI 50-sec VI 90-sec; and a replication of FI 200-sec VI 360-sec. The data of Bird 58 exhibit a good deal more scatter, but there is no evidence of systematic ordering of the data for the different FI schedules.

Overall relative responding departed from the matching relation expected with concurrent VI schedules. This departure is seen to be systematic when the data are treated as in the papers by Staddon (1968) and Baum and Rachlin (1969). Instead of using relative measures of responding, these investigators employed ratios. Figure 3 presents on logarithmic axes the relation between the ratios: $\frac{\text{FI responses}}{\text{VI responses}}$, and $\frac{\text{FI reinforcements}}{\text{VI reinforcements}}$. When data are transformed in this way, the matching relation implies a slope of 1.0. Lines fitted by the method of least squares to the data of Birds 59 and 60 have slopes of 0.48 and 0.50, respectively. No line was fitted to the data of Bird 58 because of its scatter; however, the trend of the data points suggests a similar slope.

Fig. 2. The data points represent the number of responses on the FI key, relative to the sum of responses on the FI and VI keys, as a function of the number of FI reinforcements relative to the sum of FI and VI reinforcements. Data are summed for the final three sessions at each pair of schedule values. The diagonal line represents equality between relative responding and relative reinforcement.

Fig. 3. The relation between the ratio of responses on the FI and VI keys, and the ratio of reinforcements obtained on the FI and VI keys, for all schedule pairs not including extinction. Identical logarithmic scales are employed on the ordinate and abscissa. The data for the three subjects are displaced arbitrarily along the ordinate. Lines fitted by the method of least squares are included for Birds 59 and 60.

This transformation also reveals individual biases toward one or the other key (see also Baum and Rachlin, 1969). When the ratio of reinforcements equals 1.0, the ratio of responses should also equal 1.0 if responding is unbiased. An intercept above 1.0 indicates a bias toward the FI key, while an intercept below this point indicates a bias toward the VI key. Bird 58 was heavily biased toward the VI key, and Bird 60 was slightly biased in the same direction, while Bird 59 favored the FI key.

Throughout the study, responses on both keys were tallied in successive fifths of the scheduled FI. Rates of responding on the FI key generally increased throughout the FI, as expected from Catania's (1962) data, but the details of the pattern of responding on the FI and VI keys depended on both the FI and VI

schedule values. This aspect of the findings is illustrated in Fig. 4, which presents the rates of responding on the FI and VI keys under six pairs of schedule values for Bird 60. The following points should be noted:

- (1) With extinction on the VI key, the rates and patterns of responding on the FI key were substantially identical on FI 50-sec and FI 200-sec. Responding on the VI key remained at a low level throughout the FI in both cases.
- (2) When reinforcement was scheduled on the VI key, most of the responding on that key occurred early in the FI 50-sec interval, but was more nearly uniform throughout the FI 200-sec interval.
- (3) When FI reinforcement was scheduled every 50 sec, the value of the VI schedule had no appreciable effect on FI responding. However, at FI 200-sec, the FI pattern was markedly attenuated, in that initial-segment rates increased while terminal-segment rates decreased as VI reinforcement was scheduled more frequently.
- (4) At concurrent FI 50-sec VI 90-sec and concurrent FI 200-sec VI 360-sec, which are equated for relative reinforcement, the patterns of responding were different even though the overall proportions of responses on the FI key were similar (0.58 and 0.60 respectively).

These aspects of performance on both keys were evident in the data of all three birds.

To summarize the data for all schedules except extinction, the proportion of responses on the FI key in each segment of the FI was calculated and averaged across birds. The results, presented in Fig. 5, indicate how the patterns of relative responding were affected by the FI and VI schedule values. As the frequency of VI reinforcement increased, relative responding throughout the FI was slightly reduced, with little change in slope, at FI 50-sec; systematically reduced with little change of slope at FI 100-sec; and generally reduced with systematic reduction of the slope at FI 200-sec. Within the columns with equal relative reinforcement, there is no systematic difference between the relative patterns at concurrent FI 50-sec VI 180-sec, and FI 100-sec VI 360-sec; progressive flattening is evident as one moves from concurrent FI 50-sec VI 90-sec to FI 200-

Fig. 4. Response rates on the FI and VI keys during successive fifths of the interval between reinforcements on the FI key. The data are for Bird 60, averaged for the final three sessions at the indicated pairs of schedule values.

sec VI 360-sec; and a still larger difference appears between performances at concurrent FI 100-sec VI 90-sec and FI 200-sec VI 180-sec. Thus, even at comparable relative reinforcement values, the absolute schedule parameters became important determinants of response patterning as the overall time between reinforcements increased.

DISCUSSION

Several aspects of these data merit consideration. First, it is clear that the COD was effective

in preventing responding on one key from being directly affected by reinforcement of pecking the other. The response rate on the VI key often decreased while FI responding was increasing (Fig. 4), and the characteristic FI-key response pattern was maintained at least qualitatively regardless of the presence or absence of VI reinforcement. In the latter respect, these data replicate Catania's (1962).

Second, the slopes of the functions for relative responding between FI reinforcements depended on the parameter values of the FI and VI schedules, even when the relative values of

Fig. 5. The number of responses on the FI key, relative to the sum of responses on both FI and VI keys, within each successive fifth of the interval between FI reinforcements, averaged for the three subjects over the last three sessions of each condition. Separate panels for each pair of schedule values are arrayed in rows according to the FI values, and in columns with equivalent relative schedule values. Schedules with relatively frequent FI reinforcement appear at the upper right, and those with relatively frequent VI reinforcement at the lower left, as in Fig. 2 and 3. Replication data are indicated by the squares.

the two schedules were equated. Thus, no simple summary of relative response patterns in relation to relative reinforcement is possible. At the same time, relative overall levels of responding were roughly independent of the absolute values of the schedules, and depended on relative reinforcement. The orderliness of the relation between relative or ratio measures of responding and reinforcement held despite variations in the local patterns of responding. At the upper right-hand end of the functions in Fig. 3, representing short FI and long VI schedules, the distribution of responding varied systematically across the two keys within the FI. At the lower left, the distribution of responding maintained by long FI and short VI schedules was nearly uniform throughout the FI. Nevertheless, the overall data could be described by a simple continuous function. This aspect of the findings accords with Herrnstein's (1970) view that the gross characteristics of performance may be more orderly, or more simply orderly, than the momentary patterns of responding.

Finally, the overall response data departed from the matching relation commonly found with concurrent VI schedules.

In connection with this departure, some comment on the merits of the different data representations of Fig. 2 and 3 is in order. Figure 2 exhibited the relation between relative frequencies of responses and reinforcements, which has become a conventional method for presenting the results of concurrent-schedule experiments since the work of Herrnstein (1961). More recently, Staddon (1968) and Baum and Rachlin (1969) employed double-logarithmic plots of response ratios in relation to reinforcement ratios, in the form of Fig. 3, to summarize the results of experiments with concurrent schedules. Staddon (1968) pointed out that the matching law relating frequencies of responding and reinforcement is simply a special case of a power-law relationship between response and reinforcement ratios, and argued that the latter is to be preferred as the more general. Baum and Rachlin (1969) employed the double-logarithmic plot to reveal the proportionality between ratios of time allocation and ratios of reinforcements, despite a pronounced bias toward one side of their chamber. Lander and Irwin (1968) discussed the use of the power-law relationship to summarize data from a variety of

complex schedules, and argued that the exponent might provide a simple characterization of the sensitivity of differential responding to differential reinforcement in various experimental arrangements. The present use of the double-logarithmic plot of response and reinforcement ratios in Fig. 3 yielded linear relations that departed from the matching law, and revealed individual differences in bias toward one or the other key. Therefore, these data provide further support for the generality and utility of the power-law relationship between response and reinforcement ratios.

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