REINFORCEMENT FREQUENCY AND CONTINGENCY AS FACTORS IN FIXED-RATIO BEHAVIOR¹

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Two variables often confounded in fixed-ratio schedules are reinforcement frequency and response requirement. These variables were isolated by a technique that yoked the distributions of reinforcements in time for one group of pigeons to those of pigeons responding on various fixed-ratio schedules. The contingencies for the yoked birds were then manipulated by adding various tandem fixed-ratio requirements to their schedules. Post-reinforcement pause was approximately equal for the yoked and ratio pigeons, and was relatively insensitive to changes in the tandem requirement. Terminal response rate increased with increases in the tandem requirement, even though reinforcement rate was invariant. This increase was attributed to the progressive interference of the tandem requirement with the differential reinforcement of long interresponse times.

Although reinforcement contingencies are quite different on fixed-interval (FI) and fixed-ratio (FR) schedules, the behavior patterns engendered by these schedules can be surprisingly similar. Fixed ratio schedules of moderate value are characterized by a pause after reinforcement followed by a quick transition to a steady, high rate of responding (Ferster and Skinner, 1957). This terminal rate increases as FR requirement is increased to some critical ratio, and then decreases with further increases in the FR. The value of the critical ratio fluctuates widely between subjects, with values ranging between 25 and 80 for rats (Boren, 1953; Barofsky and Hurwitz, 1968). A similar "break-and-run" pattern of responding is found on FI schedules, with postreinforcement pause increasing and terminal rate uniformly decreasing as the FI is increased (Sherman, 1959; Schneider, 1967).

A plausible analysis of these schedules might suggest that the break-and-run pattern of responding is due to the way reinforcements are distributed in time; the higher terminal rate on FR schedules could be attributed to some peculiarity of the response requirement on

these schedules, which might establish a contingency that differentially reinforces short interresponse times (IRTs). No such analysis is tenable, however, until the effects of independent variation of reinforcement frequency and reinforcement contingency have been assessed. In the case of FI and FR schedules, this requirement of independent variation presents special problems. The number of responses emitted per reinforcement is not under experimenter control in interval schedules, just as the interreinforcement interval is not under experimenter control in ratio schedules. When an FR is varied, changes in post-reinforcement pause and rate could be due to changes in reinforcement frequency, changes in response requirement, or to some combination of both.

In the present study, a yoked technique was employed to provide distributions of reinforcements in time which were characteristic of various FR schedules. With reinforcement frequency thus controlled, the terminal contingencies of reinforcement were manipulated to produce interval schedules whose behavioral effects successively approximated those of ratio schedules.

METHOD

Subjects

Eight male White Carneaux pigeons, all with previous experimental histories, were maintained at 80% of their free-feeding weight.

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Apparatus

Two identical experimental chambers were enclosed in separate acoustically insulated boxes. A plastic response key was centrally located in each chamber, and was transilluminated by two 7-w green bulbs. Responses on these keys of at least 14-g force were recorded and produced feedback clicks. Reinforcement consisted of 3.5-sec access to mixed grain from a hopper located below the response key. General illumination was provided by two 7-w white bulbs, except during reinforcement. White masking noise was continuously present.

Procedure

(A) *Determination of baseline response rates.* In order to provide similar experimental histories, and to assess typical individual rates of responding, all birds were given 15 days on a random-interval schedule (Farmer, 1964). On this schedule, a timer continually cycled with a period of 6 sec. The first response in each period was reinforced with a probability of 0.07. All subsequent responses, before the timer recycled, were ineffective in producing reinforcement.

(B) *Assignment to experimental conditions.* Birds were rank-ordered according to their rates of responding under procedure (A). The pair of birds with the lowest rates was assigned to Condition 25, the next lowest pair to Condition 50, and so on for Conditions 75 and 100. Within each condition, the birds were randomly assigned to yoked or ratio schedules.

(C) *Nature of reinforcement schedules.* The birds assigned to the ratio schedules received food according to standard FR schedules: reinforcement occurred as soon as the bird emitted N responses, with the value of N being 25, 50, 75, or 100 for different birds, and remaining at that value throughout the experiment. The birds assigned to the yoked schedules were run at the same time as the ratio birds, with reinforcement following the first response they emitted after the ratio bird obtained food. No signal was given to the yoked birds when reinforcement became available.

After the birds were run for about 42 days on this simple yoked-ratio procedure, the schedule for the yoked birds was modified. Reinforcement became conditional on their emission of at least M responses after the ratio

bird had received food. This new yoked procedure may be thought of as a tandem schedule, tand(yoke (FR N), FR M), where the change between components is determined by the behavior of the matched ratio birds. Values for M of 3, 6, and 12, in that order, were used for all yoked birds, with approximately 38 sessions at each value. The original schedule for the yoked birds may be treated as a tandem with $M = 1$.

In all procedures, the birds produced 45 reinforcements per session. No data were recorded until the birds had received their first reinforcement of the session; thereafter the times to the first and fifth responses, the total number of responses, and the total session time were recorded.

RESULTS

Table 1 contains the response rates on the random-interval schedule and the reinforcement rates obtained in subsequent conditions. After the initial session at each tandem requirement, the yoked birds responded at a high enough rate to produce all reinforcements set up by the ratio birds. Figure 1 shows the cumulative records from the last days at each tandem requirement for the yoked birds, and typical records for the ratio birds.

Increases in the tandem requirement above FR 3 seemed to have little effect on the Yoked-25 and Yoked-50 pigeons, which were already responding at a fairly high rate. The other two yoked birds showed a progressive increase in the terminal rate of responding as the tandem requirement was increased. These changes are seen more clearly in Fig. 2, where the terminal rate of responding is plotted as a function of the tandem requirement. The terminal rate is calculated as the rate from the fifth

Table 1

Mean response rate over the last four days of the random-interval schedule, and reinforcement rate in the subsequent conditions of the experiment.

Con- dition	<i>Responses per Minute</i>		<i>Reinforcements per Minute</i>			
	<i>Yoked</i>	<i>Ratio</i>	<i>1</i>	<i>3</i>	<i>6</i>	<i>12</i>
25	42	36	5.6	5.5	5.9	5.8
50	52	52	1.7	2.3	2.4	2.4
75	60	65	0.85	1.1	1.2	1.1
100	70	67	0.90	0.75	0.76	0.74

Fig. 1. Typical cumulative records for yoked and ratio birds for each reinforcement condition.

response after each reinforcement until the next reinforcement, and is the median value from the last seven sessions at each tandem requirement. The open circles show the terminal rates, calculated in the same manner, for the ratio birds. Because the ratio birds were on the same schedules throughout the experiment, the mean values of the seven day medians are plotted in Fig. 2. It appears that as the tandem requirement is increased, the response rates of the yoked birds approach those of the matched ratio birds. The only exception to this rule is manifest by the Yoked-50 pigeon, whose rate shows a slight decrease as the tandem requirement is increased beyond 3.

While the form of the curves in Fig. 2 depends on the effect of added tandem requirements, the absolute level of the curves is a

function both of the particular bird, and of the reinforcement frequency provided that bird by the schedule: in the course of the experiment, slow changes in the response rates of the ratio birds caused proportional changes in the reinforcement frequency of the yoked birds. These changes in reinforcement frequency were correlated with changes in the response rates of the yoked birds, suggesting some control of their rate by reinforcement frequency. The use of different subjects for each condition, however, precludes quantitative evaluation of the role of reinforcement frequency in the determination of these curves.

In Fig. 3, the post-reinforcement pause, on a logarithmically spaced ordinate, is plotted as a function of the tandem requirement. The data are seven-day medians of the time to the

Fig. 2. Terminal response rates for the yoked and ratio birds. Data for the yoked birds are the median values over the last seven days at each condition; data for the ratio birds are averaged over the conditions. Terminal rate is measured from the fifth response after each reinforcement until the next reinforcement.

first response after each reinforcement; once again, the average of these medians is plotted with open circles for the ratio birds. Unlike Fig. 2, the picture here is one of invariance;

Fig. 3. Post-reinforcement pause for the yoked and ratio birds. Data for the yoked birds are the median values over the last seven days at each condition; data for the ratio birds are averaged over conditions.

with the possible exception of the Yoked-100 curve, there is no general relation between pause length and the tandem requirement. The average pause for the yoked birds on the tand 1 schedule was 10.5 sec, and for the ratio birds 10.8 sec.

DISCUSSION

In most studies of FR behavior, the variable controlling pause length and response rate is assumed to be the response requirement of the FR schedule (e.g., Felton and Lyon, 1966; Powell, 1968). In the present study, however, pause lengths for the ratio and yoked birds were approximately equal in the initial (tand 1) condition, even though the terminal rate of the ratio birds was twice that of the yoked (144 responses/minute *versus* 75 responses/minute). Furthermore, with reinforcement frequency held approximately constant for the yoked birds, increases in the tandem requirement increased their terminal rate without affecting the post-reinforcement pause. When reinforcement frequencies were equal, pause lengths were approximately equal; where reinforcement frequency varied (*i.e.*, across conditions), pause length also varied. There seems, therefore, to be a higher correlation of pause length with reinforcement frequency than with other aspects of the schedules, such as response requirement or terminal response rate. When pause length is seen to vary with FR value, it probably does so because changes in the FR requirement affect reinforcement frequency, which in its turn affects pause length.

This conclusion is strongly reinforced by a recent study of Neuringer and Schneider (1968). By presenting a blackout after each response, these investigators independently varied interreinforcement time and interreinforcement responses on FI and FR schedules. They found post-reinforcement pause to be independent of the number of interreinforcement responses, but to be a linear function of the interreinforcement time.

While pause length may be largely independent of response requirement, this is obviously not the case for response rate. Figure 2 shows an orderly increase in rate as a function of the tandem response requirement. The slope of the curves for the Yoked-75 and Yoked-100 pigeons suggest that further in-

creases in tandem requirements would result in further rate increases for those birds. This increase is also suggested by the fact that even under the tand 12 requirement, rates for the yoked birds were still below those of the matched ratio birds.

The various tandem requirements were employed in an ascending sequence, and no attempt was made to recover earlier data points. Such an attempt would probably yield data showing a certain amount of hysteresis, with the recovered points lying higher than the original points.

It is interesting to note that the rates of the ratio birds are inverted from the order found in the baseline condition; the pigeons with the lowest rates on the random-interval schedule show the highest rates on the yoked and ratio schedule. This inversion is reminiscent of the one found by Boren (1953) and Barofsky and Hurwitz (1968) for large fixed ratios. It is probably due to the "overpowering" of FR contingencies by the lower reinforcement frequency found on the larger FR schedules, rather than to some sort of reactive inhibition or reflex fatigue. The inversion also obtained for the yoked pigeons, even in the tand 1 condition, where response requirement was minimal and rates for some of the pigeons were quite low.

While the analysis of performance in terms of differential reinforcement of various classes of IRTs works quite well for interval and paced schedules (Anger, 1956; Catania and Reynolds, 1968; Shimp, 1967), it seems to be of less value in the analysis of ratio schedules. It is obvious that interval schedules differentially reinforce pausing (*i.e.*, long IRTs), but in what manner do ratio schedules selectively reinforce short IRTs? Morse (1966) suggested that on FR schedules, relatively more short IRTs will be reinforced per hour than long IRTs, since reinforcement rate is proportional to response rate on ratio schedules. This analysis does not explain the present data, where the addition of tandem requirements to the yoked schedules did not affect the reinforcement rate, which was always the same as that of the matched ratio birds, but did produce a regular increase in terminal response rates to levels comparable with those of the matched

ratio birds. The simplest and most satisfactory explanation of these data is that ratio contingencies are correlated with high response rates not because they selectively reinforce short IRTs, but because they interfere with the selective reinforcement of long IRTs that obtains on interval schedules. On ratio schedules the only behavior that is reinforced is responding; interval schedules reinforce any behavior that precedes a response and takes time.

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