PREFERENCE FOR MIXED- VERSUS FIXED-RATIO SCHEDULES¹

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Pigeons' pecks on one key produced a stimulus correlated with a mixed-ratio schedule of food reinforcement. Pecks on a second key produced a stimulus correlated with a fixed-ratio schedule. When the arithmetic mean of the mixed ratios equaled the fixed ratio, the former stimulus maintained a higher rate of pecking. When the fixed ratio was sufficiently smaller, preference shifted to it. The pigeons' relative preference for the schedules could be described by comparing the geometric mean of the reinforcement rates in the several mixed-ratio components with the reinforcement rates in the fixed-ratio components.

Chained schedules of reinforcement are a useful tool in studying secondary (or conditioned) reinforcement. In a two-link chained schedule, for example, responding in the presence of a first stimulus is reinforced by a second stimulus; responding in the presence of the second stimulus is reinforced with food (Ferster and Skinner, 1957). Kelleher and Gollub (1962) have presented evidence that responding in the early links of a chain is maintained primarily by conditioned reinforcement. If two chained schedules are concurrently available, an organism's preference for one secondary reinforcer (S^r) relative to the other S^r may be measured by the relative amount of responding (responses on one key/total responses) maintained by that S^r . The organism may be required to choose between two S^r s when each is correlated with a different schedule of primary reinforcement (Autor, 1960; Reynolds, 1963). Using this technique, Herrnstein (1964a) showed that the relative rate at which pigeons' pecks were maintained by a secondary reinforcer matched the relative rate of primary reinforcement in its presence when primary reinforcement was programmed on variable-interval (VI) or variable-ratio (VR) schedules. Matching was not

found, however, when a fixed-interval (FI) schedule was programmed concurrently with a VI schedule having the same mean interval as the FI (Herrnstein, 1964b). Instead, the pigeons responded at a higher rate when the S^r was correlated with the VI schedule of primary reinforcement. Similarly, rats were found to prefer the side of a Y-maze in which reinforcement was delayed for either 0 or 30 sec over the side in which reinforcement was always delayed by 15 sec (Pubols, 1962). Neither of these two experiments revealed how the component rates of reinforcement on the variable schedule might be averaged so that preference might be approximated by the relative rates of reinforcement. Both experiments did indicate that arithmetic averaging was insufficient.

The present study was a more extensive search for a method of averaging reinforcement rates which would approximate response rates. During most of the experiment, the variable schedule was made up of two values only. Reinforcements in the presence of one S^r were programmed on a single fixed-ratio (FR) schedule, while reinforcements during the other S^r were programmed on a mixed-ratio (MR) schedule. A fixed-ratio schedule is a schedule of intermittent reinforcement providing reinforcement upon completion of a fixed number of responses. An MR schedule is one in which reinforcement occurs on alternating FR schedules; no exteroceptive stimuli indicate which FR is in effect. An MR schedule differs from conventional VR schedules in that only a small number of FR values are possible in the MR.

In one experiment, the range and number of ratios comprising the MR were varied while

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the arithmetic mean of the ratios equaled the FR. In a second study, the single FR was varied in order to determine the ratio which would be about equally preferred to a particular MR.

METHOD

Subjects

Seven male, adult White Carneaux pigeons were maintained at approximately 80% of normal body weights (determined during free access to grain). Each pigeon had a long experimental history, including at least three months prior experience with concurrent chained schedules.

Apparatus

The experimental chamber was a modified picnic icebox (Ferster and Skinner, 1957) containing two translucent response keys mounted 9 in. above the floor. The left key was transilluminated either by a white circle, 0.5 in. in diameter, or by a red light. The right response key was transilluminated either by a white triangle, 0.5 in. high, or by a green light. Transillumination was accomplished by mounting a projection system (One Plane Digital Display Unit, Model #10495, Industrial Electronics Engineers) behind each key. A minimum force of 10 g was required to operate each response key. Each effective response produced auditory feedback by operating a 110 v ac relay. The chamber also contained a solenoid-operated hopper that occasionally presented grain to the pigeon, and two 6 w lamps for general illumination.

Stimulus conditions were programmed by relays, resetting timers, stepping switches, and interval programmers. Recording was accomplished with counters, running-time meters, and cumulative recorders.

Procedure

The birds were observed on concurrent [chain VI FR, chain VI mix (FRFR)] schedules of reinforcement. At the start of a session, the left key was transilluminated by a white circle, the right key by a white triangle. Identical, but independently operated, VI schedules were correlated with these stimuli. In Part A, each VI schedule had a mean interreinforcement interval of 3 min. In Part B, each had a mean interreinforcement interval of 1.5 min. When reinforcement was scheduled by either VI pro-

grammer, it stopped operating, but the other VI programmer continued to operate. The pigeon's next response on the appropriate key produced the S^r associated with that key and two additional events: (1) the VI programmer associated with the other key stopped operating; (2) illumination was removed from the other key, which became inoperative. For the left key, the S^r was transillumination with red light; the right key with green light. Pecks during the S^r were reinforced on FR schedules with 3-sec access to grain. For the five pigeons used in the body of the experiment, a single-value FR was programmed on the left ("fixed") key. Mixed schedules were programmed on the right ("mixed") key. These mixed schedules consisted of two or three FRs. The mixed FRs were equiprobable, their order determined by an irregular sequence. On either key, after a single food reinforcement was delivered, the two white figures reappeared and both VI programmers began operating. The session ended after 36 reinforcements. This procedure kept the number of reinforcements for responses on each key fairly constant over a wide range of preference. If a pigeon responded exclusively to one key, all reinforcements were delivered for those responses. On concurrent VI schedules, however, the pigeon will produce a higher rate of reinforcement if it responds on both keys. Hence, for each pigeon in each procedure, the average number of reinforcements on each key was equal.

"Initial link" refers to the period in which responses, in the presence of white figures, were reinforced with an S^r . "Terminal link" refers to the period, during either S^r , in which responses were reinforced with food. The general procedure is schematized in Fig. 1.

In Part A of the experiment, all responses on the fixed key were reinforced on FR 50. Responses on the mixed key were reinforced on FR 50 or on mixed schedules with an arithmetic mean of 50. In Part B, the schedule on the mixed key was mixed FR 1 FR 99, while the FR on the fixed key was varied. Table 1 lists the order of procedures used, and the number of sessions for each pigeon under each procedure. Each pigeon was generally studied daily providing it was not overweight.

The pigeons were studied on a particular procedure until their relative response rates in the initial links reached a visual stability cri-

Fig. 1. Pictorial representation of the concurrent-chains procedure used throughout most of the experiment. Fig. 1A indicates the sequence of events when responses on the left key were reinforced; Fig. 1B represents the analogous sequence on the right key.

terion for at least 12 sessions. This generally took at least a month of daily sessions. The response rates appeared stable in the second procedure after only 16 sessions. Data from the second procedure are not presented except for pigeon 242. Since the data for some pigeons on this procedure were not substantially different from those of the first procedure, this procedure was later replicated for approximately 38 sessions (procedure 9), except for pigeon 242, which did not participate in the replica-

tion. A beak injury prevented it from operating the response keys. A beak injury also accounts for the large discrepancy between the number of sessions for 242 and the other pigeons in the sixth procedure.

Table 1 indicates that mixed schedules were never programmed on the left key. This omission is justifiable because both keys were identical except for position and stimulus lights, and because the last procedure, in which each S_r was correlated with an FR 50, controlled against position preference. As an additional control, to demonstrate that analogous results could be obtained by programming mixed schedules on the left key, pigeons 50 and 67 were studied with mixed FR 1 FR 99 during the terminal links on the left key and FR 50 during the terminal links on the right key. Pigeon 50 was studied daily for 28 sessions, pigeon 67 daily for 29 sessions.

RESULTS

Part A. The relative rate of responding during the initial links under each procedure, in which the MR consisted of not more than two FRs, is shown in Fig. 2. These rates were obtained as follows: (1) for each of the last four sessions of each procedure, the number of responses in the initial link on the mixed key was divided by the total initial link responses; e.g., if during the initial links, 1000 responses were made to the mixed key and 1500 to the fixed key the relative rate of responding for the mixed key would be $\frac{1000}{1000 + 1500} = 0.40$; (2) the arithmetic mean of the four quotients for each procedure was then computed.

Table 1
Order and Duration of Experimental Procedures.

Procedure	Part A or B	Schedules in Terminal Links		Number of Sessions for Pigeon Number				
		Left Key	Right Key	93	233	242	261	262
1	A	FR 50	mixed FR 10 FR 90	45	44	44	44	45
2	A	FR 50	mixed FR 1 FR 99	16	16	16	16	16
3	A	FR 50	mixed FR 25 FR 75	31	29	28	29	31
4	B	FR 25	mixed FR 1 FR 99	22	22	22	22	22
5	B	FR 20	mixed FR 1 FR 99	48	47	46	47	48
6	B	FR 1	mixed FR 1 FR 99	69	66	36	67	52
7	B	FR 10	mixed FR 1 FR 99	57	57	53	56	56
8	A	FR 50	mixed FR 1 FR 50 FR 99	46	37	42	43	44
9	A	FR 50	mixed FR 1 FR 99	38	38	—	38	37
10	A	FR 50	FR 50	45	49	36	48	49

Fig. 2. Relative rate of responding maintained by the mixed S^r for each pigeon and for the average of the five pigeons during each of four procedures. The ratio requirements in the presence of the mixed key are listed at the bottom. The requirement in the presence of the fixed S^r was always FR 50.

Figure 2 indicates that, with one exception, the relative rate of responding maintained by the S^r correlated with the MR schedule (the "mixed S^r ") was above 0.50. The exception occurred for pigeon 262, when the MR was FR 25 FR 75. When FR 50 was programmed on each key no systematic preference was evident. As the numerical difference between the two FRs comprising the MR increased, responding maintained by the mixed S^r also increased. Two inversions occurred in the individual data (for pigeons 261 and 262).

No systematic differences were evident when the data for the procedure in which the MR consisted of three FRs (FR 1, FR 50, FR 99) were compared with those in which the MR consisted of FR 1 and FR 99.

Does the preference for the mixed key depend on relative rates of reinforcement? These rates are generally computed (Autor, 1960; Herrnstein, 1964a, b) by dividing the number of reinforcements obtained in the presence of an S^r by the total duration of the S^r . Then, by dividing the rate of reinforcement during the mixed S^r by the sum of the rates of reinforcement during each S^r , the relative rates of reinforcement for the mixed key are obtained. For example, if 18 reinforcements were obtained in 9 min in the presence of the mixed S^r , the rate of reinforcement during the mixed S^r would be 2.0 reinforcements per min.

If the analogous rate in the presence of the S^r correlated with FR 50 were 3.0 reinforcements per min, then the relative rate of reinforcement for the mixed S^r would be $2/(2 + 3) = 0.40$. The arithmetic means of these rates over the last four sessions were then computed. For each bird the relative rate of reinforcement in the mixed S^r generally decreased as the relative rate of responding for the mixed S^r increased. This decrease resulted from "pauses" which occurred for each pigeon during high FR requirements, especially FR 99. After a single peck or burst of pecks on this schedule, the pigeon generally stopped responding for some time. In most cases these pauses were of less than 1-min duration, but occasionally one continued for up to 5 hr until the pigeon was removed from the apparatus. Figure 3 presents a typical cumulative record of the behavior on each key. After the session depicted, the pigeons were changed to the tenth procedure in which all ratio schedules were FR 50. Figure 4, also typical for each pigeon, shows how the pausing diminished by the second session on the new procedure.

The relative rates of reinforcement discussed above were each obtained by dividing the total number of primary reinforcements on a single key by the total time that the S^r was present, and then finding the relative rate of reinforcement. Since the rates of reinforce-

Fig. 3. Cumulative record for complete session on last day of procedure 9 (FR 50 on left, mixed FR 1 FR 99 on right) for pigeon 233. Displacement of the recording pen indicates that the S^r was in effect. When FR 1 was in effect this displacement appears as a single blip. Each recorder operated when either S^r appeared, though neither operated during primary reinforcement. Hence, displacements on one record are correlated with periods of non-responding on the other record. The preference for the S^r of the mixed key is reflected by the steeper slope on the right key records. Long pauses occurred in the presence of the mixed S^r [at (a)–(d)]. Short pauses of less than 15-sec duration sometimes occurred during the S^r on the left key as well [(e) through (h)]. These may be distinguished from those on the right key, not only because of their brevity, but also because they generally occurred before the emission of a single response in the presence of the S^r .

ment associated with each of the FRs comprising the MR schedule are not considered separately, the rates on the MR will be called the "combined rates". It is also possible, however, to consider separately the rates of reinforcement associated with each of the FRs comprising the MR schedule. The number of reinforcements on an FR may be divided by the time spent executing the ratio. The rates for different FRs in the MR schedules may then

be averaged in some way, *e.g.*, arithmetically or geometrically. The relative rates of reinforcement may then be found in the usual manner. For example, if pecks were reinforced at a rate of 1 per min on FR 90, and 15 reinforcements per min on FR 10, the arithmetic rate for the mixed S^r would be 8 reinforcements per min and the geometric rate 3.9 reinforcements per min. If the rate of reinforcement on the FR 50 of the fixed key were 3 reinforcements per min, then the relative rate of reinforcement for the mixed S^r based on the arithmetic rates would be $8/(8 + 3) = 0.73$ while that based on the geometric rates would be $3.9/(3.9 + 3) = 0.57$. Do either of these rates of reinforcement describe the relative rates of responding in the initial links?

Figure 5 presents data for each pigeon when the relative rate of responding is plotted against the relative geometric rate of reinforcement. In addition, Fig. 5 presents the average regression lines for the five pigeons.

Fig. 4. Total durations of each terminal link for pigeons 93 and 233 in each of the first six sessions of procedure 10 (FR 50 on each key). Session "0" was the last session of the previous procedure (FR 50 on left, mixed FR 1 FR 99 on right).

Fig. 5. Relative rate of responding during the initial link as a function of the relative geometric rate of primary reinforcement in the terminal link. The dashed diagonal lines show the locus of perfect matching between ordinate and abscissa. The solid lines are the calculated linear regression lines through the data points. The linear equations and standard deviations around the regression lines are shown for each pigeon.

Figure 5 does not plot relative rates of responding against the relative arithmetic rates of reinforcement. Although this yields a good linear relation it provides a poor approximation to the locus of perfect matching, since the rates of responding are considerably lower than these rates of reinforcement. A similar situation arises when the relative rates of re-

sponding are plotted against the relative rates of reinforcement for the shortest FRs only.

The relative rates of responding and relative rates of reinforcement for pigeons 50 and 67 are shown in Table 2. Both pigeons developed a marked preference for the mixed S⁺ when it occurred on the left key. Again, the response rates are best approximated when the

Table 2

Relative rates of responding and of reinforcement for pigeons 50 and 67.

	#50	#67
Relative rate of responding on mixed key	0.64	0.81
Relative rate of reinforcement on mixed key (obtained from combined rates)	.31	.40
Relative rate of reinforcement on mixed key (obtained from arithmetic rates)	.95	.94
Relative rate of reinforcement on mixed key (obtained from geometric rates)	.75	.75

FR rate is obtained from the geometric rates.

Part B. A positive linear relation between the relative rates of reinforcement and responding is evident from the data of Part A when geometric rates of reinforcement are computed on the mixed key. In Part B the FR on the fixed key was varied in order to determine at what point subjects would switch their preference away from the mixed S^r . The relative rates of reinforcement based on the "combined", "geometric", and "arithmetic" rates were examined to determine the extent to which they described the switch in preference.

The relative rate of initial link responding (*i.e.*, maintained by the S^r) on the fixed key for each of the four FR requirements is shown in

Fig. 6. Data for each pigeon and for the average of the five pigeons are shown. The requirement in the terminal links on the mixed key was always mixed FR 1 FR 99. For each pigeon, preference for the mixed S^r decreased as the FR requirement on the fixed key was reduced. For only one pigeon (93), however, did the relative rate of responding increase monotonically as the ratio requirement decreased. An inversion occurred for each of the other four.

For four pigeons, the geometric mean rate of reinforcement in the mixed S^r was greater than in the fixed S^r , when the FR was 25 or 20. Hence, if the relative response rates were to follow faithfully the relative geometric rates of reinforcement, these pigeons should have shifted their preference away from the mixed S^r when the FR on the left key was between 20 and 10. Only pigeon 233 did so. When the data are averaged over the five pigeons, however, the shift does occur between 20 and 10. The other rates of reinforcement considered in Part A are again less valuable in describing the rates of responding. The relative arithmetic rates shift between 10 and 1 for all pigeons. The combined relative rates shift at some value greater than 25. Thus, these results are consistent with the results obtained in Part A in that the relative geometric rates more closely approximate the relative response rates.

Fig. 6. Relative rate of responding maintained by the S^r on the fixed key for each pigeon and for the average of the five pigeons during each of four procedures. The ratio requirements in the presence of the fixed key are listed at the bottom of the figure. The requirement in the presence of the mixed S^r was always mixed FR 1 FR 99.

DISCUSSION AND CONCLUSIONS

Since the degree and frequency of pausing increased as a function of FR length, the range of the FR schedules in the presence of the mixed S^r varied inversely with the combined rate of reinforcement (reinforcements/time) in the presence of the mixed S^r . Nonetheless, each pigeon's preference for the mixed S^r increased as the range of the FRs increased. This suggests that the combined rate of reinforcement is not the critical determinant of the strength of the mixed S^r , supporting Herrnstein's (1964b) finding with FI and VI schedules. This rate weights the longer FRs far more than the shorter ones since more time is spent executing the longer FRs. The pauses on the MR schedules indicate that the pigeons were probably discriminating between the two FR requirements. This fact gives intuitive support to the notion that the rates of reinforcement should be computed for each FR. The rates for each FR were thus obtained separately and then combined arithmetically and geometrically. When the arithmetic rates were used, the relative rates of responding maintained by the mixed S^r were generally lower than the relative rates of reinforcement in its presence. Hence, in Part B, these reinforcement rates were higher for the mixed S^r than for an FR 10. Yet pigeons preferred the FR 10. When the geometric rates were used, however, the relative rate of responding maintained by the mixed S^r approximated the relative rate of reinforcement in its presence.

These results are consistent with Herrnstein's (1964a) finding that the relative rate of responding maintained by an S^r equals the relative rate of reinforcement in its presence. They indicate, however, that the relative rate of reinforcement should not generally be found by dividing the number of reinforcements by the time spent in the presence of the S^r . This procedure suffices for those cases in which the schedules of primary reinforcement are comparable, *e.g.*, both variable or both fixed. In such cases the relative rates obtained from the combined rates, and those obtained from the geometric rates, should not differ greatly. When a variable schedule of primary reinforcement is programmed on one key while a fixed schedule is programmed on the other, however, the two methods may produce radically different relative rates of reinforce-

ment. The present experiment suggests that the relative rates based on the combined rates do not approximate choice, while those based on the geometric means provide a reasonable description of choice. It is possible, of course, that some other method of averaging would provide an even closer approximation to the relative rates of responding.

The present study was guided by the assumption that some method of averaging reinforcement rates would enable them to approximate response rates. It could, however, be argued that another important consideration is the degree of correlation between the response and reinforcement rates. By this argument, the critical reinforcement rates are those which correlate most highly with the response rates regardless of their fit to the locus of perfect matching. On this basis, the present experiment cannot choose between the geometric rates, the arithmetic rates, and the rates based on the shortest FRs. All produced high positive correlations (in Part A, for example, the smallest Pearson r for an individual pigeon was 0.69, the highest 0.98), but it is not meaningful to compare them since the various reinforcement rates had disparate ranges. These correlations could be compared in a study which controlled the ranges of the various reinforcement rates. The shortest FR rates could also be studied in a design which varied the length of the longer FRs comprising the MR. If, for example, the lower reinforcement rates associated with the longer FRs have no effect upon choice, a mixed FR 1 FR 20 should be equally preferred to a mixed FR 1 FR 200.

The preference for the mixed S^r was evident for all pigeons despite the apparent aversiveness of high FR schedules (*e.g.*, Azrin 1961). Thompson (1964) has shown that pauses during the high FR components of MR schedules will be accompanied by escape (time outs) from the situation if escape is available. The pauses in the present study were sometimes so great that the pigeon was removed from the apparatus after several hours of non-responding in the presence of the S^r . These pauses never occurred during FRs of 25 or less or during the initial links. The frequency and duration of pauses were increased by slight increases in body weight as previously reported by Sidman and Stebbins (1954). When pecks were extinguished in four of the pigeons by omitting food reinforcement, pauses increased

dramatically in the presence of the S^rs although sustained responding was maintained by the S^rs. The S^rs were still reinforcing responding although they no longer served as discriminative stimuli for responding in their presence. This indicates that an S^r need not be a discriminative stimulus and complements Gollub's (1958) finding that a discriminative stimulus need not be an S^r. The implications of this and related findings for the discriminative stimulus hypothesis of secondary reinforcement have been reported previously (Fantino, 1965).

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