ALTERING THE PROPORTION OF COMPONENTS IN A MIXED FIXED-RATIO SCHEDULE¹

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Pigeons were trained under a schedule consisting of a number of fixed-ratio 100 components followed by a single fixed-ratio 10 component. The proportion of fixed-ratio 100 to fixed-ratio 10 components was varied according to several ascending and descending series within the range of 99:1 to 1:1. When this proportion was reduced to about 20:1 and below, the pause following each fixed-ratio 100 gradually decreased in length. Primes, a burst of responses at the start of the fixed-ratio 100 component, increased in frequency, and then decreased when the proportion became extremely low. Also, when the relative frequency of fixed-ratio 10 components was very high, primes were seldom observed in the first fixed-ratio 100 component following a fixed-ratio 10 component, but were distributed evenly throughout the remaining fixed-ratio 100 components.

In a mixed schedule, reinforcement is arranged according to two or more schedules in which the same stimulus is present. For example, under a mixed fixed-ratio 100 fixed-ratio 10 schedule (*mix* FR 100 FR 10), reinforcement occurs after 10 responses or after 100 responses, depending upon which component is in effect. Ferster and Skinner (1957, p. 729) stipulated that the two schedules (in the above example, FR 10 and FR 100) can be presented "at random or according to a program in any determined proportion".

These investigators described performance on mixed fixed-ratio schedules in terms of two variables; pausing after reinforcement and priming. A prime was defined as the emission, at the beginning of the larger FR, of the approximate number of responses of the smaller FR component, followed by a pause before the balance of the larger FR requirement was completed (Ferster and Skinner, 1957, p. 580). Using mixed schedules composed of two randomly presented FRs, *e.g.*, FR 60 and FR 360, Ferster and Skinner (1957) concluded that the appearance of pauses depended on the mean size of the ratios as well as the proportion of the ratios composing the mixed schedule.

Related results have been reported in other mixed schedules in which the sequence of components was fixed, rather than random. For example, Dews (1958) reported priming in the FI component of a *mix* FR 50 FI 15-min schedule. Very short pauses preceded both the FR and FI components. Similarly, in a schedule composed of fixed numbers of FR 24s followed by a 10-min extinction period, *i.e.*, *mix* FR 24 EXT 10 min, Weissman (1960) found short pauses between the FR 24s. During each extinction period the animals gave several priming runs before ceasing to respond. In a progressive ratio (*mix* FR 32 FR 132 FR 528) Findley (1962) reported that the length of pause preceding each ratio was proportional to the size of the ratio. However, he did not present data on priming. According to Keehn (1965), rats on a *mix* FR 15 FR 45 FR 15 FR 135 paused longest before the FR 135; the other pre-ratio pauses were about the same length. Also, priming was not mentioned in this study. In a mixed fixed-ratio schedule composed of only two components that simply alternated, Crossman (1971) found that primes were largely absent and the pre-ratio pause lengths were proportional to the size of the following ratios for a wide range of FR values.

A description of priming in mixed schedules has been limited to qualitative statements based on the inspection of cumulative records. With the exception of the studies by Keehn (1965) and Crossman (1971), the same may be

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said for pausing. The purpose of the present study was to give quantitative expression to these two variables as a function of parametrically manipulating the proportion of components in a mixed schedule. A relatively simple mixed schedule with only two components, FR 100 and FR 10, was chosen. The number of FR 100s that preceded a single FR 10 was varied according to several ascending and descending series.

METHOD

Subjects

Two male White Carneau pigeons, with experimental histories of exposure to FR schedules, served.

Apparatus

The scheduling of events in a standard operant conditioning pigeon chamber was accomplished by electromechanical systems. A cumulative recorder, counters, and running-time meters recorded the behavioral events throughout each experimental session. Also, a PDP-5 computer (Digital Equipment Corporation) recorded and analyzed the data.

Procedure

Because both birds were experienced in performing under ratio schedules, they were immediately placed on an FR 100 schedule of food reinforcement. Reinforcement was 3-sec access to Purina Pigeon Chow at the completion of each ratio. Throughout the ratio, the key was illuminated by a white vertical line. During the reinforcement cycle, the key was dark and a white light illuminated the food hopper. An experimental session, which lasted 110 min, was scheduled each day, five days a week. Supplemental food was provided in the home cage only on weekends. During the week, the birds could obtain food only by completing the schedules during the session. In effect, the birds were on 22 hr food deprivation at the beginning of each session.

After 10 sessions on the FR 100, the schedule was changed so that an FR 10 schedule followed the completion of every 99 FR 100 schedules, *i.e.*, a proportion of 99:1. The same key stimulus, a white vertical line, was present during both the FR 100 and FR 10 components. Thus, the basic schedule employed throughout the experiment was a mixed

schedule consisting of a fixed number of FR 100 components followed by a single FR 10 component. Both birds were exposed to a descending series of proportions, an ascending series, and finally a descending series. In addition, Bird MXL-2 was given a second ascending series. The actual proportions for MXL-1 were: Series 1—infinity (no FR 10 components), 99:1, 49:1, 32:1, 19:1, 15:1, 13:1, 11:1, 9:1, 7:1, 5:1, 4:1, 3:1, 2:1, and 1:1; Series 2—15:1, 20:1, 30:1, 40:1, 50:1, 60:1, 70:1, and 80:1; Series 3—70:1, 60:1, 50:1, 40:1, 30:1, 20:1, 15:1, 13:1, 11:1, and 9:1. For MXL-2, the proportions were: Series 1—infinity (no FR 10 components) 99:1, 49:1, 32:1, 19:1, 15:1, 13:1, 11:1, 9:1, 7:1, 5:1, 4:1, 3:1, 2:1, and 1:1; Series 2—15:1, 20:1, and 30:1; Series 3—20:1, 15:1, 13:1, and 11:1; Series 4—13:1, 15:1, 20:1, 30:1, 40:1, and 50:1.

Within a particular series, the change from one proportion to the next occurred when the median postreinforcement pause, the time from the end of the reinforcement cycle on the FR 100 or FR 10 component until the subsequent response on either the FR 100 or FR 10 component, showed no consistent trend for five consecutive sessions. In almost every case this stability criterion was achieved by the tenth session. The change from one series to the next also was determined by the length of the post-reinforcement pause. When this pause reached a minimum of about 2 to 3 sec in the descending series and showed no signs of further change, the ascending series was begun. In the ascending series, when the post-reinforcement pause became large (about 17 to 20 sec), a descending series was initiated.

RESULTS

The principal dependent variables were changes in the length of the postreinforcement pause and in the number of primes that occurred in the FR 100 component as well as their locations within the various sequences of FR 100 components.

Table 1 shows the median postreinforcement pause in seconds taken from the last five-session medians and the range of these medians. Note that 34.12 sec was the maximum possible value due to computer limitations during the first four proportions in Series 1. This was later expanded to measure pauses of several hours duration should they occur. In

Table 1

Data for last five sessions at each proportion of FR 100s: FR 10s for Birds MXL-1 and MXL-2.

<i>Schedule</i>	<i>Median Postrein- forcement Pause</i>	<i>Range of Median Postrein- forcement Pauses</i>	<i>Number of Rein- forcers</i>	<i>Mean Body- weight</i>	<i>Schedule</i>	<i>Median Postrein- forcement Pause</i>	<i>Range of Median Postrein- forcement Pauses</i>	<i>Number of Rein- forcers</i>	<i>Mean Body- weight</i>
BIRD MXL-1					BIRD MXL-2				
Series 1					Series 1				
∞	23.62	6.38- 34.12	366	482	∞	31.57	15.67- 34.12	345	536
99:1	25.13	23.63- 34.12	368	498	99:1	34.12	34.12- 34.12	291	544
49:1	23.27	19.00- 34.12	355	513	49:1	34.12	34.12- 34.12	311	546
32:1	29.52	22.23- 34.12	255	519	32:1	34.12	34.12- 34.12	392	543
19:1	20.58	16.40- 28.85	388	512	19:1	22.88	17.45- 33.58	420	540
15:1	11.55	10.95- 14.77	430	525	15:1	25.95	10.55- 29.60	427	543
13:1	10.65	10.18- 11.63	495	522	13:1	22.77	14.15- 28.40	387	539
11:1	9.90	7.23- 12.67	446	520	11:1	16.13	9.30- 22.40	435	538
9:1	7.05	6.72- 9.62	453	534	9:1	4.47	3.47- 6.38	438	543
7:1	1.73	1.62- 3.52	430	530	7:1	1.82	1.48- 2.65	430	542
5:1	1.24	1.18- 1.47	422	527	5:1	1.33	1.22- 1.37	405	539
4:1	1.11	.95- 1.08	475	546	4:1	1.12	1.07- 1.22	397	550
3:1	1.28	1.17- 1.68	480	546	3:1	1.17	1.13- 1.28	400	543
2:1	1.22	1.18- 1.59	441	544	2:1	1.12	1.09- 1.33	405	536
1:1	1.07	1.06- 1.07	476	550	1:1	.95	.93- 1.03	348	536
Series 2					Series 2				
15:1	1.65	1.33- 1.87	346	536	15:1	1.28	1.22- 1.47	278	521
20:1	3.16	2.48- 4.68	366	522	20:1	1.22	1.12- 1.46	210	506
30:1	9.98	4.62- 11.77	314	534	30:1	51.77	3.38- 64.57	263	513
40:1	6.88	5.56- 11.03	328	537	Series 3				
50:1	7.81	5.82- 11.02	271	542	20:1	43.18	33.75- 56.88	350	515
60:1	8.95	5.80- 13.00	297	541	15:1	1.62	1.57- 6.67	391	534
70:1	15.52	12.80- 20.23	297	540	13:1	1.27	1.16- 1.25	325	523
80:1	18.43	14.43- 23.76	311	521	11:1	1.11	1.05- 1.32	316	515
Series 3					Series 4				
70:1	23.75	20.28- 40.28	316	520	13:1	1.15	1.07- 1.35	376	526
60:1	29.34	26.88- 44.52	311	525	15:1	1.44	1.17- 1.34	420	518
50:1	26.42	22.26- 33.22	346	528	20:1	1.21	1.19- 1.35	326	527
40:1	28.93	8.23- 30.69	299	534	30:1	1.27	1.19- 1.35	334	521
30:1	7.05	6.50- 16.60	351	531	40:1	1.65	1.50- 1.98	271	523
20:1	7.41	5.12- 10.10	355	530	50:1	49.83	2.32- 71.60	325	518
15:1	3.89	3.52- 4.28	338	528	60:1	73.08	62.43-107.98	283	522
13:1	3.54	2.33- 12.16	307	518					
11:1	2.43	2.19- 2.93	404	536					
9:1	2.95	2.15- 3.14	425	524					

general, it can be seen that as the proportion of FR 100s:FR 10s decreased, the post-reinforcement pause shortened and its variability decreased. Based upon non-overlapping ranges, there are three distinct groupings for MXL-1 in all three series. For example, in Series 1, the first group of postreinforcement pauses extends from 99:1 to 19:1, the second group from 15:1 to 9:1, and the third group from 7:1 to 1:1. Although the ranges show slight overlap in some cases, these pauses can also be placed into three categories for Series 2 and 3. It is also interesting to note that in Series 2, an ascending series, the postreinforcement pause increased at a later point in the series than it

had decreased during Series 1, or Series 3, both descending series.

Changes in the postreinforcement pause for MXL-2 as shown in Table 1 are similar to those for MXL-1. There are three distinct groups of pauses in Series 1. In Series 2, 3, and 4, however, only two categories of pauses are evident. For example, in Series 2 a sudden increase in postreinforcement pause length occurs when the proportion is changed from 20:1 to 30:1.

Besides the pause information, Table 1 also contains data on the total number of reinforcers taken during the last five sessions and the mean body weight for this same period of

time. While there is some tendency for the number of reinforcers to increase as the relative frequency of FR 10s increases, the effect is not consistent and there are numerous reversals. Fluctuations in body weight also appear to be somewhat correlated with the changes in proportions, but there are significant reversals and inconsistencies within, as well as between, birds over the 18-month period in which the experiment was conducted.

For the last five sessions at each proportion, the range and mean percentage of FR 100s that contained primes (herein defined as a run of 10 to 20 responses followed by a pause of at least 9 sec at the beginning of an FR 100) are shown in Figure 1. Because there was very few

primes at 99:1 or infinity (no FR 10s), Figure 1 does not extend to these proportions. To permit easier inspection, the points of 15:1 and 20:1 for MXL-2 in Series 4 have been displaced to the right of their true position.

The top portion of Figure 1 shows that in the first descending series, the number of primes increases between about 20:1 and 4:1 and then decreases down to 1:1. A similar picture obtains from the second descending series, Series 3, although this series stopped at 9:1 (MXL-1) or 10:1 (MXL-2) since the post-reinforcement pause on which the stability criterion was based, appeared to have reached asymptote in this region. It is also interesting to note in Series 3 that the rise in primes

Fig. 1. Mean percentage and range of percentage of FR 100s over last five sessions that contained primes as a function of the proportion of FR 100s:FR 10s for Birds MXL-1 and MXL-2. Top shows series in which the proportion of FR 100s:FR 10s was decreased: bottom contains data from the ascending series. Numbers above the arrows indicate the order in which the data were actually obtained. See text for further explanation.

appears to occur slightly earlier than in Series 1.

The bottom portion of Figure 1 shows the ascending series for both birds. As in the case of the Series 3 curves, the beginning points in each of the bottom curves represent the last proportions from the preceding series. These points are simply included to preserve continuity between series. Essentially, the curves for the ascending series reveal a relationship

similar to that in the top curves; *i.e.*, as the proportion of FR 100s:FR 10s increases, the number of primes first increases and then decreases. Note, however, that compared to the descending series, it was necessary to go to higher proportions in order to reduce priming substantially.

The cumulative records in Figure 2 illustrate the absence as well as presence of priming. At 19:1 (top), there are virtually no in-

MXL-1 19:1

MXL-1 4:1

Fig. 2. Cumulative records of last sessions for MXL-1 at proportion of 19 FR 100s:1 FR 10 (top) and 4 FR 100s: 1 FR 10 (bottom). Pen resets to baseline at beginning of reinforcement cycle. See text for further explanation.

stances of primes according to the definition used in this paper. At 4:1 (bottom) however, a considerable number of primes can be seen below the closed circles. The present definition of a prime encompassed most of the behavior which, by visual inspection, looked like a prime. Nevertheless, there were a few exceptions where the number of responses in the initial run was slightly greater than 20 (*e.g.*, letter a) or where the pause following the run was a little shorter than 9 sec (*e.g.*, letter b).

The bottom record in Figure 2 suggests that primes seldom occurred in the first FR 100 after an FR 10. Furthermore, within a sequence of FR 100s, those containing primes appear to be distributed more or less at random. This relationship was confirmed by subsequent analysis, which revealed that when the proportion of FR 100s:FR 10s was less than 7:1 for MXL-2 and 5:1 for MXL-1, the number of primes in the first FR 100 following an FR 10 was considerably lower than in any of the other FR 100s in the sequence. However, no other relationship between FR 100s containing a prime and their location within the sequence was discovered.

Finally, the bottom record in Figure 2 suggests that the length of pause preceding an FR 100 component (excepting the post-FR 10 pause) bore no relation to whether or not that component contained a prime. Further analysis at other proportions supported this observation. Also, it is apparent in Figure 2 that the mean length of pause following the FR 10 was greater at 4:1 than at 19:1. While the mean post-FR 10 pause length was found to be inversely related to the proportions in Series 1, this relationship was not replicated in the subsequent series. Also, at any proportion, the lengths of the other postreinforcement pauses did not consistently change as a function of their position in the sequence of pauses preceding the FR 10.

DISCUSSION

The present results indicate that behavior on a mixed schedule is sensitive to changes in the proportional mixture of component schedules, in this case the number of FR 100 components that precede a single FR 10 component. Ferster and Skinner (1957) provided a general, qualitative account of performance on mixed fixed-ratio schedules. They pointed out

that the postreinforcement pause in each FR component tended to be short and that primes occurred in many of the larger FR components. Furthermore, they indicated that as the proportion of large FR components to small FR components increased, the duration of the postreinforcement pauses appeared to increase and the frequency of primes decreased. But these effects were only qualitatively described and, unlike the present schedule, the schedule used by Ferster and Skinner consisted of a number of large FR components randomly alternated with a number of small FR components. Nevertheless, the present findings are consistent with those of Ferster and Skinner. As the proportion of FR 100s:FR 10s decreased, the postreinforcement pause decreased and the percentage of FR 100s that contained a prime increased.

When the proportion was reduced to about 4:1, however, primes began to decrease and practically vanished at 1:1. The explanation for this decrease hinges upon the fact that at these low proportions, primes occurred infrequently in the first FR 100 following an FR 10. By reducing the proportion of FR 100s:FR 10s, the frequency of those FR 100s that immediately followed an FR 10 increased. In spite of the fact that between 4:1 and 1:1, the percentage of primes actually increased in the other FR 100s in the sequence, the low incidence of primes in the first FR 100 outweighed these increases, and produced a decrease in the overall percentage of primes.

It might be expected that primes would appear in greater quantity during the latter part of a particular sequence of FR 100s as the FR 10 was approached than during the early part of a sequence. However, such sequential effects were not discovered, aside from the observation that, at the low proportions, priming was reduced in the first FR 100 of the sequence. The low frequency of primes in this FR 100 suggests that the birds were able to discriminate the fact that this component was FR 100 rather than FR 10. Had a random sequence been scheduled in which FR 10s occasionally followed one another, there would have undoubtedly been primes in the FR 100 immediately after an FR 10 (*cf.* Ferster and Skinner, 1957). Other studies support the notion that animals can discriminate certain components of mixed fixed-ratio schedules in which the number of different components is

small and the sequence is fixed rather than random (Keehn, 1965; Crossman, 1971). In addition, the present study points out that even though the number of different components in the fixed sequence may be small, the length of the sequence can destroy such discriminations. When the number of FR 100s preceding an FR 10 was greater than about five for one bird and seven for the other bird, the percentage of primes in the first FR 100 of the sequence was not reliably different from the remaining FR 100s.

A close inverse relation was discovered between the post-reinforcement pause and priming. As the proportion of FR 100s:FR 10s decreased, priming increased and the post-reinforcement pause diminished in length. The converse was also true; a decrease in priming accompanied an increase in the post-reinforcement pause during the ascending series. Whether changes in the post-reinforcement pause were a function of the changes in priming or changes in the proportion of FR 100s:FR 10s is uncertain. The study would have to be repeated using a multiple schedule in which there would be no primes.

There is some basis, however, to support the idea that the changes in priming are a direct function of the different proportions. As a group of approximately 10 responses, the prime may be considered a unit of behavior susceptible to the processes of reinforcement and extinction, just as individual responses are. Such a view was suggested by Ferster and Skinner (1957, pp. 587-588). They reported that one bird that had primed on mix FR 60 FR 360, and then was placed on a simple FR 360, continued to show primes even after more

than 3 hr on the FR 360 in spite of the "... extinctions of the priming break". In the present study, increasing the proportion of FR 100s:FR 10s was somewhat analogous to this extinction procedure described by Ferster and Skinner, since runs of 10 responses at the beginning of the ratios would produce fewer and fewer reinforcers. The data from the ascending series support this analogy because the proportions where primes substantially decrease are higher than the proportions where large increases in primes occur in the descending series. It follows that the increases in priming during the descending series depend upon the gradual increase with which runs of 10 responses at the beginning of the ratios are reinforced as the frequency of FR 10s is increased.

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