TEMPORAL PATTERNS OF RESPONDING IN SMALL FIXED-RATIO SCHEDULES

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Pigeons were exposed to an ascending series of small fixed-ratio schedules from fixed-ratio 1 to 7. Two of those pigeons were later placed on a fixed-ratio 30 schedule. The two primary dependent variables were the postreinforcement pause and the interresponse time. Changes in these variables under small fixed ratios were sometimes opposite to changes reported with large fixed ratios. For example, postreinforcement pauses decreased in length as the fixed-ratio requirement increased from fixed-ratio 1 to fixed-ratio 3. Also, the interresponse times early in the small fixed-ratio schedule were shorter than those immediately preceding reinforcement. These findings question the role of interresponse-time reinforcement in determining temporal patterns of responding under small fixed-ratio schedules. They also suggest that there may be a limited region in which the independent variable, fixed-ratio size, does not operate as previously described.

Key words: fixed-ratio, interresponse time, postreinforcement pause, interreinforcement interval, acquisition, interresponse-time reinforcement theory, key peck, pigeons

A fixed-ratio (FR) schedule of reinforcement involves the presentation of a reinforcing stimulus upon the completion of every n th response (Ferster & Skinner, 1957). The resulting performance pattern is typically described as a postreinforcement pause (PRP) immediately following reinforcement and a steady rate of responding, continuing until delivery of the next reinforcing stimulus (Felton & Lyon, 1966). Response rate following the PRP is commonly referred to as running rate and is often studied in terms of interresponse time (IRT)—that is, the time between two consecutive responses (Ferster & Skinner, 1957).

Several researchers have concluded that the variables that affect PRP duration are largely independent of those variables that affect IRT durations (Powell, 1969; Shull, 1979). The PRP duration depends on such variables as interreinforcement interval (IRI; Neuringer & Schneider, 1968), FR size (Felton & Lyon, 1966; Powell, 1968),

percentage reinforcement (Crossman, 1968), reinforcer magnitude (Inman & Cheney, 1974), and deprivation level (Sidman & Stebbins, 1954). Shull (1979) concluded that IRT durations are relatively insensitive to these variables and instead are correlated with factors such as the immediacy of reinforcement and the number of responses required. There is, however, controversy surrounding the issue of IRT and PRP independence. Immediacy of reinforcement following the last response has been shown to affect PRP duration as well as IRT duration (Meunier & Ryman, 1974; Topping, Johnson, & McGlynn, 1973). Crossman, Heaps, Nunes, and Alferink (1974) demonstrated that response requirement also affects the length of the PRP. Shull (1979) also stated that as PRPs lengthen, IRTs become shorter; yet Powell (1969) demonstrated that on FR schedules a slight decrease in running rate occurred as PRPs increased.

The data described in the preceding controversy have been generated by exposing animals (typically pigeons) to FR schedules with requirements greater than FR 10. Perhaps the discrepant data on FR response

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rates is, in part, a function of FR size. Large FRs generate complex IRT patterns, thereby creating multiple interactions between individual ITRs or groups of IRTs. For this reason, the present study focused on small FRs (less than FR 10). It was hoped that by analyzing small FRs, and small increases in FR size, the relationship between IRTs and PRPs might be better understood.

Another reason for examining the temporal properties of performance on small FR schedules is that there is some evidence of differences between large and small FR schedules. For example, Gott and Weiss (1972) and Mazur (1983) have reported that in large FR schedules ($> \text{FR } 19$), the IRTs at the beginning of the ratio were longer than those that immediately preceded reinforcement. Kintsch (1965) reported a similar IRT pattern on a variable-ratio (VR) 15 schedule. In contrast, Davison (1969) found the reverse pattern with small FRs. He placed rats on an FR-6 schedule in which the delivery of each reinforcer was followed by a 5-s timeout. Davison observed that the IRTs were relatively shorter at the beginning of the ratio, but gradually increased throughout the ratio. By starting with the smallest FR schedule, FR 1, and gradually increasing the requirements of this schedule by the smallest increment possible, it was hoped that the resulting changes in the temporal properties of performance, and the relations between these properties, might be clarified.

METHOD

Subjects

Six experimentally naive, mixed-breed pigeons served. Sessions were conducted only when a bird's weight was within 15 g of 80% of its free-feeding weight. Supplementary feedings, when necessary, were provided no sooner than 20 min following the termination of an experimental session. Water was freely available in the home cage.

Apparatus

The experimental chamber (40.6 cm wide, 61 cm deep, and 53.3 cm high) contained

three (2.5 cm diameter) plastic keys spaced 5.1 cm apart and 25.4 cm above the floor. Only the left key was used, and it was trans-illuminated red. The length of the key throw (distance to actuate the microswitch) was 4.32 mm (Crossman & Serna, 1982), and the force required to close the microswitch was 0.5 N. The food hopper, located directly below the center key and 6.4 cm above the chamber floor, contained Purina Racing Checkers that were available for 3 s, during which time the hopper light was illuminated and the left key was darkened. The house-light remained on throughout the session. The chamber was enclosed within a sound-attenuated box that contained a fan for ventilation and for masking noises. Sessions were terminated in blackout after 30 hopper presentations.

A PET 2001 (Commodore Business Machines) microcomputer, a custom-engineered interface (Crossman, Stephenson, & Lynch, 1980), and electromechanical equipment controlled stimulus events and recorded times on tape for the occurrence of all stimulus events and responses, with a resolution of 1/60 s. These data were later transferred to a floppy disk for analysis. This equipment was housed in a room adjacent to the experimental chamber.

Procedure

Subjects were magazine trained and the key-peck response was hand shaped during a training phase that varied between one and three sessions. The pigeons were then exposed to a series of FR schedules with requirements less than 10. Pigeons B201 and B302 then received training on FR 30. Four subjects (B302, B303, B304, B305) initially were trained on FR 1, and two subjects (B200 and B201) began training on FR 2. The sequence of experimental conditions and number of sessions at each condition for each subject are shown in Table 1.

Sessions were conducted 6 days a week within an hour of the same time each day. The stability criteria were as follows: Each condition was in effect for a minimum of 10 sessions and was terminated when (1) there

Table 1

Order of conditions (from left to right) for each subject. Number of sessions at each condition is shown in parentheses to the right of the respective condition.

Birds	Condition							
	1	2	3	4	5	6	7	8
B200	FR2(36)	FR3(17)	FR4(16)	FR5(12)	FR6(13)	FR7(13)		
B201	FR2(38)	FR3(17)	FR4(15)	FR5(14)	FR6(16)	FR7(16)	FR30(10)	
B302	FR1(26)	FR2(15)	FR3(12)	FR4(14)	FR5(10)	FR6(14)	FR7(10)	FR30(19)
B303	FR1(29)	FR2(22)	FR3(10)	FR4(15)	FR5(10)	FR6(21)	FR7(17)	
B304	FR1(19)	FR2(12)	FR3(10)	FR4(18)	FR5(18)	FR6(10)	FR7(17)	
B305	FR1(23)	FR2(12)	FR3(10)	FR4(11)	FR5(11)	FR6(10)	FR7(14)	

had been five consecutive sessions with no new high or low mean IRTs or PRPs for that condition, and (2) when there had been no increasing or decreasing trends in the mean IRTs or PRPs for five consecutive sessions. Conditions were terminated after a maximum of 20 sessions, except for Bird B303 under Conditions 2 and 6. Also, more than 20 sessions were conducted under the first condition to test the adequacy of stability criteria (see Bird B304 in Table 1 for an exception).

RESULTS

The data in all figures are from the last five sessions unless otherwise stated. Some figures (e.g., Figures 1 and 2) show session data in blocks of five trials or reinforcers. Thus, in those figures that show PRP data in blocks, the data in block one were based on four, instead of five, trials because the first PRP in the session was omitted from the calculations. In those instances where the differences in the data from individual birds were slight or nonexistent, such data are summarized as group means.

Acquisition

Figure 1 shows changes in the FR-1 PRP during Sessions 1, 5, 10, and the last session, which differed for each bird depending upon when it reached stability. By the fifth session, the absolute value of the PRP had decreased dramatically, but the PRPs for Block 1 remained higher than the PRPs in

the later blocks. Even by the 10th session, the first block of PRPs was higher than the other blocks, but during the last session there was no apparent difference between the first and remaining blocks. Another noteworthy feature is the absence of the declining PRP across the session that occurred in the first session but not thereafter.

The key pecking of Birds B200 and B201 was hand shaped and then their schedule was changed to FR 2. Figure 2 shows the course of acquisition under FR 2 for these

Fig. 1. Mean data from fixed ratio 1 (FR 1) for Birds B302, B303, B304, and B305, showing changes in mean postreinforcement pause (PRP) within and across selected sessions. Each point (one block) is the mean PRP for five successive reinforcers except for the first block, which is the mean PRP for four successive reinforcers because the first pause in the session was omitted.

Fig. 2. Mean data from fixed ratio 2 (FR 2) for Birds B200 and B201, showing changes in mean postreinforcement pause (PRP) within and across selected sessions. Each point (one block) is the mean PRP for five successive reinforcers except for the first block, which is the mean PRP for four successive reinforcers because the first pause in the session was omitted.

two subjects. Again, mean data, which are representative of individual subjects, are presented for Sessions 1, 5, 10, and the last session. In general, the same course of acquisition noted for FR 1 occurred with FR 2. The first block of PRPs was always higher than the remaining blocks in the session, and there was a gradual decrease in the absolute value of the mean PRP across sessions. One departure from the FR-1 curve occurred in the last session under FR 2, where the first block of PRPs was higher than the remaining blocks.

On FR 2, a single IRT occurs. Figure 3 shows changes in the length of this IRT during Sessions 1, 5, 10, and the last session on the schedule (note the greatly expanded ordinate in contrast to Figure 2) for Birds B200 and B201. These data, which are representative of the individual subjects, show that the IRTs during the first block (all sessions) and sometimes during the second block (Sessions 1, 5, and 10) were longer than the other blocks, resembling the PRP data in the previous figure. As with the PRPs, the mean IRT decreased with continued exposure to the schedule, and the primary reduction in IRT length occurred in the early part of the

Fig. 3. Mean data from fixed ratio 2 (FR 2) for Birds B200 and B201, showing changes in mean interresponse time (IRT) within and across sessions. Each point (one block) is the mean of all IRTs for five successive reinforcers.

session. However, unlike the PRPs (Figure 2), the decrease in IRTs was distributed more evenly across the blocks, except for the last session.

FR Requirement

This section examines changes in mean PRPs and IRTs as a function of FR size, calculated across the last five sessions on each FR value. Figure 4 shows changes in mean PRP for each bird. For three of the four

Fig. 4. Individual mean postreinforcement pause (PRP) data as a function of fixed-ratio (FR) requirement. Each value of r is the correlation between mean PRP and standard deviation. Data are means based upon the last five sessions.

birds exposed to FR 1, there was a relatively large decrease in PRP as the FR value increased from FR 1 to FR 2 (Birds B200 and B201 were not exposed to FR 1). Increasing from FR 2 to FR 3 decreased the PRP slightly for Birds B201, B302, B303, and B305; B304's PRP remained the same, and the PRPs of B200 increased. Changing from FR 3 to FR 4 did not produce any consistent change in PRP, but when the FR was increased to FR 5, four of six birds showed an increase in PRP. This increase continued as the FR requirement was changed to FR 6 and FR 7 for these birds. Bird B200 did not show an increased PRP at these values, and B304's PRP increased only when the FR was changed from FR 6 to FR 7.

As a measure of variability, the standard deviation of the mean PRP was computed for each bird. As mean PRP increased, the variability of the mean also increased. To verify this observation, a Pearson Product-Moment Correlation Coefficient was calculated between the mean PRP and its standard deviation for each bird across FR size. The r values shown above the curve for each bird generally confirmed the positive correlation.

Changes in the mean IRT as a function of FR requirements are shown in Figure 5. The most striking aspect of these data is the drop in the mean IRT observed for all birds when FR size was increased from FR 2 to FR 3. Above FR 3 the changes in mean IRT are difficult to characterize simply. The IRTs of some birds increased, others decreased, and B201 revealed a cyclical pattern in mean IRT. Again, a strong positive correlation between IRT size and variability, ranging from .44 (B200) to .92 (B302), was observed.

Figure 6 shows the amount of time in the IRI taken up by the PRP (bottom part of bar) and the amount of work time (top of bar)—that is, time from the first response to the onset of reinforcement. At FR 2 the PRP took up the largest proportion of the IRI. On FR 3 or FR 4, however, work time and PRP became approximately equal. Above FR 3 or FR 4, work time began to occupy an increasing proportion of the IRI, but this is not

Fig. 5. Individual mean interresponse time (IRT) data as a function of fixed-ratio (FR) requirement. Each value of r is the correlation between mean IRT and standard deviation. Data are means based upon the last five sessions on each condition.

unexpected because more responses are required. Figure 6 also reveals relations described earlier—namely, the PRP decreased from FR 1 to FR 2, and the mean IRT dropped as the FR was increased from

Fig. 6. Individual mean data, showing amount of interreinforcement interval (IRI) occupied by postreinforcement pause (PRP) in the bottom (filled) bars and work time in the top (unfilled) bars as a function of fixed-ratio (FR) requirement. Data are means based upon the last five sessions.

Fig. 7. Individual relative-frequency distributions of mean postreinforcement pauses (PRPs) for the last five sessions under each fixed ratio (FR). Bin size is 0.125 s except for the first bin, which is 0 to 0.375 s, and the last bin, which contains all PRPs greater than 2.63 s.

FR 2 to FR 3. The height of the top part of the bar at FR 3 is not twice the height of the top part of the bar at FR 2, even though there were twice as many IRTs at FR 3.

In Figure 7, the relative frequencies of PRPs are shown for each bird as a function of FR size. The bin size is 0.125 s, except for the first bin, which ranges from 0 to 0.375 s, and the last bin, which represents the percentage of all PRPs > 2.63. Technically, it is improper to connect the points that represent the height of each bin because these data are not continuously related; a bar graph would have been more appropriate. However, it was judged easier to make visual comparisons from graph to graph with a point-to-point line graph.

Most graphs in Figure 7 are unimodal with an occasional instance of a secondary mode (e.g., see B200 at FR 2 and B302 at FR 1). The percentage of PRPs greater than 2.63 s was low at almost all FR sizes. Com-

pared to the distributions at other FR sizes, the distributions at FR 1 tend to be flatter (i.e., more variable). Increasing from FR 1 to FR 2 decreased the mean PRP (B302, B303, B304, B305) and the variability of the PRPs was reduced somewhat as indicated by the increased number of PRPs in the modal bin. Distributions with fairly pronounced modes also occurred at FR 3 and FR 4. As FR requirement increased above FR 4, this mode was reduced, indicating greater variability in the PRP. In many cases, the mode of the distribution changed in the same direction as did the mean PRP, but other parts of the distribution also shifted in concert with the mode. Variability and mean PRP tended to be positively correlated, but there were some exceptions (cf. FR 2 to FR 3 for B303).

The IRT relative-frequency distributions for each bird for FR 2 through FR 7 are shown in Figure 8. The bin size is 0.05 s

Fig. 8. Individual relative-frequency distributions of mean interresponse times for the last five sessions under each fixed ratio (FR). Bin size is 0.05 s except for the 20th bin, which contains all postreinforcement pauses greater than 0.95 s.

except for the last bin, which represents all IRTs > 0.95 s. The IRT distributions were stable with a pronounced peak that remained in either of two bins (for an individual bird) throughout changes in FR size. The modal frequency was in Bins 6, 7, or 8 (IRTs of 0.25 to 0.30, 0.30 to 0.35, and 0.35 to 0.40 s) for different birds. Overall, the shape of the distribution was unimodal, but occasional, less pronounced secondary modes can also be seen (see FR 5 for B302 or FR 5 for B304). Secondary modes were typically located between Bins 10 and 15 (IRTs of 0.5 to 0.75 s). Although the pattern differed somewhat between birds, for each bird the location of both primary and secondary modes remained relatively constant regardless of FR size. Finally, a comparison of the graphs for FR 2 and FR 3 suggests that variability was greater for FR 2; the standard deviation (across birds) at FR 2 was 0.28, but at FR 3 the standard deviation had decreased to 0.17.

In Figure 9 the distributions of reinforced

IRTs (the last IRT in each FR) were compared with the distributions of nonreinforced IRTs (all IRTs except the last one). There was considerable overlap between the two distributions, although the peaks of reinforced IRT distributions (broken lines) tended to occur to the right of the peaks of the nonreinforced IRTs (solid lines) in those nonoverlapping cases. Thus the median reinforced IRT was longer than the median nonreinforced IRT in 70% of the cases. In 20% of the cases, medians of the reinforced and nonreinforced IRTs were equal, and in only 10% of the cases was the median reinforced IRT shorter than the median nonreinforced IRT.

Figure 10 shows mean IRT durations as a function of their position within the FR. Position 1 refers to the first IRT in a particular FR, Position 2 refers to the second IRT, etc. At the smaller FRs, the IRTs that occurred early in the FR were shorter than the IRTs in the latter part of the FR. At FR 3, for example, the first IRT was shorter

Fig. 9. Relative-frequency distributions for reinforced (broken lines) and nonreinforced (solid lines) inter-response times (IRTs) for each subject. Bin size is 0.05 s except for the 20th bin, which contains all IRTs greater than 0.95 s. Data are means based upon the last five sessions.

than the second (reinforced) IRT for all birds except B304. This observation corresponds to the data in Figure 9, which showed that the median reinforced IRT was usually longer than the median nonreinforced IRT. As FR size was increased, this pattern of short-long IRTs was maintained in some birds (B200 and B302), even up to FR 7. However, in other birds, the early IRTs either became the same length as later IRTs, or in the case of B305 at FR 4 to FR 7 and in the case of B303 at FR 6, the early IRTs actually became longer than the IRTs that occurred later in the ratio. This tendency to show a reversed pattern with increases in FR size suggested the examination of the IRT pattern under a larger FR—hence the expo-

sure to FR 30 for two of the birds. As is apparent in the data for B201 and B302, the first two IRTs in FR 30 were much longer than the two IRTs that immediately preceded reinforcement. It should be noted that in the case of FR 3 to FR 7, the absolute differences between the IRTs are small, ranging from 0 to 0.3 s, whereas at FR 30, the differences between long and short IRTs range from 0.45 to 1.45 s.

Figures 11 and 12 display two kinds of temporal sequential dependencies at the various FRs. The basic question is this: Given that an IRT (or PRP) of a certain length has just occurred, is the length of the immediately subsequent IRT (or PRP) likely to be affected? This is an autocorrelation

Fig. 10. Individual data showing interresponse times (IRTs) at each position in the fixed ratio (FR). First position refers to the IRT between the first and second response; second position refers to the IRT between the second and third response, etc. Only IRTs for the first and last two positions under FR 30 are shown. Note the different ordinate values for FR 30. Data are means based upon the last five sessions.

with a lag of one. In the present experiment, only sequential dependencies of adjacent pairs of PRPs and IRTs were examined because it was anticipated that the strongest effect, if there were one, would occur with events that were closest together in time.

Figure 11 shows group data for PRP sequential dependencies at FR 1 to FR 7 for the last five sessions at each FR. At FR 1 the data do not include Birds B200 or B201, which were not exposed to FR 1. These data

were calculated in the following manner. For each session a relative frequency distribution of PRPs was first calculated for each bird. This distribution was then divided into three equal parts, designated as short, medium, or long PRP lengths. For example, in a particular session it might be the case that the short category would encompass those PRPs which were 0 to 0.99 s in length. The medium category could extend from 1.0 to 2.49 s, and the long category would extend

Fig. 11. Mean data showing the relative frequencies of sequential dependencies in postreinforcement pauses (PRPs) as a function of fixed-ratio (FR) requirement. Abbreviations S, M, and L refer to short, medium, and long PRPs, respectively. Thus, for example, S-S refers to one short PRP followed by another short PRP, etc. Data from FR 1 are means obtained from Birds B302, B303, B304, and B305. Data from FR 2 through FR 7 are means obtained from Birds B200, B201, B302, B303, B304, and B305. All data are means based upon the last five sessions.

from 2.50 to 6.00 s, assuming that one third of the total PRPs were in each category. After these categories had been established for a particular session, each of 29 PRPs in that session was labeled as either a short, medium, or long PRP. Finally, comparisons were made between the first and second PRP, the second and third PRP, etc., with each pair classified as S-S, S-M, S-L, M-S, M-M, M-L, L-S, L-M, or L-L. A pair of PRPs classified as S-S indicates a short PRP

followed by another short PRP; S-M indicates a short PRP followed by a medium PRP, etc. After relative frequencies were calculated for each category for a particular bird, means of these frequencies across birds were calculated yielding the group data shown in Figure 11.

In Figure 11 the most frequent category was S-S, except at FR 3 and FR 4. In other words, between 15% and 17% of successive pairs of PRPs consisted of a short PRP

Fig. 12. Mean data showing relative frequencies of various types of sequential dependencies in inter-response times (IRTs) as a function of fixed-ratio (FR) requirement for Birds B200, B201, B302, B303, B304, and B305. Abbreviations S, M, and L refer to short, medium, and long, respectively. Thus, for example, S-S refers to one short IRT followed by another short IRT, etc. Data are means based upon the last five sessions.

followed by another short PRP. At FR 3 and FR 4, the S-S category contained 14.5% of the PRP pairs, but there were other categories with similar representation. Across all FRs the category with the least representation was the S-L category. Apparently, once a short PRP was emitted, it was seldom followed by a long PRP. The final feature of these data is that the L-L category, which encompassed only a few cases at FR 1, gradually increased in representation as FR size increased.

The same type of analysis described for PRP sequential dependencies was performed on adjacent pairs of IRTs within the FR for FR 3 to FR 7. Figure 12 shows the results of these comparisons. These data are group means calculated in the same way as the data shown in Figure 11. These distributions resemble the PRP distributions seen in the previous figure in that the most frequent type of dependency was one short IRT immediately followed by another short IRT. At FR 3, however, the M-S category had slightly more cases than the S-S category.

The least frequent category, at least for FR 2 to FR 5, was L-S. If a long IRT had just occurred, it was followed by another long IRT more frequently than by a medium or short IRT. As FR size increased, the percentages of each category of dependencies tended to equalize, except for the S-S category, which clearly exceeded the others.

Session Variables

Figures 13 and 14 depict changes in mean PRP and IRT lengths across successive blocks of 5 reinforcers within individual sessions. In Figure 13 group mean PRPs are shown for all birds, except at FR 1 to which Birds B200 and B201 were not exposed. Data are also shown for the two birds (B201 and B302) that were exposed to FR 30. At FR 1 there was a slight tendency for the PRPs to increase in length toward the end of the session (see Blocks 5 and 6). However, at FR 2 through FR 7 the PRPs in the first block were the longest; that is, at the beginning of the session the birds tended to show a warmup effect in that the initiation of responding on the FR schedule was delayed more than was the case during other parts of the session. There was also a noticeable, but not as pronounced, tendency for the PRP to increase toward the end of the session, although the duration of these PRPs was less than those at the first of the session. The pattern at FR 30 was distinctly different in that there was a shift toward longer PRPs in the latter part of the session, but the PRPs at the beginning of the session were extremely short.

The same type of analysis for IRT changes within the session is shown in Figure 14. Again the data are group data based upon the means for the last five sessions at each FR. The mean IRT in the first block of five FRs was the longest in every instance, except for FR 3, where the mean IRTs for the first and second blocks were equal. In other words, in small FRs the birds took longer to complete the FR in the first part of the session. It is possible that this was a warmup effect that paralleled the long PRPs that occurred at the same point in the session (see Figure 13). An opposite pattern

Fig. 13. Mean data showing changes in length of the postreinforcement pauses (PRPs) across the session. Data from fixed ratio 1 (FR 1) are from Birds B302, B303, B304, and B305. Data from FR 2 through FR 7 are from Birds B200, B201, B302, B303, B304, and B305. Data from FR 30 are from Birds B201 and B302. Block one is the mean of the second through fifth PRPs in the session (the first pause was omitted). The other blocks are means of five successive PRPs. All data are means based upon the last five sessions.

occurred at FR 30 with Birds B201 and B302; that is, the mean IRTs at the end of the session were longer than at any other point in the session. This finding is consistent with the shift to longer PRPs at later parts of the session under FR 30; the longest PRPs occurred in the middle of the session, whereas the longest IRTs occurred at the end of the session.

DISCUSSION

Comparisons Between Small and Large Ratios

In any attempt to understand ratio performance, the task is considerably easier if the characteristics of performance are similar throughout the entire range of the independent variable (i.e., the fixed-ratio requirement). Nevertheless, the present experiment showed that performance under small fixed-

Fig. 14. Mean data showing changes in length of interresponse times (IRTs) across the session from various fixed-ratio (FR) schedules. Data from FR 2 through FR 7 are from Birds B200, B201, B302, B303, B304, and B305. Data from FR 30 are from Birds B201 and B302. Block one is the mean of the IRTs from the first five ratios; Block six is the mean of the IRTs from the last five ratios in the session. All data are means based upon the last five sessions.

ratio schedules differed in several significant ways from performance recorded at higher ratio values. For example, when the FR requirement was increased from FR 1 to FR 2 to FR 3, the PRP decreased, whereas the opposite relationship has been reported for large FR schedules (Felton & Lyon, 1966; Powell, 1968). Mazur's (1982) model of ratio performance predicts that PRPs should increase with FR size, but the decreases in PRPs between FR 1 and FR 3 do not support that model. Eventually, with increasing

FR requirements, the PRP increased, usually at FR 6 or FR 7; this is consonant with Mazur's model.

In large FRs, with increasing FR requirements, response rates typically decrease or stay the same (cf. Mazur & Hyslop, 1982). However, in the present study, when FR 2 was changed to FR 3, response rate increased (mean IRTs decreased) for all subjects. Increasing the FR requirement above FR 3 did not produce a consistent change in the mean IRT,

a finding that parallels the IRT data obtained with large FR schedules.

Another departure from data previously reported for large FR schedules was the IRT pattern emitted. Within small FR schedules, birds emitted a relatively short IRT at the beginning of the ratio and a long IRT just before reinforcement. Davison (1969) reported a similar finding with rats at FR 6. Previous reports have indicated that the first few IRTs in a large FR (Gott & Weiss, 1972; Mazur, 1983) or VR (Kintsch, 1965) are longer than subsequent IRTs. In the present experiment, data from the two birds on FR 30 confirmed this pattern. As the FR increased from FR 1 to FR 7, the IRT lengths at all ordinal positions tended to equalize for some birds, and reversed for Bird B305. This suggests that the pattern of IRTs within a ratio may be on a continuum. Thus, as the FR requirement is increased, the short IRTs early in the ratio gradually increase and the long IRTs near the end of the ratio diminish. Additional research is required to clarify this point.

Finally, the changes in mean PRPs and IRTs across the session differed for large and small ratios. With small FRs, a warm-up effect occurred (Ferster & Skinner, 1957). Early in the session (the first block), the mean IRTs and PRPs were relatively long, but decreased as the session progressed. In contrast, with FR 30 the opposite pattern was observed. The IRT differences could be a sampling artifact—there are many more IRTs in each block of five trials with FR 30 than with a small FR—but this would not account for the PRP differences. Another possibility is that with small FRs, food delivery frequently interrupts responding. The early formation of a nonrhythmic pecking pattern could temporarily lengthen both IRTs and PRPs.

Clearly, additional research is needed to determine the factors responsible for the differences between large and small FR performance. At this point it appears that FR performance as a function of FR requirement cannot be characterized as a simple, monotonic relationship.

IRT Reinforcement

Even though an FR schedule does not specify that IRTs must be a certain length for reinforcement to occur, it is possible that some classes of IRTs are differentially reinforced. Skinner (1938) maintained that bursts of responses (short IRTs) were likely to be reinforced under the FR contingency. The IRT sequential-dependency data in the present experiment, which showed that pairs of short IRTs were relatively more frequent than pairs of other length IRTs, support Skinner's suggestion. However, although the overall shapes of the distributions of reinforced and nonreinforced IRTs were quite similar, for most birds the longer IRTs occurred closest to reinforcement, and the shortest IRTs were located at the start of the ratio. Thus the mean reinforced IRT was usually longer than the mean nonreinforced IRT. According to Morse (1966), Anger reported a similar finding with variable-interval (VI) schedules (i.e., that the IRT reinforcement mechanism may affect the "major trend" of the distribution of IRTs, but not necessarily the fine details).

In the present experiment the first opportunity for differential reinforcement of short IRTs occurred on FR 3. With FR 2, of course, IRTs of all lengths were reinforced. Changing to FR 3 decreased the mean IRT for all birds and the mean reinforced IRT became longer than the first (nonreinforced) IRT in the ratio. Because IRTs of all lengths could be reinforced under the FR 3 schedule, it should be the case that some birds would develop patterns other than the short-long pattern, but this did not happen. This is especially curious in light of Morse's (1966) comment that short IRTs are more susceptible to reinforcement than are long IRTs. Accordingly, although the close correspondence between the reinforced and nonreinforced IRT distributions suggests the influence of an IRT-reinforcement mechanism, the prevalence of the short-long pattern questions the role of IRT reinforcement in explaining performance under small FR schedules.

The observed short-long IRT pattern also

poses problems for Mazur's (1982) model, which predicts that the probability of a response should increase (the IRT should decrease) as the distance to reinforcement, in terms of the absolute number of responses, decreases. Davison (1969), who also reported a short-long IRT pattern on FR 6, suggested a possible explanation for such a pattern, based upon two observations: (1) control by response number is more accurate in short FRs than in large FRs (Mechner, 1958), and (2) rats on FR 3 schedules frequently approach the food tray before completing the ratio (Hurwitz, 1962). If the pigeons oriented to the food hopper more frequently as the end of the ratio approached, such behavior, which is incompatible with key pecking, could have lengthened the terminal IRTs. Such a pattern seems especially likely to emerge in pigeon experiments that usually present the food reinforcer on a limited-hold basis.

Relationship between PRPs and IRTs

Although mean PRP was more sensitive to the primary independent variable (FR requirement) than was mean IRT, in other ways changes in these temporal variables often showed close correspondence. For example, when the birds first were exposed to either FR 1 or FR 2, the negatively decelerated curves that showed the reductions in mean IRTs and PRPs across sessions were similar. Also, the relative-frequency distributions of PRPs and IRTs were similar in that both contained a primary mode with an occasional, reduced secondary mode. These two variables were also similar when sequential dependencies were examined; the most consistent feature of the distributions of these dependencies was that short IRTs tended to follow short IRTs and that short PRPs tended to follow short PRPs. In terms of session variables, early in the session both IRTs and PRPs tended to be relatively long under small FRs. Finally, examination of the PRP and IRT changes that take place in the interreinforcement interval (IRI) as a function of FR requirement showed that, at first, these two temporal variables were in-

versely related. Thus, from FR 1 through FR 3, the PRP decreased while the amount of time in the IRI occupied by the IRTs (work time) increased. At FR 4 or FR 5, for most birds, both PRP and work time began to increase, but work time occupied an increasingly larger proportion of the IRI. Neuringer and Schneider (1968) argued that the direct relation between PRP length and FR requirement is a function of the length of the IRI; events within the IRI, such as number of responses or IRTs played no role in determining PRP length. Crossman et al. (1974) demonstrated that an increase in number of responses required was one factor that controlled PRP length, although other variables, such as an increasing IRI, may also have been important. However, neither of those experiments can account for the changes in PRP that occurred between FR 1 and FR 3. Perhaps the small increases in FR requirement or the exclusively ascending series of FR requirements to which the birds were exposed was responsible for the decreasing PRP between FR 1 and FR 3, as well as other changes in the PRPs and IRTs noted in the present study. Additional research should include manipulation of these two variables, because it may be that a thorough understanding of how behavior develops under small FRs can offer important clues for behavioral patterns that have been reported with large FRs.

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