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STEADY-STATE PERFORMANCE ON FIXED-, MIXED-, AND RANDOM-RATIO SCHEDULES

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Three groups of rats pressed a lever for milk reinforcers on various simple reinforcement schedules (one schedule per condition). In Group M, each pair of conditions included a mixed-ratio schedule and a fixed-ratio schedule with equal average response:reinforcer ratios. On mixed-ratio schedules, reinforcement occurred with equal probability after a small or a large response requirement was met. In Group R, fixed-ratio and random-ratio schedules were compared in each pair of conditions. For all subjects in these two groups, the frequency distributions of interresponse times of less than one second were very similar on all ratio schedules, exhibiting a peak at about .2 seconds. For comparison, subjects in Group V responded on variable-interval schedules, and few interresponse times as short as .2 seconds were recorded. The results suggest that the rate of continuous responding is the same on all ratio schedules, and what varies among ratio schedules is the frequency, location, and duration of pauses. Preratio pauses were longer on fixed-ratio schedules than on mixed-ratio or random-ratio schedules, but there was more within-ratio pausing on mixed-ratio and random-ratio schedules. Across a single trial, the probability of an interruption in responding decreased on fixed-ratio schedules, was roughly constant on random-ratio schedules, and often increased and then decreased on mixed-ratio schedules. These response patterns provided partial support for Mazur's (1982) theory that the probability of instrumental responding is directly related to the probability of reinforcement and the proximity of reinforcement.

Key words: fixed-ratio, mixed-ratio, random-ratio, preratio pause, lever press, rats

As two of the four basic schedules of reinforcement, fixed-ratio (FR) and variable-ratio (VR) schedules have been used in countless experiments since they were first examined by Ferster and Skinner (1957). Nearly every introductory text on learning or on general psychology describes the typical patterns of behavior produced by these schedules. VR schedules are said to generate a rapid, steady pattern of responding. FR schedules are said to produce a pause after reinforcement—the postreinforcement pause or preratio pause (PRP)—followed by an abrupt transition to rapid, steady responding. Considering the number of studies that have involved FR and VR schedules, it is surprising that no study has made systematic, within-subject comparisons of performance on these two schedules. To my knowledge, the only direct comparison of performance on simple FR and VR schedules was made by Ferster and Skinner (1957). For a single pigeon, the size of a VR schedule was gradually increased to VR 360, and on this schedule the cumulative record showed fairly steady responding at a rate of about three responses per second. When the subject was switched to FR 360 for six sessions, the long pauses characteristic of a large FR began to emerge (a pattern sometimes called "ratio strain"), and as a result the average response rate was several times lower than on VR 360. The long pauses disappeared with a return to VR 360 and reappeared with a second presentation of FR 360. These results indicate that, at least with larger ratios, VR schedules can produce higher overall response rates than FR schedules of equal size.

A few subsequent studies made less direct comparisons of ratio schedules with fixed- and variable-response requirements. Fantino (1967) used a concurrent-chains procedure to measure pigeons' preferences between FR schedules and mixed-ratio (MR) schedules, in which two or

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more ratio sizes alternate in a random manner. In Fantino's choice situation, pigeons showed a preference for MR schedules over FR schedules with equal mean response:reinforcer ratios. For example, a MR schedule where 25 responses were required on half of the trials and 75 responses were required on the other half (MR 25,75) was preferred over FR 50. Similarly, Sherman and Thomas (1968) found a preference for VR schedules over FR schedules in a study employing a discrete-trials procedure. The results from these studies of preference are important theoretically, but neither study reported much information about performance on the FR, MR, or VR schedules after a choice was made.

Boren (1973) examined the performance of pigeons in a complex procedure involving second-order schedules and a matching-to-sample task. The "first-order schedule" in Boren's task was the completion of one correct matching-to-sample trial. Each correct trial served as a single response in a second-order FR or VR schedule, since subjects received food reinforcement only after completing either a fixed or variable number of correct trials. As ratio size was increased, many long pauses appeared in the FR schedules but not in the VR schedules. Subjects' local response rates and accuracy on the matching task were similar on the FR and VR schedules, and Boren concluded that the major difference in performance on these two schedules was the amount of time spent pausing.

Based on these studies, it seems reasonable to conclude that (1) VR or MR schedules are preferred over FR schedules of equal size, (2) long pauses occur on large FR schedules, especially near the beginning of a ratio, but long pauses are infrequent on VR schedules, and (3) as a result of the long pauses, overall response rates may be much lower on long FR schedules than on equally long VR schedules. Many other questions about performance on these schedules remain unanswered, however. What are the relative sizes of PRPs on FR, MR, and VR schedules? When are other pauses in responding most likely to occur? How do momentary response rates vary as a subject progresses through a ratio on the three types of schedules? How do the answers to all of these questions change as a function of ratio size?

The present research was conducted to answer these and other questions about steady-state performance on ratio schedules. For one group of rats, performance on FR and MR schedules was compared. For a second group, the comparison was between FR and random-ratio (RR) schedules. In a RR schedule, each response has an equal probability of reinforcement (e.g., on a RR-20 schedule, each response has a .05 probability of reinforcement). For a third group of rats, variable-interval (VI) schedules were used, so that performance differences between ratio and interval schedules could be examined.

METHOD

Subjects

Ten female Lashley rats, bred in the laboratory, were maintained at 80% of their free-feeding weights. Four subjects served in Group M, four in Group R, and two in Group V. The subjects were approximately six months old at the start of the experiment. One subject from Group M died early in the experiment, and the partial results from this animal are not presented.

Apparatus

The experimental chamber was 23 cm long, 21 cm wide, and 19 cm high. During reinforcement periods, a dipper presented .12 ml of milk to the subject in a square recess (5 by 5 cm) in the bottom center of the front wall. The milk was Carnation nonfat dry milk sweetened with sugar (20 g sugar per liter of milk). Two 2-W white lights mounted in the upper right portion of the front wall were lit whenever the dipper was available. Two 2-W white lights above the Plexiglas ceiling provided general illumination throughout a session except during reinforcement periods. A response lever (Gerbrands Corp.), 5 cm long and 1.2 cm thick, protruded 1.6 cm from the left portion of the front wall. The lever was located 9 cm above the floor of the chamber, 2 cm from the left wall, and required a downward force of approximately .15 N to operate. The chamber was enclosed in a sound-attenuating box which contained an air-blower for ventilation and a speaker producing continuous white noise to mask extraneous sounds. A PDP-8 computer in another room used a SUPERSKED program to control the stimuli and record responses.

Procedure

Groups M and R. Subjects were trained to drink milk from the dipper, and then were hand-shaped to press the lever for milk reinforcement. They then received about four weeks of sessions on a FR 10 schedule, under procedures identical to those used in the remainder of the experiment. After this pretraining phase, the experiment consisted of 12 conditions for both groups of subjects, as shown in Table 1. As can be seen, the average response:reinforcer ratio in a condition was either 10, 20, 30, or 40. In Group M, every pair of conditions consisted of a FR schedule and a MR schedule with the same average response:reinforcer ratio. The longer response requirement in all MR schedules was nine times larger than the small response requirement. In Group R, pairs of conditions consisted of equal-sized FR and RR schedules. The final four conditions of the experiment were replications of earlier conditions.

Sessions were usually run 7 days a week. Each session ended after 30 min or after 40 reinforcements, whichever came first. Each reinforcer consisted of 3 sec of access to the milk dipper. In the MR conditions, the short and long ratio requirements were selected at random, with the constraint that each ratio was presented 20 times if a session lasted for 40 reinforcers. In a RR condition, every response had a $1/n$ probability of reinforcement, where n is the nominal size of the ratio.

For each subject, a condition lasted for a minimum of 12 sessions and was terminated when three conditions were met: (1) The overall response rate for none of the last five sessions could be the highest or lowest daily response rate of that condition; (2) the average response rate across the last five sessions could not be the highest or lowest of the condition, compared to all other groups of five consecutive sessions; (3) the average response rate across the last five sessions could not differ from that of the previous five sessions by more than five responses/min or by more than 10% (whichever of these two values was larger).

The number of sessions in each condition is presented in the appendix. Every interresponse time (IRT, the time between two responses or between reinforcer termination and the subsequent response) was recorded to the nearest .01 sec, but because of storage limitations, these large data files were saved for only the last five sessions of each condition.

Group V. Two subjects, V1 and V2, were trained to press the lever as in the other groups. These subjects received no experience with ratio schedules; instead, they received 30 sessions with a VI 40-sec schedule, followed by 12 sessions with a VI 10-sec schedule. In the last five sessions of each condition, IRTs were recorded as for Groups M and R, and except for the difference in schedules, the procedures were the same for all three groups.

Table 1

Order of Conditions in Groups M and R

Condition	*Group M*	*Group R*
1	FR 10	FR 10
2	MR 2, 18	RR 10
3	MR 4, 36	RR 20
4	FR 20	FR 20
5	FR 40	FR 40
6	MR 8, 72	RR 40
7	MR 16, 144	RR 80
8	FR 80	FR 80
9	MR 8, 72	RR 40
10	FR 40	FR 40
11	FR 20	FR 20
12	MR 4, 36	RR 20

RESULTS

Whole-session response measures. All analyses are based on the last five sessions of each condition. From these sessions, the appendix presents some summary statistics for each subject: the mean number of responses and reinforcers per session, mean session duration, and mean cumulative PRP time per session. These data can be used to calculate three of the most common measures of ratio schedule performance—the mean PRP duration per trial, the running response rate (responses per minute, excluding PRP time and reinforcement time), and the overall response rate (responses per minute, excluding reinforcement time). Figures 1 and 2 display these measures for individual subjects in Groups M and R. Two points are plotted for each schedule with two replications, and the solid or broken line passes through a point marking the mean of the two replications. On the FR schedules, mean PRP durations increased substantially with increasing FR size. On MR and RR schedules, ratio size had a much smaller influence on PRP duration. For two subjects (Subjects R1 and R2),

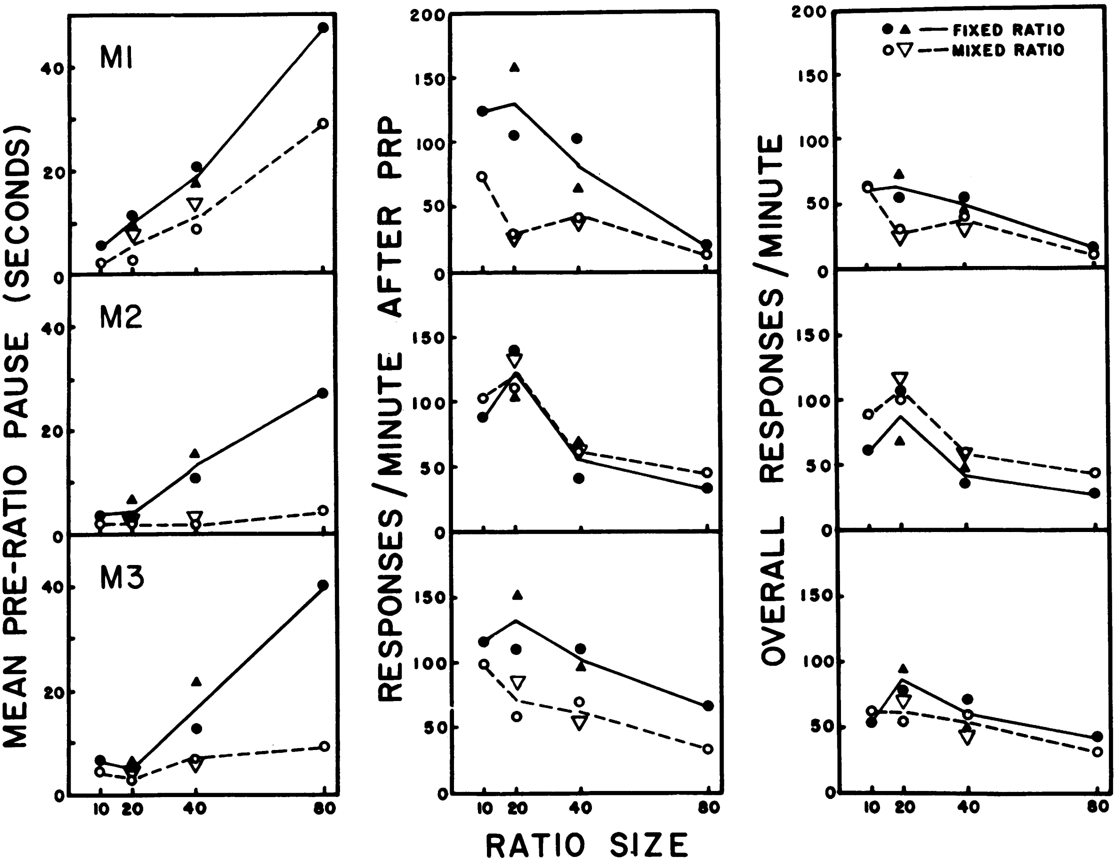

Fig. 1. For the three subjects in Group M, mean PRPs, running response rates, and overall response rates are shown for each condition. Triangles represent the second replication of a schedule. For schedules with two replications, the solid or broken lines mark the mean of the two replications.

PRP duration on RR schedules bore no consistent relation to ratio size. PRP duration increased at least slightly with ratio size for the other five subjects. However, one pattern that was consistent among all subjects was the difference in mean PRP duration between FR and MR or RR schedules. PRPs were longer on FR schedules at all ratio sizes, but the differences between FR and MR or RR schedules grew larger with increasing ratio size.

Although PRPs were longer on FR schedules, running response rates were usually higher, as shown in the middle columns of Figures 1 and 2. The only major exceptions to this generalization were Subject M2, for whom running response rates were roughly equal on FR and MR schedules, and Subject R4 with a ratio size of 10. As ratio size increased, running response rates declined on all three types of schedules. It should be clear that the overall response rates shown in the right columns of Figures 1 and 2 are entirely a function of the information contained in the first two columns. Since PRPs were longer on FR schedules but running response rates were faster, it is not surprising that there were no large or consistent differences in overall response rates among the three schedule types. For instance, overall response rates on FR schedules were slightly higher than MR rates for Subjects M1 and M3, but slightly lower for Subject M2. There were no major differences in overall response rates between FR and RR schedules for any subject.

IRT distributions. Figure 3 plots the frequency distributions of IRTs for all subjects in Groups M and R from each condition. PRPs were not included in these distributions. Each panel compares a FR condition with the equivalent MR or RR condition that immediately preceded or followed it. For five of the seven subjects, the distributions exhibited a

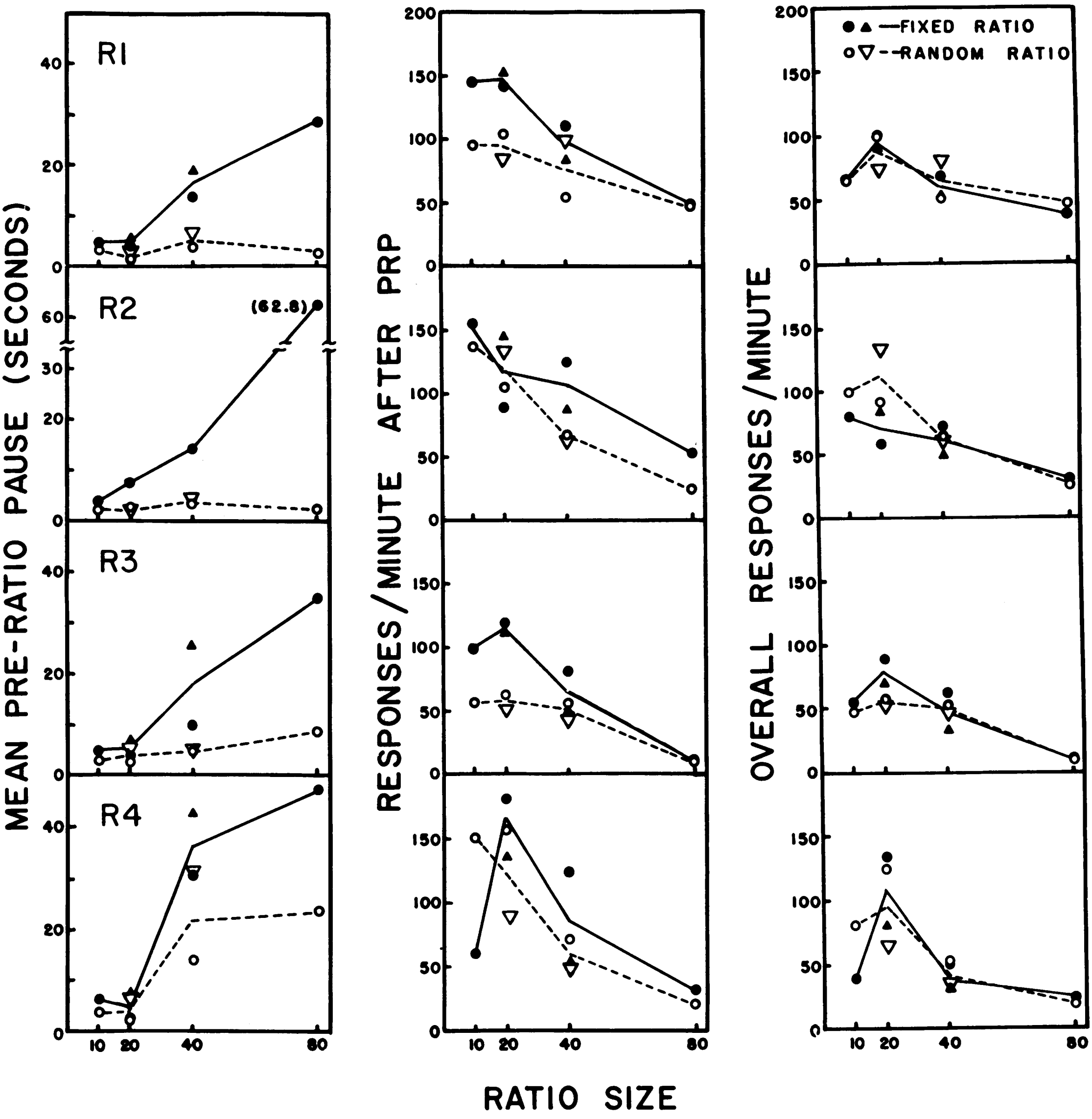

Fig. 2. For the four subjects in Group R, mean PRPs, running response rates, and overall response rates are shown for each condition. Triangles represent the second replication of a schedule. For schedules with two replications, the solid or broken lines mark the mean of the two replications.

sharp peak in the vicinity of .2 sec. For Subject M3, the peak was more rounded and occurred between .2 and .4 sec. For Subject M2, a peak near .2 sec was present in some conditions but not in others. Overall, however, the IRT distributions for a single subject showed considerable consistency across conditions. There were no systematic differences in the distributions for matched pairs of FR and MR or RR conditions. Furthermore, there was no tendency for the peaks to shift toward longer IRTs as ratio size increased, despite the large declines in running response rates shown in Figures 1 and 2.

The IRT distributions from Groups M and R can be compared to those from Group V. First of all, it should be noted that the short VI schedules were chosen to ensure that reinforcement rates would be at least as high as on most of the ratio schedules. On the ratio schedules, reinforcement rates were roughly 400 reinforcers/hr with a response:reinforcer ratio of 10, and about 70 reinforcers/hr with a response:reinforcer ratio of 40. In compari-

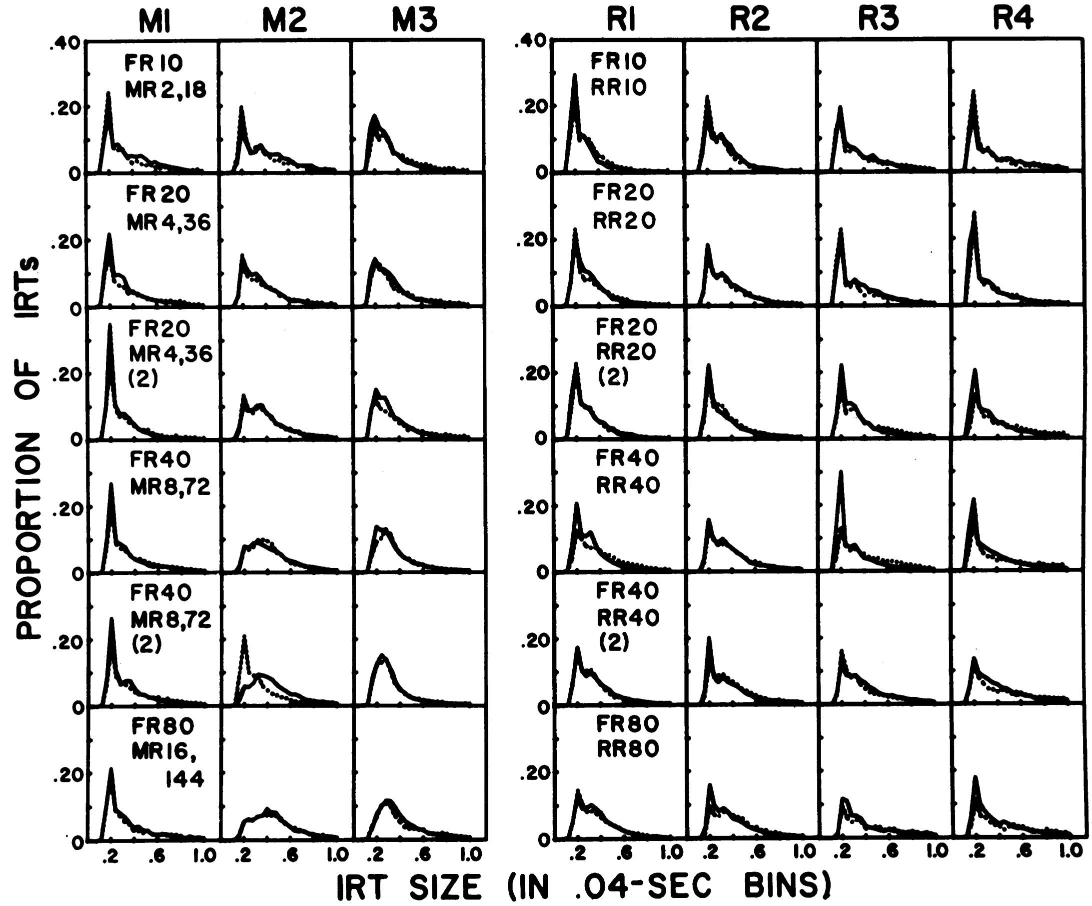

Fig. 3. IRT frequency distributions are shown for each condition and each subject from Groups M and R. Solid lines represent FR schedules, and broken lines represent MR or RR conditions. The number 2 in parentheses indicates the second replication of the two schedules in that panel. IRTs were separated into .04-sec bins, and PRPs were excluded from these analyses.

son, reinforcement rates for Subjects V1 and V2 were, respectively, 509 and 410 reinforcers/hr on the VI 10-sec schedule, and 76 and 71 reinforcers/hr on the VI 40-sec schedule. However, Figure 4 shows that the IRT distributions for these subjects differed greatly from those in Groups M and R. As in Figure 3, PRPs were excluded from these distributions. Virtually no IRTs were observed in the .2 to .4 sec range. (Note the different scale on the x-axis.) With VI 40-sec, the distribution of IRTs was roughly flat, but with VI 10-sec there was a peak in the 2 to 3 sec range. In other words, the model IRT size was fully 10 times larger on the VI schedules than on the ratio schedules.

Since the distributions of IRTs of less than one sec were similar on all ratio schedules, it follows that differences in running response rates across conditions must be due to different amounts of time spent pausing. In order to examine this possibility, it was necessary to choose the minimum IRT size that would be treated as a "pause." This involved an arbitrary decision, since the IRT distributions exhibited no natural divisions between continuous responses and pauses. For the purpose of this analysis, IRTs greater than one sec were treated as pauses—this category includes unusually long IRTs, representing less than 10% of all IRTs. Figure 5 shows the proportion of running response time occupied by IRTs of one sec or less in each condition. The proportion of time occupied by short IRTs is plotted rather than pause time so that the results can be more easily compared to the running response rates in the middle columns of Figures 1 and 2. Such a comparison shows that,

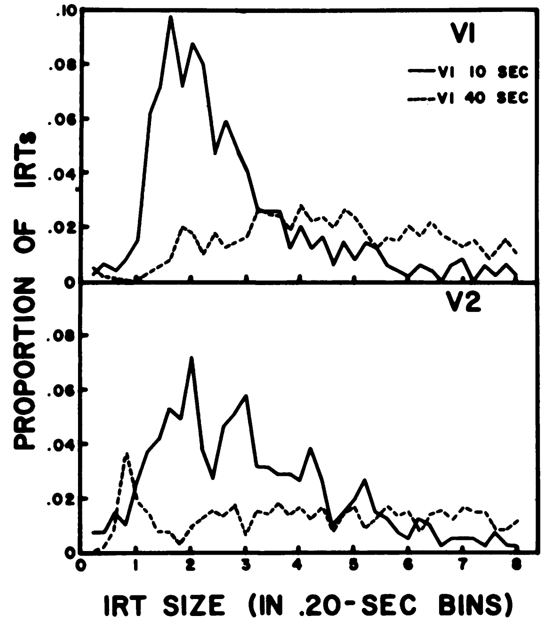

Fig. 4. IRT frequency distributions are shown for the two subjects in Group V. IRTs were separated into .20-sec bins, and PRPs were excluded from these analyses.

for every subject, there was a close correspondence between running response rates and the proportion of running response time occupied by IRTs of one sec or less.

Within-trial response patterns. For Groups M and R, Figures 6 and 7 show how responding changed as a subject progressed through a trial. To avoid redundancy and an excessive number of graphs, these figures present the results from only one, typical subject from each group in addition to the group means. However, all cases where the response patterns from individual subjects differed substantially from those presented in Figures 6 and 7 are noted below.

In Figure 6, the probability of an IRT greater than one sec is plotted as a function of response location within a ratio. IRTs were separated into bins representing successive response locations within a ratio, and the size of each bin was one tenth of the nominal size of the ratio. PRPs were excluded from these analyses. Thus for FR 40, RR 40, and MR 8,72, the first bin included response locations 2 through 4 (since the first IRT is the PRP), the second bin includes response locations 5 through 8, and so on. Each point in the panels depicting the group mean is the simple algebraic mean of the corresponding points for all the subjects in that group. For FR and MR schedules, the broken vertical lines indicate the points where reinforcers occurred (always at the end of the 10th bin on FR schedules, and either at the end of the 2nd or 18th bin on MR schedules). Of course, on RR schedules a reinforcer could occur after any response. The format of data presentation is the same in Figure 7 as in Figure 6, except that Figure 7 depicts the average response rate at different points within a ratio.

The data showed considerable variability in some places (especially for individual subjects in Figure 7); nevertheless, several trends are apparent in the results. The results from FR schedules were fairly consistent across subjects and conditions. Figure 6 shows that the probability of a "pause" (an IRT greater than one sec) was generally highest at the start of a trial and then decreased as a subject moved closer to the next reinforcer. Similarly, Figure 7

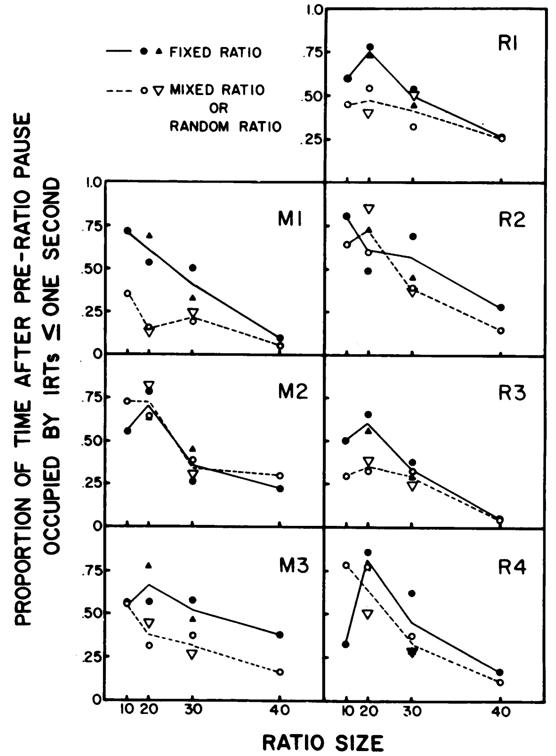

Fig. 5. The proportion of running response time occupied by IRTs of one sec or less is shown for each condition and each subject from Groups M and R. Running response time is equal to the total session time minus PRPs and reinforcement periods. Triangles represent the second replication of a schedule. For schedules with two replications, the solid or broken lines mark the mean of the two replications.

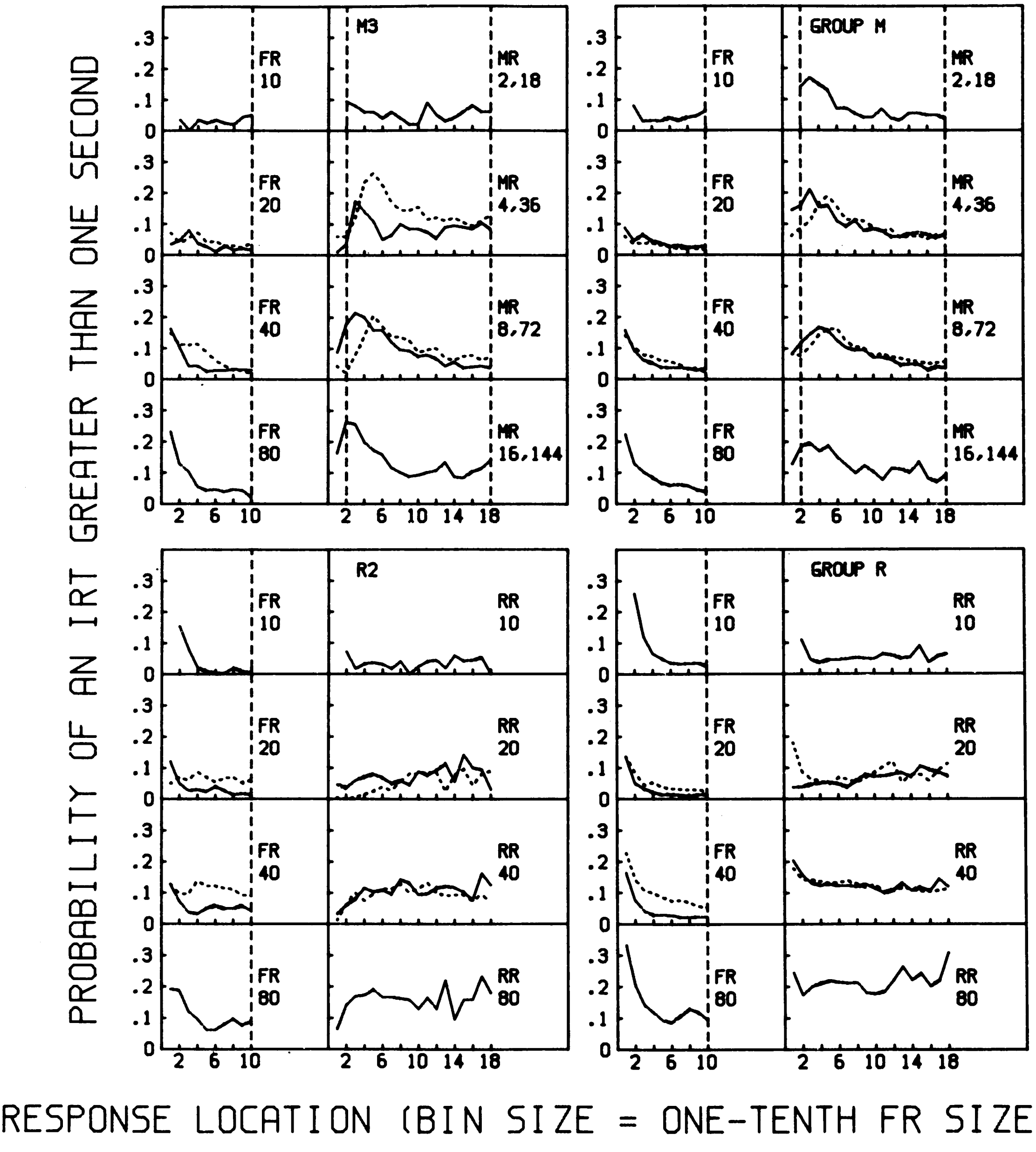

Fig. 6. For Subjects M3 and R2 and Groups M and R, the probability of an IRT greater than one second is plotted for successive response locations. Response locations were divided into 10 bins for FR schedules and 18 bins for MR and RR schedules, and the bin size is one-tenth the nominal size of the ratio. PRPs were excluded, so the first bin is smaller, beginning with the second response of a trial. Dotted lines represent the second replication of a schedule.

shows that response rates were lowest at the start of a FR trial and then increased substantially across response locations. Although there were a few exceptions to these patterns (e.g., in Figure 6, the second replications of FR 20 and FR 40 for Subject R2), all seven subjects displayed patterns of decreasing pause probabilities and increasing response rates in most cases. These trends are clearly evident in the group means in Figures 6 and 7.

The results from MR schedules were less consistent. On these schedules a reinforcer

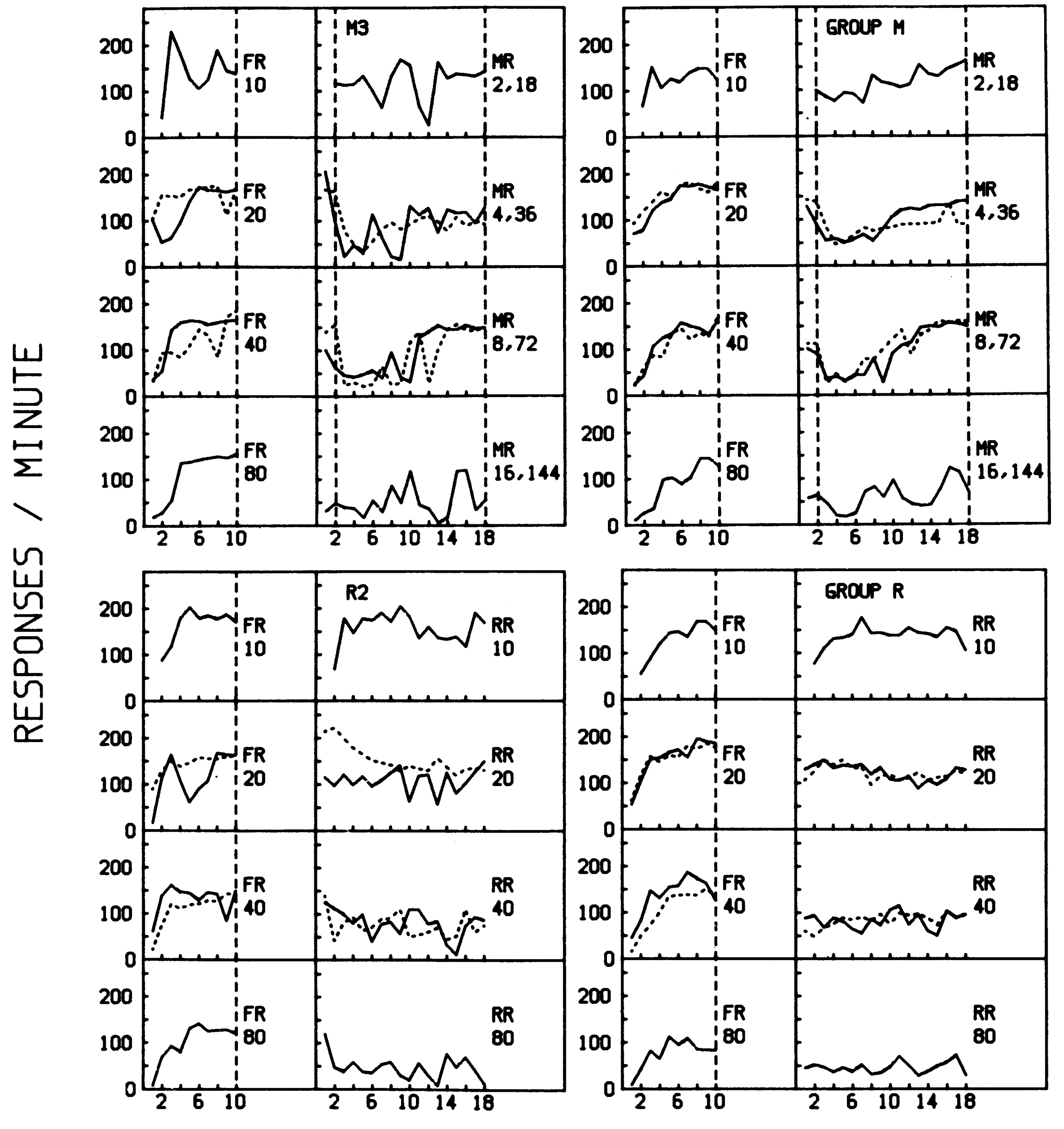

Fig. 7. For Subjects M3 and R2 and Groups M and R, average response rates are plotted for successive response locations. Response locations were divided into 10 bins for FR schedules and 18 bins for MR and RR schedules, and the bin size is one-tenth the nominal size of the ratio. PRPs were excluded, so the first bin is smaller, beginning with the second response of a trial. Dotted lines represent the second replication of a schedule.

might occur after either a small number of responses or a large number of responses, and in about half of the conditions, within-trial response patterns reflected these two possibilities for reinforcement. For Subject M3, Figure 6 shows a bitonic pattern in all MR schedules except MR 2,18: Pause probabilities were low at the start of a ratio, increased to a maximum about 10 to 20% of the way through the ratio, and then declined over the remainder of the ratio. For this same subject, Figure 7 shows that response rates on MR 4,36 and MR 8,72 exhibited a complementary bitonic pattern—starting high, decreasing to a minimum, and then gradually rising again. However, in the other two MR conditions, response rates showed no clear pattern for this subject. The other two subjects in Group M displayed similar inconsistency in within-ratio response patterns. Response rates exhibited a bitonic pattern in two of six MR conditions for Subject M1 and in four of six MR conditions for Subject M2. Not surprisingly, the group averages for MR performance in Figures 6 and 7 show the bitonic pattern more clearly and with less variability than the results from Subject M3. Although the orderliness in the group averages is encouraging, it must be remembered that these averages depict patterns that were not observed for every subject in every condition. In any case, the group averages show a definite difference in within-ratio response patterns between FR and MR schedules.

On RR schedules every response has an equal probability of reinforcement, and Figure 6 shows that, to a first approximation, pauses were about equally probable at all response locations for Subject R2. In contrast to this subject's performance on FR schedules, there was no tendency for pause probabilities to be higher at the start of a RR trial. Figure 7 shows that response rates for this subject bore no consistent relationship to response location. Subjects R1 and R3 showed similar within-trial response patterns. The pause probabilities for Subject R4 provided the only exception to this pattern: In several RR conditions, this subject's pause probabilities were high in the first few bins and then decreased markedly. In the RR panels for Group R in Figure 6, the slightly higher pause probabilities in the first one or two bins for some conditions are due entirely to the performance of Subject R4. Nevertheless, the group averages in Figure 6 depict fairly stable pause probabilities across response locations. A comparison across schedules shows that pause probabilities tended to increase as RR size increased. Similarly, Figure 7 shows that the average response rates for Group R were approximately constant across response locations within a RR schedule, but these average rates declined across schedules as ratio size increased. A comparison of FR and RR performance for Group R shows the distinct differences in within-ratio response rates that were generated by these two types of ratio schedules.

Besides determining when a pause in responding was most probable on different ratio schedules, it is also informative to examine how the average duration of a pause changed within a trial. For FR and RR schedules, Figure 8 shows how the mean duration of all IRTs greater than one sec varied as a function of response location. The extreme variability in the durations of these long IRTs made it necessary to group response locations in bins that were much larger than those used in Figures 6 and 7. For FR schedules, long IRTs were divided into two bins representing the first and second halves of individual trials. Two bins of the same size were used for the corresponding RR schedules. Once again, PRPs were not included in these analyses. For FR schedules, Figure 8 shows that in some cases there was a substantial decrease in pause durations from the first half of the ratio to the second, but in other cases there was no decrease. On RR schedules, pause durations were much more uniform across response locations. In short, there was an inconsistent tendency for pause durations to decrease across response locations on FR schedules, but there was no such tendency on RR schedules.

DISCUSSION

Pear and Rector (1979) proposed that in analyzing instrumental responding it is useful to distinguish between response "propensity" (the proportion of time a subject devotes to performing the response) and response "speed" (the rate of continuous responding). For the pigeons in their study that performed on FR or VR schedules, Pear and Rector found that response propensity (measured as the amount of time subjects spent standing on a response platform) varied inversely with ratio size, whereas response speed (pecking rate while on the platform) was comparatively stable. Their results provide some support for the notion that varying schedule requirements may alter the amount of time devoted to instrumental responding while leaving the speed or "tempo" of continuous responding unchanged. The idea that subjects may develop a particular tempo of responding on a certain class of schedules (e.g., VR schedules or VI

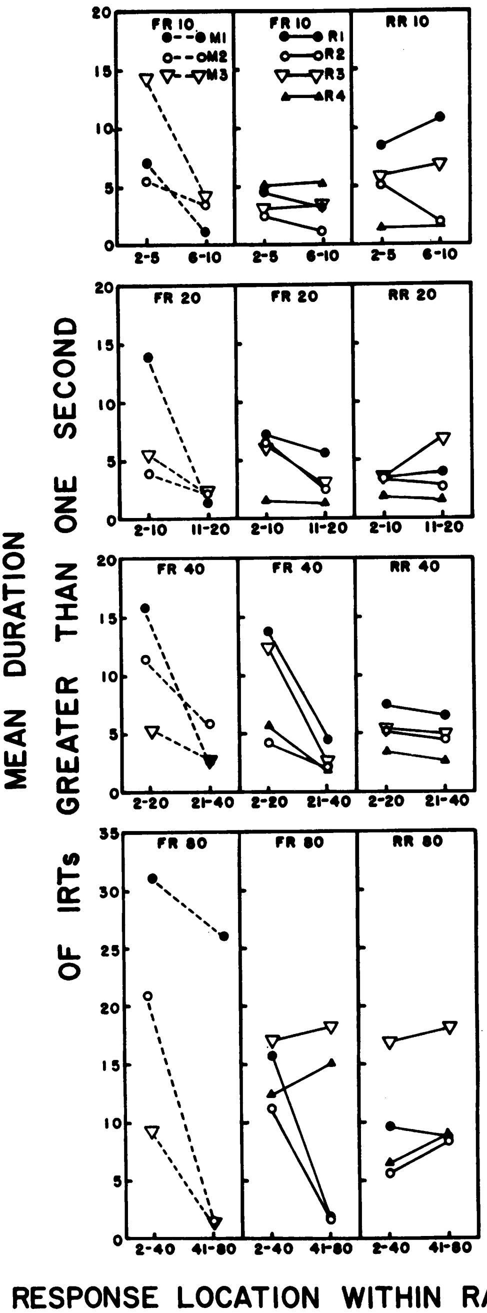

Fig. 8. In the first two columns, the two points plotted for each subject are the mean durations of all IRTs greater than one sec in the first half of the response locations and the second half of the response locations on FR trials. For Group R, the right column shows the corresponding results from RR conditions.

schedules) has been suggested by many writers in a number of different contexts. For example, researchers analyzing the reinforcement of different classes of IRTs have proposed that short IRTs are more frequently reinforced on VR schedules than on VI schedules, and as a result response rates are faster on VR schedules (e.g., Anger, 1956; Morse, 1966; Skinner, 1938). Regarding FR schedules, Powell (1969) proposed that running response rates are essentially constant as ratio size varies, and Sidman and Stebbins (1954) found that running response rates were not affected when subjects' levels of deprivation were changed. More recently, Mazur and Hyslop (1982) presented additional evidence supporting the notion of a constant response tempo on FR schedules. In this experiment, the great majority of IRTs for all three pigeons were either about .1 sec or about .3 sec in duration, and these characteristic IRT durations did not change between FR 50 and FR 150 (although overall response rates decreased substantially).

The present experiment reproduced the findings of Mazur and Hyslop (1982) and extended their generality, since the subjects were rats instead of pigeons, and three different types of ratio schedules were examined. For most subjects, the IRT frequency distributions had a sharp peak at around .2 sec, and the location of this peak did not change as a function of ratio size or type of ratio schedule. This constancy among the various ratio schedules is especially impressive when the results are compared to the IRT distributions for VI schedules in Figure 4. On the VI schedules, there were almost no IRTs in the vicinity of .2 sec, and the peaks (if any) of the distributions were at IRTs several times larger than .2 sec.

If the rate of continuous responding was constant across different ratio schedules as Figure 3 suggests, then variations in running response rates must be due to differences in the amount of pausing. In the present study, this prediction was examined by dividing the total running response time of each session into periods of continuous responding (all IRTs of 1 sec or less) and pauses (all IRTs greater than 1 sec). Subject by subject comparisons consistently showed a close correspondence between running response rates (middle columns of Figures 1 and 2) and the proportion of time occupied by continuous responding (Figure 5). This comparison shows that variations in running response rates across different ratio schedules were almost entirely the result of different proportions of time spent pausing. Taken together, this finding and the IRT distributions indicate that, at least to a first approximation, the rate of continuous responding was constant across all ratio schedules, and what varied from condition to condition was the amount of pausing.

This argument for a constancy in the rate of continuous responding across different ratio schedules is not meant to imply that no manipulations can change the tempo of responding on ratio schedules. Thus, Weiss and Gott (1972) found that the peaks of IRT distributions from pigeons on a FR 30 schedule sometimes shifted when subjects were administered amphetamines or other drugs. Furthermore, in several studies two or more peaks have been observed in IRT frequency distributions from FR schedules (Gott & Weiss, 1972; Mazur & Hyslop, 1982; Weiss & Gott, 1972). Gott and Weiss (1972), for example, found several peaks at multiples of about .3 sec, and they reported that the multiple peaks were the result of one or more ineffective pecks occurring between two recorded pecks. Yet regardless of the shape of a particular IRT distribution, the results of Mazur and Hyslop (1982) and of the present study suggest that changing the ratio size or the type of ratio schedule will not substantially alter the shape of that distribution.

This experiment illustrated two parameters of reinforcement that influence behavior on ratio schedules: probability of reinforcement (the probability that a reinforcer will be delivered after one more response, or after 10 more responses, etc.), and what might be called proximity to reinforcement (the number of responses remaining before reinforcement). The three types of ratio schedules used in this study vary in the extent to which these two reinforcement parameters play a role. On FR schedules, the role of probability is minimized, since it is at least theoretically possible for the subject always to know exactly how many responses remain before reinforcement (although the accuracy of this information depends on the subject's ability to count responses). On MR schedules, both proximity and probability are involved, since a subject moves closer to a reinforcer with each response, but there is uncertainty as to whether the reinforcer will occur after a small or a large number of responses. On RR schedules, the role of proximity is minimized, because on a RR *n* schedule, regardless of the number of responses since the last reinforcer, the expected number of responses before the next reinforcer remains at a constant value of *n*. Thus, from a probabilistic viewpoint, the proximity to reinforcement is the same for every response on a RR schedule.

In a recent chapter, Mazur (1982) described a quantitative model of moment-to-moment performance on ratio schedules. Although its details cannot be repeated here, the model assumes that both the proximity and probability of reinforcement determine the likelihood of an instrumental response at a given moment. The model makes a number of predictions relevant to the present experiment. Among its predictions for PRP durations are (1) that PRPs will be larger on FR schedules than on equivalent MR or RR schedules, (2) that PRPs will become longer with increasing ratio size on all three types of schedules, and (3) that PRP durations will increase more rapidly with increases in FR size than with increases in MR or RR size, so the differences between FR and MR or RR will become larger with larger ratios. These predictions all follow from the assumption that the "momentary value" of instrumental responding (which determines the likelihood of a response at a given moment) is highly dependent on the proximity to reinforcement, and that this value is larger on MR and RR schedules because of the possibility that a reinforcer will occur after some small number of responses. Mazur (1982) showed that these predictions are consistent with studies showing a preference for MR or VR schedules over FR schedules (e.g., Fantino, 1967; Sherman & Thomas, 1968). Figures 1 and 2 show that each of the three predictions about PRPs was confirmed, except that two subjects showed no systematic changes in PRP durations on RR schedules. This may have been simply a failure in detection, since the other subjects showed the predicted pattern.

Mazur's (1982) model also makes some specific predictions about the relationship between response location within a ratio and the probability of responding. It predicts that, because of the increasing proximity to reinforcement, average response rates should increase across response locations on FR schedules. On the other hand, because the probability and expected proximity of reinforcement are constant on a RR schedule, response rates should remain constant at all response locations. Figure 7 shows that, as predicted, response rates increased across the average FR trial but remained roughly constant across a RR trial. The increase in response rates across response locations on FR schedules is consistent with previous results (e.g., Gott & Weiss, 1972; Platt & Senkowski, 1970), although a slight decrease in response rates toward the end of a FR trial is sometimes observed (e.g., Davison, 1969). The within-trial results from RR schedules are similar to those observed by Kintsch (1965) with rats on a VR 15 schedule. Kintsch found that the average duration of an IRT was fairly constant across response locations, except that IRTs were substantially longer for the first three or four response locations (a phenomenon Kintsch called a "warm-up" effect). In Figure 7, response rates on RR 10 for both Subject R2 and for Group R as a whole showed a similar warmup effect.

For MR schedules the model predicts that the probability of a pause should reach a maximum immediately after the small-response requirement has been met without reinforcement, for at this point it becomes certain that a large number of additional responses must occur before reinforcement. In Figure 6, a peak in approximately the predicted location (bin 3) was seen in some cases but not in others. Although the results from MR conditions were quite variable, the within-ratio response patterns were certainly different from those found on either FR or RR schedules, and the directions of the differences were consistent with the predictions of the model. The failure for the maximum probability of a pause to occur exactly where predicted is not surprising in light of previous studies of MR schedules (e.g., Alferink & Crossman, 1975, 1978; Crossman & Silverman, 1973). For example, Crossman and Silverman observed that a long pause in responding sometimes occurred only after a subject produced two or three times as many responses as required by the short component of a MR schedule. Probably because of the subjects' limited counting abilities, within-ratio pauses do not generally occur exactly when the shorter FR requirement is met unless an external stimulus change occurs at this point (Alferink & Crossman, 1976).

As in the study of Mazur and Hyslop (1982), the results from FR schedules were inconsistent with Mazur's (1982) model in one important respect. Stated simply, the model predicts that the probability of responding on FR schedules depends on the absolute number of responses remaining before reinforcement. Thus, a particular response rate should occur with the same number of responses remaining before reinforcement regardless of the overall size of the FR schedule. Yet Figure 7 shows that response rates were low at the start of a FR trial regardless of the absolute size of the response requirement. Similar results led Mazur and Hyslop to suggest the possibility that responding on FR schedules might be controlled by the relative location within a ratio and not the absolute number of responses before reinforcement. It should be noted that in the present study, within-ratio responding on MR schedules also appeared to vary as a function of relative response location. For instance, the four panels for Group M in Figure 6, which are normalized so that each MR schedule is divided into 18 bins, contain functions of fairly similar shape despite the fact that the absolute sizes of the MR schedules vary by a factor of eight. This hypothesis that responding is determined by relative location within a ratio is similar to Gibbon's (1977) scalar expectancy theory for fixed-interval schedules, and it deserves to be explored further.

One unexpected finding of the present study was that overall response rates on RR schedules were no higher than on equivalent FR schedules. This finding contrasts with the results of Ferster and Skinner (1957) and Boren (1973), who obtained higher response rates on VR schedules. In the present study, PRPs were longer on FR schedules, but there was more within-ratio pausing on RR schedules, and these two effects tended to cancel out when overall response rates were calculated. The approximate equivalence of FR and RR response rates was probably coincidental. It seems likely that any manipulation that decreased the amount of within-ratio pausing would yield a superiority for RR schedules in overall response rates, and one that increased within-ratio pauses might actually produce a net advantage for FR schedules.

As discussed above, this experiment supported Mazur's (1982) model in some respects but not in others. Nevertheless, the results provided encouragement concerning the feasibility of developing a comprehensive model of steady-state performance applicable to all ratio schedules. Insofar as performance on ratio schedules can be characterized as consisting of only two behavior categories—steady, continuous responding and pausing—the task of theory development is greatly simplified. The problem is reduced to specifying when pauses will occur and how long they will last.

APPENDIX

Summary Statistics: Means from the Last Five Sessions of Each Condition

Subject	*Condition*[a]	*Sessions*	*Responses*	*RFTS*	*Session Time (sec)*	*PRP Time (sec)*	*Condition*	*Sessions*	*Responses*	*RFTS*	*Session Time (sec)*	*PRP Time (sec)*
M1	FR 10	23	400	40.0	392	219	MR 2-18	16	400	40.0	379	85
	FR 20	15	770	38.4	850	434	MR 4-36	12	592	28.8	1196	83
	FR 20(2)	13	800	40.0	656	367	MR 4-36(2)	18	651	31.8	1545	284
	FR 40	17	1388	34.6	1532	738	MR 8-72	14	1095	26.8	1667	233
	FR 40(2)	27	1229	30.4	1665	542	MR 8-72(2)	15	882	21.6	1481	294
	FR 80	13	497	6.0	1782	333	MR 16-144	12	337	4.2	1787	151
M2	FR 10	23	400	40.0	391	146	MR 2-18	13	400	40.0	285	76
	FR 20	14	800	40.0	416	90	MR 4-36	22	800	40.0	480	71
	FR 20(2)	23	763	38.0	666	246	MR 4-36(2)	12	793	39.8	411	68
	FR 40	14	1031	25.4	1724	280	MR 8-72	16	1402	35.0	1378	59
	FR 40(2)	19	1307	32.6	1615	511	MR 8-72(2)	12	1355	32.2	1377	56
	FR 80	12	833	10.2	1769	301	MR 16-144	12	1167	14.2	1614	67
M3	FR 10	24	400	40.0	449	264	MR 2-18	18	400	40.0	384	164
	FR 20	20	793	39.6	609	197	MR 4-36	14	800	40.0	895	109
	FR 20(2)	13	800	40.0	507	206	MR 4-36(2)	12	800	40.0	694	157
	FR 40	15	1537	38.4	1289	469	MR 8-72	15	1487	37.0	1526	291
	FR 40(2)	14	1295	32.2	1544	752	MR 8-72(2)	13	1282	31.4	1641	241
	FR 80	12	1229	15.2	1754	651	MR 16-144	12	884	15.8	1769	155
R1	FR 10	19	400	40.0	355	206	RR 10	15	385	40.0	353	137
	FR 20	16	800	40.0	485	165	RR 20	16	764	40.0	465	51
	FR 20(2)	19	800	40.0	533	235	RR 20(2)	17	821	40.0	657	114
	FR 40	12	1529	38.2	1345	537	RR 40	25	1260	33.2	1488	136
	FR 40(2)	13	1129	28.2	1334	547	RR 40(2)	17	1498	40.0	1124	255
	FR 80	13	1107	13.8	1759	423	RR 80	13	1375	16.8	1750	49
R2	FR 10	19	400	40.0	298	159	RR 10	20	403	40.0	244	86
	FR 20	18	800	40.0	820	307	RR 20	15	794	40.0	518	92
	FR 20(2)	13	800	40.0	574	259	RR 20(2)	16	675	40.0	307	65
	FR 40	14	1520	37.8	1265	545	RR 40	14	1284	38.0	1207	131
	FR 40(2)	17	1257	31.2	1528	687	RR 40(2)	12	1548	36.0	1514	152
	FR 80	19	902	11.2	1767	766	RR 80	18	758	8.2	1775	24
R3	FR 10	21	400	40.0	429	210	RR 10	14	383	40.0	487	123
	FR 20	17	800	40.0	542	160	RR 20	12	719	38.8	753	106
	FR 20(2)	14	789	39.4	682	276	RR 20(2)	13	787	38.8	880	194
	FR 40	29	1355	33.6	1306	334	RR 40	15	1395	34.0	1605	154
	FR 40(2)	13	959	23.8	1729	633	RR 40(2)	17	1263	29.0	1638	149
	FR 80	15	327	3.6	1789	161	RR 80	20	290	4.0	1793	41
R4	FR 10	21	400	40.0	612	256	RR 10	22	389	40.0	288	150
	FR 20	14	800	40.0	358	107	RR 20	20	749	40.0	358	87
	FR 20(2)	24	800	40.0	592	294	RR 20(2)	16	682	34.2	644	203
	FR 40	16	1313	32.8	1623	1001	RR 40	19	1334	29.6	1519	424
	FR 40(2)	16	723	19.2	1742	863	RR 40(2)	17	924	21.4	1736	679
	FR 80	15	709	8.6	1774	451	RR 80	17	557	10.4	1777	267
V1	VI 40 sec	30	191	35.4	1686	254						
	VI 10 sec	12	98	40.0	283	101						
V2	VI 40 sec	30	130	33.4	1697	470						
	VI 10 sec	12	82	40.0	351	208						

[a] The number 2 in parentheses denotes the second replication of a schedule.

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