FIXED-RATIO PERFORMANCE WITH AND WITHOUT A POSTREINFORCEMENT TIMEOUT

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Pigeons pecked a key, producing food reinforcement on fixed-ratio (FR) schedules requiring 50, 100, or 150 responses. In each session, 30-second timeouts were inserted before a random half of the FR trials, whereas the other trials began immediately after reinforcement. In general, preratio pauses were shorter on trials preceded by timeouts. On these trials, the probability of a first response tended to be highest in the first 20 seconds of the trials, suggesting that the shorter pauses were the result of transient behavioral contrast. Direct observations and analyses of interresponse times (IRTs) after the preratio pause indicated that IRTs could be grouped into three categories: (1) IRTs of about .1 second, which were produced by small head movements in the vicinity of the key; (2) IRTs of about .3 second, which were produced by distinct pecking motions; and (3) IRTs greater than .5 second, which were accompanied by pausing or movements away from the key. At all ratio sizes, as a subject progressed through a trial, the probability of a long IRT decreased, whereas the probability of an intermediate IRT usually increased at first and then decreased. The probability of a short IRT increased monotonically across a trial. The results show that responding changes systematically as a subject progresses through a ratio on an FR schedule. Some characteristics of performance varied as functions of the absolute size of the response requirement, whereas others appeared to depend on the relative location within a ratio (i.e., the proportion of the ratio completed at a given moment).

Key words: fixed ratio, timeout, preratio pause, local response rate, key peck, pigeons

On a fixed-ratio n (FR n) schedule, every n responses are followed by reinforcement. Performance on FR schedules is often said to exhibit a "break-and-run" pattern: a pause in responding after reinforcement—the "postreinforcement pause" or "preratio pause" (Griffiths & Thompson, 1973)—is followed by an abrupt transition to rapid and steady responding, which frequently continues without interruption until the next reinforcement is received. Previous research has shown that the size of the preratio pause depends on many factors, including the size of the ratio (Felton & Lyon, 1966; Powell, 1968), the magnitude of the reinforcer (Inman & Cheney, 1974; Meunier & Starratt, 1979; Powell, 1969), the subject's level of deprivation (Malott, 1966; Sidman & Steb-

bins, 1954), and the delay between the last response and reinforcement (Meunier & Ryman, 1974; Morgan, 1972; Topping, Johnson, & McGlynn, 1973). On the other hand, researchers have asserted that the "running response rate," or the rate of response when preratio pauses are excluded, is largely unaffected by variations in ratio size, the magnitude or delay of reinforcement, and deprivation level (Meunier, Starratt, & Sergio, 1979; Powell, 1969; Sidman & Stebbins, 1954). It is generally held that whereas the size of the preratio pause on FR schedules is controlled by a number of different variables, response rate after the pause is fairly steady and insensitive to these same variables. For example, Powell (1969) concluded that such variables as ratio size and reinforcer magnitude "have little effect on FR response rate when it is measured independently of the post-reinforcement pause" (p. 608). One major purpose of the present experiment was to examine this view that after the pretrial pause, response rates are essentially constant across a trial and across conditions on FR schedules. Although steady-state FR

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performance usually has a break-and-run appearance in a cumulative record, a closer examination of responding after the preratio pause reveals a rich collection of orderly moment-to-moment variations in responding.

A second purpose of this study was to examine the effects of a signaled timeout inserted immediately before some FR trials (where one completion of the ratio and the resultant reinforcement will be called a "trial"). Ferster and Skinner (1957) were the first to investigate the effects of such timeouts. They presented three pigeons with an FR 50 schedule for two sessions and then an FR 50 schedule with a 60-sec timeout after each reinforcement for four sessions. Ferster and Skinner found shorter preratio pauses when the timeout was inserted, but because of the small number of sessions and possible order effects, their results must be viewed with caution. A more thorough investigation of postreinforcement timeouts was recently reported by Richards and Blackman (1981). This study included five FR 40 conditions—two conditions with postreinforcement timeouts separated by three conditions with no timeouts. Timeout duration was 3 to 7 sec in one condition and 30 sec in the other condition. In general, Richards and Blackman found shorter preratio pauses with longer timeout durations. They also reported an increase in running response rates in conditions that included timeouts, but this effect was small and was reliable for only two of three subjects.

Although the results of these studies seem to imply that the preratio pause is affected by a timeout that precedes it, the results are not conclusive for the simple reason that in the timeout conditions every reinforcement was followed by a timeout. Although it seems unlikely, it is conceivable that the shorter preratio pauses occurred because each trial ended with a timeout after reinforcement, not because a timeout occurred before each trial (in much the same way that on multiple FR schedules, the pause is affected by the current ratio but not the preceding ratio, e.g., Crossman, 1968; Davison & Over, 1966; Schuster, 1959). To demonstrate that the size of the preratio pause is influenced by a timeout that precedes it, a within-session comparison of timeout and no-timeout trials is necessary. That is, some randomly selected trials should be preceded by a timeout, and others should begin immedi-

ately after the preceding reinforcement period. Clark (1959) conducted such a study with rats on an FR 11 schedule and occasional 3-min timeouts. Although Clark's report is brief, he observed no evidence for shorter pauses after timeouts. Since Clark's study was the only one employing a within-session comparison of timeout and no-timeout trials, there is no definitive evidence showing that preratio pauses on FR schedules are affected by timeouts that precede them.

Richards and Blackman (1981) suggested that the shorter preratio pauses after timeouts could be the result of behavioral contrast (Reynolds, 1961). An FR schedule with a postreinforcement timeout can be viewed as a multiple FR extinction schedule, where the FR schedule and the extinction schedule are correlated with different discriminative stimuli (e.g., keylight on versus keylight off in the Richards and Blackman study). In a multiple schedule, behavioral contrast is an increased response rate in one schedule resulting from a low reinforcement rate in the other schedule. From previous research on behavioral contrast (e.g., Gamzu & Schwartz, 1973; Reynolds, 1961; Schwartz & Gamzu, 1977), it seems reasonable that the alternation of an FR schedule and a timeout period might produce an increased probability of responding on the FR schedule (i.e., shorter preratio pauses). Yet if the shorter pauses after timeouts are interpretable as behavioral contrast (i.e., due to the juxtaposition of a timeout period and an FR trial), they should be observable in a within-session comparison as well as in an across-session comparison. Since behavioral contrast is usually greatest immediately after a transition from one schedule to another (e.g., Malone, 1976; Nevin & Shettleworth, 1966; Schwartz, 1978; Staddon, 1969), the preratio pause on an FR trial should be shorter if the trial is preceded by a timeout rather than by another FR trial. If the effects of timeouts cannot be observed in a within-session comparison, this would tend to discredit the behavioral contrast explanation.

Other possible explanations of the Richards and Blackman (1981) results do not necessarily predict a comparable effect in a within-session comparison. One explanation can be called the "satiation hypothesis": Perhaps each reinforcement produces a temporary decrease in the subject's level of hunger on a simple FR

schedule, but the addition of postreinforcement timeouts provides time for this temporary satiation to dissipate. Another explanation can be called the "fatigue hypothesis": The effort of responding may produce fatigue that dissipates to some extent during the timeout (cf. Hull's 1952 concept of reactive inhibition). Notice that the satiation and fatigue hypotheses do not demand a within-session demonstration of the effects of timeouts on pre-ratio pauses, because the effects might be cumulative and require several successive trials with timeouts before they are measurable.

In an effort to distinguish among the several possible explanations of the Richards and Blackman (1981) results, the present study examined the effects of postreinforcement timeouts in a within-session comparison of timeout and no-timeout trials. In three separate conditions, subjects responded on FR 50, FR 100, and FR 150 schedules, and in each session a random half of the trials were preceded by a 30-sec timeout.

METHOD

Subjects

Three adult White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights. All had previous experience with a variety of experimental procedures.

Apparatus

The experimental chamber was 30 cm long, 30 cm wide, and 33 cm high. Three response keys, each 2.5 cm in diameter, were mounted in the front wall of the chamber, 20.5 cm above the floor. Only the center key was used in this experiment. A force of .10 N was required to operate the center key, and when the key was illuminated, each effective response produced a feedback click. A hopper below the center key provided controlled access to mixed grain, and when grain was available the hopper was illuminated by two 6-W white lights. Two 6-W white lights above the wiremesh ceiling of the chamber provided general illumination. The chamber was enclosed in a sound-attenuating box that 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 SUPER-

SKED program to control the stimuli and record responses.

Procedure

The experiment consisted of three conditions, each with a different FR requirement. The schedule was FR 50 in the first condition (22 sessions), FR 150 in the second condition (20 sessions), and FR 100 in the third condition (15 sessions). Sessions were conducted seven days a week.

Each session lasted for 30 reinforcements or 60 minutes, whichever came first. The start of a session was signaled by the lighting of the houselights, which remained on throughout the session except during reinforcement periods (when the only illumination came from the lights above the food hopper). A session consisted of a continuous series of trials, some beginning with a 30-sec timeout period (TO trials) and some with no such timeout (NTO trials). On TO trials, the center key was dark for the first 30 sec, and responses were ineffective during this time. After the timeout, the key was transilluminated with yellow light, and the FR schedule was in effect. When the subject completed the ratio, the keylight and houselights were extinguished and grain was presented for 3 sec. NTO trials had no pre-ratio timeout, and the keylight was illuminated immediately at the start of the trial. Otherwise NTO trials were identical to TO trials. Immediately after each reinforcement period, a new trial began (with a 30-sec timeout if it was a TO trial; with the illumination of the keylight if it was a NTO trial). TO and NTO trials were intermixed in a random order, with the constraint that the two types of trials should occur about equally often each session. (In sessions where all 30 trials were completed, the number of TO trials ranged from 12 to 18.)

Each condition was continued until the performance of all subjects was judged to be stable over the last 10 sessions. A subject's performance was considered stable when (1) cumulative records from all 10 sessions displayed typical FR (break-and-run) performance, and (2) median postreinforcement pause durations for both TO and NTO trials showed no systematic trends over the 10 sessions. For the final 10 sessions of every condition, every interresponse time (IRT, the time

between two responses or between a reinforcer and the subsequent response) was recorded to the nearest .01 sec and stored on a floppy disk.

RESULTS

The Effects of Timeouts

All analyses were based on the last 10 sessions of each condition for each subject. In these 90 sessions, subjects made very few responses during timeout periods. In 62 sessions there were no responses during any timeout, and in only eight sessions were more than five timeout responses recorded.

For each subject, the left half of Figure 1 shows the median duration of preratio pauses on TO and NTO trials. Overall, this figure shows that preratio pauses tended to be shorter on TO trials. Timeouts had the largest effect on preratio pauses for Subject 3, a smaller effect for Subject 1, and for Subject 2 the effect is evident only in the FR 150 condition. Table 1 provides some evidence concerning the reliability of the effect of timeouts. For each subject and each condition, this table presents the number of sessions where NTO trials had a larger median preratio pause, and the number of sessions where TO trials had a larger median pause duration. As can be seen, TO trials actually had a larger median pause duration than NTO trials in many sessions. This result can be attributed to the large trial-by-trial variation in preratio pause durations. Nevertheless, for all three subjects and all three conditions, a majority of the sessions had greater NTO pause durations. This result provides strong evidence that timeouts had an effect on pause duration ($p < .004$, two-tailed sign test). Much of the session-to-session variability in preratio pause durations was due to the presence of frequent long pauses (i.e., pauses of several minutes duration), which were most likely more indicative of ratio strain than of differences between TO and NTO trials. In a further analysis, the contribution of these long pauses was minimized by calculating the harmonic means of NTO and TO pause durations in each session. In 77 of the 88 individual sessions (87%), the harmonic mean was larger for NTO trials. This session-by-session consistency leaves little doubt about the reality of the timeout effect.

The right half of Figure 1 shows the running response rates (response rates excluding

Fig. 1. The left panels show the median preratio pause durations in each condition for both TO and NTO trials. The right panels show the running response rates (response rates excluding preratio pauses) on TO and NTO trials.

Table 1

Number of individual sessions where NTO trials had a larger median preratio pause and where TO trials had a larger median preratio pause.

	FR 50		FR 100		FR 150		Subject Total	
	NTO	TO	NTO	TO	NTO	TO	NTO	TO
S1	8	2	9	1	5	4 ^a	22	7
S2	7	3	6	4	7	3	20	10
S3	8	2	7	3	8	1 ^a	23	6
Condition Total	23	7	22	8	20	8	65	23

^aThe totals do not equal 10 in these conditions because response rates were so low that in one session the subject did not receive both types of trials.

timeouts, reinforcements, and preratio pauses) for TO and NTO trials. No systematic effect of timeouts was evident in the running response rates of this experiment. Response rates were approximately equal in TO and NTO conditions for Subjects 2 and 3, and Subject 1 showed somewhat slower responding on TO trials in two conditions.

This experiment demonstrates that the mechanism producing shorter pauses operates at a local level—a timeout tends to produce a shorter pause on the subsequent trial. Thus a substantial dissipation of fatigue or satiation must occur over a single period of 30 sec if either of these two hypotheses is correct. If

satiation or fatigue dissipates rapidly after every reinforcement, this should have predictable effects on the probability of responding as time passes during a preratio pause. To be specific, on NTO trials the probability of a first response in, for example, the first 20 sec of the trial should be relatively low; if a response does not occur in the first 20 sec, the probability should increase in the next 20 sec, due to a dissipation of satiation or fatigue. In short, both the satiation and fatigue hypotheses predict an increasing probability of responding as time passes at the start of a NTO trial. On TO trials, the satiation or fatigue should at least partially dissipate during the timeout. Therefore, the probability of a first response should begin at a higher level on a TO trial, but it may continue to rise slightly as the trial continues due to further dissipation of satiation or fatigue.

The behavioral contrast explanation makes a different set of predictions. On a NTO trial, the juxtaposition of two FR periods without a timeout provides no opportunity for behavioral contrast, so this hypothesis predicts neither an increase nor a decrease in the probability of responding as time passes. However, on a TO trial, the juxtaposition of a timeout and an FR period should cause a temporary elevation in response probability at the start of the trial. Thus, the major prediction of the behavioral contrast explanation is that the probability of observing a first response should be high at the start of a TO trial and decrease as time passes, due to the decline of transient behavioral contrast.

Figure 2 presents the results of an analysis

Fig. 2. First responses per opportunity are shown for the first 20 sec and the second 20 sec of TO and NTO trials.

testing these different predictions. For the FR 100 and FR 150 conditions, the probability of the first response of the trial is plotted for the first 20 sec and for the second 20 sec of a trial. (The results of the FR 50 condition were not included because the great majority of preratio pauses were less than 5 sec long. It is not clear that any of the three hypotheses would predict any systematic changes in response probability over a span of just a few seconds.) The 20 to 40 sec bin considers only those cases where the preratio pause was longer than 20 sec (since a "first response" would be impossible if it already occurred in the first 20 sec). The ordinate in Figure 2 is therefore labeled "first responses per first-response opportunities." This figure shows considerable variability from panel to panel, thus limiting the confidence with which conclusions may be drawn. However, the results provide little or no support for the satiation and fatigue explanations, which predict positive slopes for NTO trials and zero or slightly positive slopes for TO trials. The overall pattern tends to support the behavioral contrast explanation, which predicts negative slopes on TO trials and approximately flat slopes on NTO trials.

Responding After the Preratio Pause

As mentioned, the right half of Figure 1 suggests that after the preratio pause there was little difference in responding on TO and NTO trials. Figure 3 provides further support for this conclusion. Figure 3 shows how the average response rate changed in each condition as a subject moved from the start of a trial to the end of a trial. Averaging across all the trials of the last 10 sessions of a condition, a separate response rate was calculated for each of the 50, 100, or 150 response locations within a ratio. For example, if across the 10 sessions, a subject reached the second response of a trial x times, and if $T_{2,3}$ is the total time (in minutes) spent between the second and third responses of all trials, then the mean response rate for Response Location 3 is $x/T_{2,3}$. Several points can be made about the results displayed in Figure 3. First, in all nine within-subject comparisons, there were no systematic differences between TO and NTO trials—the patterns of responding were quite similar on the two types of trials. Second, mean response rates after the preratio pause were not constant across all response locations. On the average,

response rates were low in the beginning of a ratio, but they increased rapidly and reached a maximum at about 20 to 40 percent of the way through the ratio. For the remainder of the ratio, response rates remained approximately constant at this high level. It should

be observed that as ratio size increased, the maximum response rate was first reached at larger and larger response locations. To provide a quantitative measure of this effect, a median response rate was calculated for the 50, 100, or 150 data points in each panel of

Fig. 3. Mean response rates are shown for every response location within a ratio on both TO and NTO trials. In each panel, the arrow shows the first response location at which the median response rate of that panel was reached or exceeded.

Figure 3. The arrow in each panel indicates the response location at which this median value was first reached or exceeded. For example, with Subject 1 and NTO trials, the median response rate was reached at Response Locations 18, 26, and 37 on the FR 50, FR 100, and FR 150 schedules, respectively. In all six rows of Figure 3, the arrows occur at successively larger response locations with larger ratios.

Despite the negatively accelerated functions shown in Figure 3, it would be incorrect to conclude that a gradual increase in response rate was characteristic of all individual trials. Individual IRTs were examined for several sessions of each condition for all subjects. The sample of IRTs presented in Figure 4, selected at random from the last session of each condition for Subject 2, is typical. As can be seen, some trials included many long IRTs (e.g., greater than 1 sec) at the beginning of the ratio, but these longer IRTs were much less frequent toward the end of the ratio. However, such long IRTs were not a necessary part

of the transition from preratio pause to rapid responding, for other trials included few or no long IRTs other than the preratio pause (Panels 2 and 3 for FR 50, Panels 1 and 4 for FR 100, and Panel 2 for FR 150 are examples). In short, responding was slow near the beginning of a ratio on some trials, but on others there was an abrupt transition from a long preratio pause to rapid responding.

One pattern that is obvious in Figure 4 is the tendency for short IRTs to fall into two distinct classes, one class averaging about .1 sec and the other averaging about .3 sec. The other two subjects also showed this pattern. Direct observations of the animals indicated that these two classes of IRTs arose from two different response topographies. IRTs of about .3 sec were produced when large, distinct head movements away from and toward the key separated two responses. The shorter, .1 sec, IRTs were the result of small head movements in the vicinity of the key. They were often produced when a subject struck the key with a glancing blow from the tip of the beak and

Fig. 4. Individual interresponse times are shown from several representative trials of each condition for Subject 2. Interresponse times are plotted to the nearest .02 sec, and IRTs greater than 1.5 sec are plotted at the top of a panel. The single arrows and double arrows indicate IRTs greater than 6 sec and IRTs greater than 60 sec, respectively.

then with the side of the beak or head in rapid succession. IRTs from either of these two categories resulted in an impression of rapid, continuous responding, since the subject did not pause or step away from the key. In contrast, longer IRTs were frequently accompanied by locomotion or by head movements toward other parts of the chamber.

These two classes of IRTs are clearly evident in the bimodal shape of the frequency distributions shown in Figure 5. The three functions shown for each subject represent the proportion of IRTs (excluding preratio pauses) that fell into successive .02-sec bins in the three conditions. The IRT frequency distributions for TO and NTO trials were indistinguishable, so the data from both types of trials were pooled in Figure 5. For all subjects, the frequency distributions of IRTs were quite similar across the three different FR sizes. The peaks around .1 sec exhibited no systematic changes across conditions. However, for each subject, the peak around .3 sec occurred at a slightly greater IRT size in the FR 150 condition than in the other conditions. The location of the peak shifted to the right by about 10% (e.g., from about .28 sec to .31 sec for Subject 3). This 10% increase in the modal duration of these intermediate size IRTs is small when compared to the change in overall running response rates from FR 50 to FR 150—the three subjects showed decreases of approximately 75%, 50%, and 65%, respectively. This comparison indicates that the primary cause of the lower running response rates with larger ratio sizes was not a shift in the peaks of the IRT frequency distributions, but rather a change in the proportion or mean duration of very long IRTs. Table 2 shows the mean durations of IRTs greater than one second and the relative frequencies of these IRTs in all conditions (preratio pauses are excluded from these analyses). As the ratio size increased, so did the mean duration of IRTs greater than one second (with the exception of Subject 1 in FR 100). In other words, within-ratio pauses were longer with the larger ratios. For Subjects 1 and 2, there was also a steady increase in proportion of IRTs that were greater than one second, but for Subject 3 the proportion remained roughly constant.

The results depicted in Figures 4 and 5 suggest that it may be informative to examine the relative frequencies of three different classes of

Fig. 5. For each of the three conditions, the proportion of IRTs falling into successive .02-sec bins is shown. IRTs from both TO and NTO trials were pooled for these analyses, and preratio pauses were not included.

IRTs at different response locations within a ratio: first, IRTs less than .2 sec, which include all of the short IRTs in the first peak of the IRT distributions in Figure 5; second, IRTs between .2 sec and .5 sec, which encompass responses in the second peak of the IRT distributions; third, IRTs greater than .5 sec, which include the long IRTs in the tails of the frequency distributions. The choice of .5 sec as a boundary was somewhat arbitrary, since Figure 5 shows no break in the IRT distributions at this point. Yet based on observations of the subjects' behavior, it seemed

Table 2

Relative frequencies and mean durations of IRTs greater than one second (preratio pauses are excluded).

	FR 50		FR 100		FR 150	
	Proportion of all IRTs	Duration (sec)	Proportion of all IRTs	Duration (sec)	Proportion of all IRTs	Duration (sec)
S1	.010	10.6	.016	5.9	.036	38.7
S2	.016	1.6	.039	4.0	.056	6.4
S3	.026	2.1	.012	4.1	.024	32.6

important to distinguish between the intermediate IRTs produced by continuous pecking motions and the long IRTs that were the result of pausing and often locomotion around the chamber. Figure 6 shows the proportions of IRTs that fell into each of the three classes in successive 5-response bins within a ratio. Without exception, the probability of an IRT greater than .5 sec was at a maximum at the start of a ratio, and it then declined and remained at a low and fairly constant level for the remainder of the ratio. The smallest IRT category showed the opposite pattern. The probability of IRTs less than .2 sec was at a minimum at the start of a ratio and gradually increased through the ratio, reaching a plateau of about .3 to .4 towards the end of a ratio. The probability of IRTs in the .2 to .5 sec category exhibited an initial rise in seven of nine cases. This initial increase in intermediate IRTs mirrored the initial decrease in long IRTs. The two cases without an initial increase in the probability of intermediate IRTs were those with the lowest initial probabilities of long IRTs. The gradual decline in intermediate IRTs through the later parts of the ratio mirrored the gradual increase in the proportion of short IRTs. In summary, although some IRTs from each class occurred at all response locations, long IRTs were at a maximum near the start of a ratio, intermediate IRTs usually reached

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Fig. 6. IRTs were divided into three categories (less than .2 sec, between .2 and .5 sec, and greater than .5 sec) for this figure. The proportions of IRTs in each category are shown for successive groups of five response locations within a ratio. The first point of each function actually includes only four response locations because preratio pauses were excluded. (That is, the first point includes Response Locations 2 to 5, the second point includes Response Locations 6 to 10, and so on.)

their maximum somewhere in the middle of a ratio, and short IRTs were at their maximum towards the end of the ratio.

These transitions from a high probability of long IRTs to a high probability of intermediate IRTs and then to short IRTs did not occur at the same response location in the different schedules. Rather, Figure 6 shows that as FR size increased, so did the response location at which a particular transition occurred. For example, for Subject 1, the probability of short IRTs reached a maximum after about 25 responses with FR 50, about 40 responses with FR 100, and about 60 responses with FR 150. As another example, the highest probability of intermediate IRTs for Subject 2 occurred at about 10 responses with FR 50, about 25 responses with FR 100, and about 65 responses with FR 150. For this same subject, long IRTs reached a minimum after about 15 responses with FR 50, about 25 responses with FR 100, and about 60 responses with FR 150. It should be noted that the response locations at which particular transitions occurred were not always strictly proportional to the size of the ratio.

DISCUSSION

The effects of the 30-sec timeouts that occurred before a random half of the trials can be summarized simply. As in the studies of Ferster and Skinner (1957) and Richards and Blackman (1981), preratio pauses were generally shorter after timeouts. The within-session comparison of TO and NTO trials in the present study ruled out the possibility that the shorter pauses might be due to the wider spacing of trials throughout an entire session. Whatever the cause of the shorter pauses, it is clear that this mechanism operates on a local (trial-by-trial) level. Furthermore, the results suggest that the shorter pauses may have been due to transient behavioral contrast (e.g., Staddon, 1969), as proposed by Richards and Blackman (1981), since the probability of a first response was usually higher after a timeout than at any other time (see Figure 2 and Table 1). If the results were the product of short-term satiation or fatigue, the probability of a first response should have been lowest at the start of a NTO trial, but this pattern was not observed.

Whereas Richards and Blackman (1981) found slightly higher running response rates

after timeouts in two of three subjects, in the present study timeouts had no systematic effects on running response rates. On the other hand, ratio size had a substantial effect on overall running response rates, with rates decreasing as the size of the FR increased (Figure 1). Despite Powell's (1969) suggestion that running response rates are affected little, if at all, by ratio size, a number of earlier studies reported results consistent with those of the present experiment. For instance, the Felton and Lyon (1966) study with pigeons and Winograd's (1965) study with rats both showed decreasing running response rates with increasing FR size. Running response rates were inconsistent in Powell's (1968) experiment, although there was a slight trend in the same direction as in the earlier studies. Kaplan (1956) found no orderly changes in running response rates from rats with escape from bright light as a reinforcer, but no ratios larger than 15 were utilized. A summary of the literature reveals that if a study found any systematic change in running response rates at all, this change was a decrease in response rate with increasing FR size.

One additional finding of the present study was that running response rates varied substantially as a function of response location within a ratio: Response rates were lowest at the start of a ratio and highest at the end. Yet despite all the evidence showing large and systematic variations in running response rates, there are two senses in which it can be said that responding exhibited stability across conditions. First, Figure 3 shows that at response locations near the end of a ratio, response rates were roughly the same in all conditions. If we consider only the last half of the responses on an average trial, this experiment provided no evidence for a decrease in response rate with increasing ratio size. Of course, it is possible that response rates near the end of a ratio would be lower if ratios larger than 150 were examined.

A second type of stability across conditions is the tendency for responses to fall into three fairly distinct categories differing in both response topography and IRT size. The IRT frequency distributions in Figure 5 show sharp peaks at about .1 sec and .3 sec, with very few IRTs in the vicinity of .2 sec. As mentioned above, the IRTs of about .1 sec were produced by small head movements in the immediate vi-

cinity of the key. Gott and Weiss (1972) observed similar short IRTs in some (but not all) pigeons on an FR 30 schedule. Gott and Weiss reported that these short IRTs were produced by "biting" or "nibbling" responses, with a subject keeping its head close to the key. For some birds, the short IRTs decreased in frequency after a number of sessions, but for at least one subject they continued throughout the experiment. In the present experiment, the short IRTs showed no signs of disappearing, for the height and modal duration of the first peak of the frequency distribution did not change substantially across conditions.

The IRTs comprising the second peak of the distribution were produced when two responses were separated by a distinct pecking motion—a large, rapid head movement away from and then toward the key. Gott and Weiss reported a similar finding: They observed that responses made by a "cleancut" pecking response produced a peak in the vicinity of .28 to .40 sec in a subject's IRT frequency distribution. Across the three conditions of the present study, the modal duration of the second peak was not quite as constant as that of the first peak. For every subject the second peak shifted to a somewhat longer duration in the FR 150 condition, indicating a slight decrease in the tempo of the pecking response. Nevertheless, this shift was small compared to the marked decrease in running response rates in the FR 150 condition.

Although the distinction between short and intermediate IRTs was unmistakable in this experiment, the occurrence of these two categories of responses is by no means a necessary result of an FR contingency. In the Gott and Weiss (1972) study, IRT distributions for some subjects showed only a single peak. Others had from two to five peaks, with the first peak around .3 sec and with subsequent peaks at multiples of .3 sec. Gott and Weiss attributed the multiple peaks to the occurrence of one or more ineffective pecks between two recorded pecks. In the present study, no peaks were observed at multiples of .3 sec, suggesting that ineffective pecks were rare. (Direct observations supported this conclusion.) These differences in IRT distributions between the present study and the Gott and Weiss study might be the result of subject differences or of subtle differences in the response key itself.

In an examination of the factors that affect

response rate, Pear and Rector (1979) distinguished between the concepts of "propensity" and "speed." Propensity refers to the proportion of time a subject devotes to instrumental responding, and speed refers to the rate of continuous responding. One pigeon in the Pear and Rector study responded on two different FR schedules. Response propensity (the amount of time spent standing on a response platform) varied with FR size, whereas speed (pecking rate while on the platform) was fairly stable. Similarly, in the present study, ratio size affected propensity much more than speed. The distribution of short IRTs changed little from condition to condition (suggesting a constancy of response speed), but as ratio size increased there were large increases in the mean durations and/or relative frequencies of long IRTs (suggesting a decrease in response propensity).

The results shown in Figures 3 and 6 are relevant to a model of ratio-schedule performance proposed by Mazur (1982). This model predicts that the momentary probability or rate of responding on FR schedules will be a direct function of the number of responses remaining before reinforcement at that moment. On the surface, the results seem to support this prediction, since response rates increased across response locations. However, the model predicts that with a given number of responses remaining before reinforcement, performance should be the same regardless of the absolute size of the entire ratio. Thus, with, for example, 49 responses remaining, performance should be the same regardless of whether the schedule is FR 50, FR 100, or FR 150. Figures 3 and 6 show that this was not the case. With 49 responses remaining before reinforcement, the probability of an IRT greater than .5 sec was relatively high in the FR 50 schedule but quite low in the other schedules. Similarly, long IRTs were numerous with 90 responses left in the FR 100 schedules but not with 90 responses left in the FR 150 schedule. In short, the probability of a long IRT was high in the first part of a ratio regardless of the size of the ratio (and regardless of the absolute number of responses remaining before reinforcement).

Why was responding slow at the start of a ratio regardless of the size of the ratio? One explanation that can be dismissed is that a subject needs to produce a certain number of

responses before it can accelerate to its maximum response rate. This explanation predicts that a subject will start slowly but reach a maximum response rate after, for example, five responses on all ratio schedules. However, Figure 3 shows that the rate at which responding increased was not the same on all schedules. Instead, the maximum response rate was reached at larger and larger response locations as ratio size increased.

Another explanation is that FR responding is controlled by relative response location within a ratio. That is, a certain proportion of short, intermediate, and long IRTs will occur when a subject has completed, for example, 20% of the ratio, regardless of the absolute size of the ratio. This approach has a parallel in research on fixed-interval schedules, where it has been shown that responding increases through an interval at a rate proportional to the size of the interval (Dews, 1970; Gibbon, 1971, 1977). The hypothesis of control by relative response location is weakened, however, by the fact that response patterns were only approximately scaled to the size of the ratio, and systematic deviations from strict proportionality were evident. For example, for Subject 1 in the top row of Figure 3, the median response rate was first reached 36% of the way through the ratio on FR 50, 26% of the way on FR 100, and 24% of the way on FR 150. This same pattern of decreasing percentages occurred in all six rows of Figure 3.

In summary, orderly within-ratio response patterns were obtained on all FR schedules, but the determinants of these patterns are not obvious. It is clear that performance cannot be predicted simply by knowing the absolute number of responses remaining before reinforcement, irrespective of ratio size. Relative position within a ratio is a better, but not perfect, predictor of within-ratio performance. Furthermore, any theory of control by relative response location has its limitations, because certain aspects of performance (e.g., preratio pause duration, within-ratio pause duration) varied as a function of the absolute response requirements. A better understanding of within-ratio and between-ratio FR performance variations awaits further research.

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