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# *STUDIES ON RESPONDING UNDER FIXED-INTERVAL SCHEDULES OF REINFORCEMENT: II. THE SCALLOPED PATTERN OF THE CUMULATIVE RECORD*

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Responding under fixed-interval schedules usually generates either scalloped or break-and-run cumulative records. Earlier, it was generally accepted that the characteristic pattern was the scallop, but in recent years there has been an increasing emphasis on the break-and-run pattern. The break-and-run pattern has been shown quantitatively to provide a good fit of certain fixed-interval patterns. In the present work, responding during fixed-interval 1000-second components of a multiple fixed-interval 1000-second fixed-ratio 50 responses schedule was examined in two rhesus monkeys. Even after responding had started in an interval, there was a high tendency for responding to accelerate over subsequent 100-second segments of the interval. In segments with responding, the rate increased from one segment to the next in 303 of 389 segments in one monkey and in 310 of 419 segments in the other. The size of the increase was substantial, the rate in the fifth segment after responding started being an average of 4.5 times higher than the rate in the first segment after responding started. Hence, the usual pattern of responding in individual intervals was of sustained and substantial acceleration, vindicating numerically the conclusion derived from inspection of the scalloped patterns of the cumulative records.

*Key words:* FI schedule, *mult* FI FR, FI scallops, break-and-run analysis, rhesus monkeys

Under the name of periodic reconditioning, Skinner studied fixed-interval (FI) schedules in the 1930s (Skinner, 1938), but the first publication of extensive cumulative records was in *Schedules of Reinforcement* (Ferster and Skinner, 1957). Many examples of smoothly increasing rates of responding through considerable portions of individual FI are shown, and the shape of the cumulative record was described as scalloped, a term introduced by Skinner (1938, p. 123). The prevailing view of the usual FI pattern of responding may be summarized as: "There is an initial pause with few or no responses at the beginning of the interval, then a period of increasing rate of responding up to an asymptotic rate that is rarely exceeded, but may not be attained" (Dews, 1970).

Already in 1957, Ferster and Skinner (1957, p. 159) noted that some individual intervals showed an abrupt transition from no responding to a constant rate that was maintained to the end of the interval. They attributed such patterns to the association in many cycles of a particular rate of responding with occurrence of the reinforcer, leading to responding at that rate being repeatedly reinforced, and so being shaped to recur. Such an effect would be a consequent effect, rather than a direct or indirect effect of the schedule (Dews, 1970). Long exposures to long sessions under FI were suggested by Cumming and Schoenfeld (1958) to contribute to the abrupt transitions in rate, which they labelled the "break-and-run" pattern.

While students of FI responding have recognized the occurrence of break-and-run patterns, and that they can become the dominant pattern in a particular subject, they were generally regarded as a variant of the fundamental smooth scalloped pattern, a variant that occurred in limited special circumstances as a consequent effect of the schedule. For example, when Herrnstein and Morse (1957), and Fry, Kelleher, and Cook (1960) wanted to summarize data on FI responding, they chose indices that were appropriate for scalloped patterns, and Killeen (1975) fit FI patterns with a derivative of the normal curve that generated a scalloped, rather than a break-and-run

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pattern. In 1969, however, Schneider published quantitative analyses of the results of his experiments on pigeons responding under FI of values up to 512 sec and concluded that the pattern was best described as break and run. He suggested that "a fixed interval schedule after extended training can be considered a multiple extinction, variable interval schedule" (Schneider, 1969).

A strength of Schneider's treatment was that he fit the pattern of individual FI. Other attempts at curve fitting to the FI pattern have averaged responding over a number of FI. A common method of summarizing numerical information on FI, as required in drug studies for example, has been to cumulate responding in segments of the FI (usually tenths) (Dews, 1964; McMillan and Healey, 1976). The method was intended to summarize the scallops of individual intervals in the form of an average scallop for the session. The average has, indeed, usually shown a scalloped pattern, but as pointed out by Schneider (1969) and others, a scalloped average curve does not establish that the individual intervals were scalloped. A break-and-run pattern in individual intervals with variable length of break could average to a smooth scallop. Schneider's analysis has attracted considerable attention, no doubt partly because of its quantitative nature, and has influenced, for example, the handling of results on drug effects in FI responding (Branch and Gollub, 1974). While the smooth scalloped pattern of the cumulative record of individual fixed interval in many experiments is vivid proof of the smooth progression of rates, only selected sections of cumulative records can be published, and the scalloped patterns have not been validated by methods summarizing all of the information from all of the fixed intervals of a number of sessions.

The present results were collected on two rhesus monkeys undergoing prolonged exposure to *mult* FI FR in the course of drug studies. For a period of time, the number of responses in every one-tenth segment of every interval was separately recorded. The object was to see whether scalloping of individual FI could be shown numerically to be the usual pattern of the FI and so to confer on the scalloped pattern the mathematical respectability now enjoyed only by the break-and-run pattern.

## METHOD

### *Subjects*

Two adult male rhesus monkeys, AD and AV, had been acquired by the New England Primate Research Center in 1970 as young adults. During the experiments, Monkey AD was maintained at close to 8.0 kg (free-feeding weight about 9.0 kg) and Monkey AV at close to 5.0 kg (free-feeding weight about 6.0 kg).

### *Apparatus*

Subjects were confined during sessions in a standard primate restraining chair. The front of the chair was covered by a plastic panel with a modified rat lever (R. Gerbrands Co.) protruding 1.5 cm through it. The lever was in the middle of the panel with respect to the sides, 30 cm above the waist piece, at the level of the upper sternum, 25 cm in front of the monkey. The lever was modified by removing the microswitch and substituting simple normally closed mechanical contacts and spring loading so that a force of 1.96 N was necessary to open the contacts. Movement of the front of the lever was limited to 2 mm. The adjustments permitted high rates of responding (more than 10 responses per second) to be recorded. Pellets of 200 mg of high-protein monkey diet were delivered according to the schedule. Water was available continuously. During sessions, the subject was in a sound-attenuating chamber with the visual stimuli in front of and above the monkey. Visual stimuli were green and yellow 25-W bulbs and a white 25-W display cabinet bulb activated for 30 msec by each response. Auditory stimuli were the click of a feed-back relay, which operated at every response and a tone of about 600 Hz.

### *Procedures*

Subjects worked under *mult* FR 50 FI 1000-sec. In the presence of the yellow light and tone, FR 50 was in effect and in the presence of the green light, FI 1000-sec was in effect. On completion of the schedule requirement, a pellet was delivered and the white light remained on. Each of the next four responses was followed by a pellet. Then, all lights were extinguished for 30 sec. Then, the next component began. The FI and FR components followed one another in an irregular sequence that was constant from session to session. There were 10 FI components in each session. Both subjects had completed more than 3000 individual FI 1000-sec over a period of about a year before the present numerical information was collected. For 10 consecutive sessions, the number of responses in each 100-sec segment of each interval was collected.

### *Calculation of Results*

The number of responses in individual segments of individual intervals for 10 sessions was tabulated, starting in each interval with the terminal segment and then continuing backwards until a segment was reached in which no responses occurred. From the table, the following computations were made:

(1) The mean number of segments per FI in which responding occurred and how often the number of responses in a segment exceeded the number in the preceding segment, indicating an increase in rate. As the first segment with responses in each FI must have more responses than the preceding segment, which had none, the first segment was excluded from the tallies. The very first segment of each FI, even if responding occurred during it, was thus necessarily excluded. Nonparametric binomial statistics were performed on the number of segments showing or not showing a higher rate of responding than the immediately preceding segment.

(2) To determine how much rate of responding continued to increase after responding started, the intervals were segregated according to whether responding occurred only in the tenth segment, only in the ninth and tenth, in the eighth, ninth, and tenth, and so on. These segregated intervals were then averaged across the segments with responding.

For comparison, a segment-by-segment average was computed across all corresponding segments, first, second, third . . . tenth, of all FI without regard to responding, in the manner performed many times in the past (*e.g.*, Dews, 1964; McMillan and Healey, 1976).

(3) The rate of responding in a segment was examined as a function of how many segments of responding had preceded it in that FI.

## RESULTS

The pattern of responding showed strong control by the discriminative stimuli, so that responding in the FR and the FI components was consistently very different (Figures 1 and 2). The cumulative records for both components are quite similar to previously published records of responding under *mult* FI FR schedules (*e.g.*, Ferster and Skinner, 1957, p. 506). Under FI, the cumulative records showed a scalloped pattern, while under FR, the rate after initiation was high and constant. Figures 1 and 2 show that the patterns of responding were similar in the two-hundredth session and in the three-hundredth session.

*Continued increase in rate through intervals.* Numerical results from a single session of Monkey AD are shown in Table 1. The number of segments in which responding occurred was 59 and, excluding the first segment with responding in each interval, the number of responses in a segment exceeded the number in a preceding segment 44 times and failed to do so five times. The intervals in this session were segregated for averaging as follows: No. 10 alone (responding in nine segments); No. 1 alone (responding in eight segments); No. 8 and No. 9 (responding in seven segments); No. 2, No. 5, and No. 6 (responding in six segments); No. 3 alone (responding in five segments); No. 4 alone (responding in three segments) and No. 7 alone (responding in two segments). The segregated intervals were then combined with similarly segregated intervals of other sessions.

If the rate of responding were equally likely to be greater or to be the same or less from segment to segment, the probability of an increase would be 0.5 and the distribution of the number of increases would be binomial with S.D. = $\sqrt{npq}$, where $p = q = 0.5$ and n is the sample size. In the session shown in Table 1, the expected number of increases in the 49 segments was 24.5 with S.D. of 3.5; the observed number of increases was 44, a deviation from expectation of 19.5 or 5.5 S.D.s. A deviation so large has a $p$ of less than $10^{-6}$, for the single session alone.

In the samples of 1000 segments for each subject (10 segments per FI, 10 FI per session, 10 sessions) there were responses in 489 segments for Monkey AD and 519 segments for Monkey AV, so each subject was responding on the average through about one-half the intervals. Excluding the first segments with responding, for Monkey AD, 303 segments had more and 86 segments had no more re-

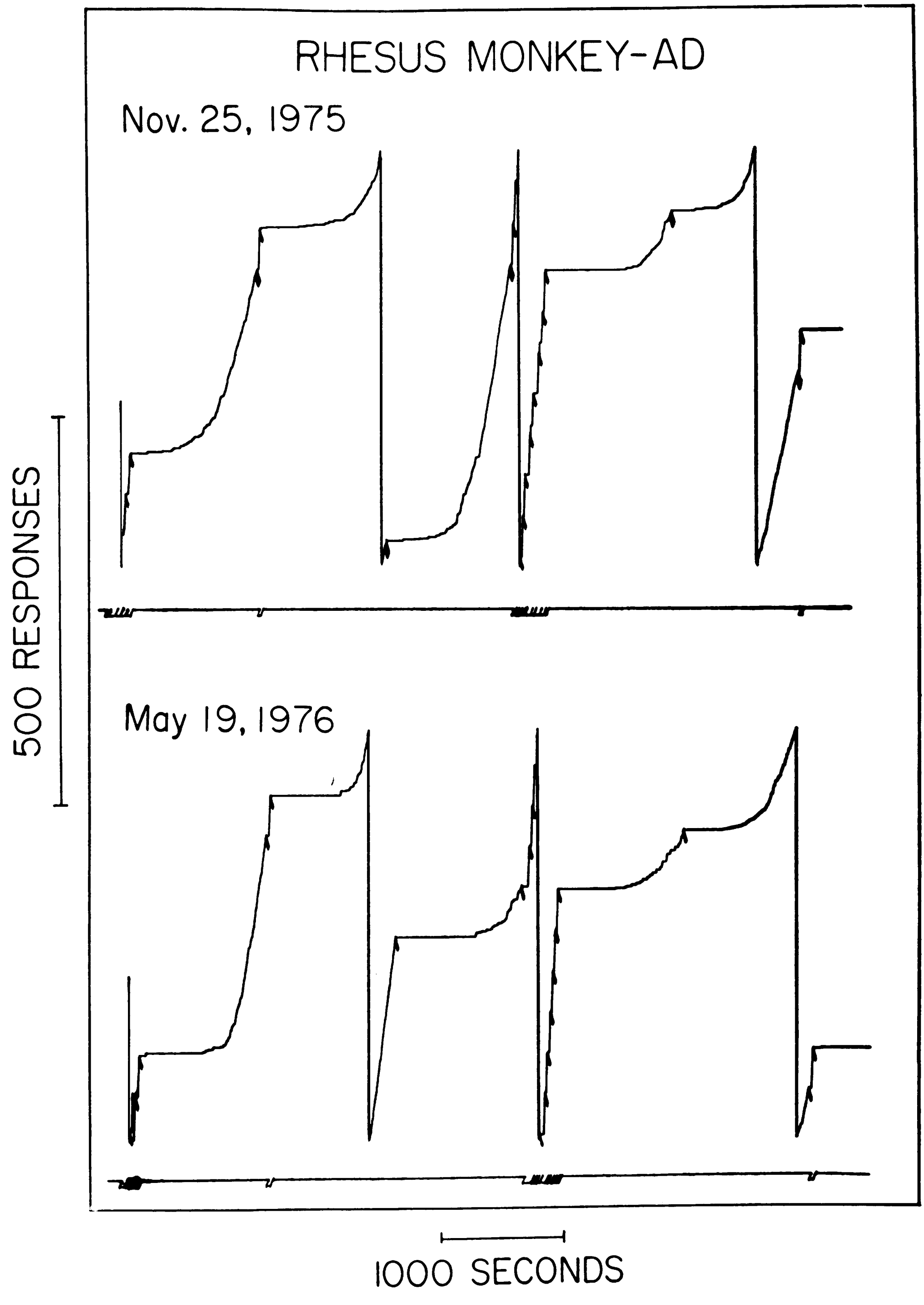

Fig. 1. Responding of Monkey AD under *mult* FI 1000-sec FR 50. Upper record (25 November 1975) illustrates pattern in two-hundredth session under schedule, lower record (19 May 1976) is from the last session of number collection for present purposes, the three-hundred-sixteenth sessions. Some 1160 FI had occurred between two records but the patterns are similar, with no greater tendency to break-and-run pattern in the lower record. The lower pen in each record is downset during FR components. Note that the rate of responding under FR was consistently much higher than even terminal rates under FI.

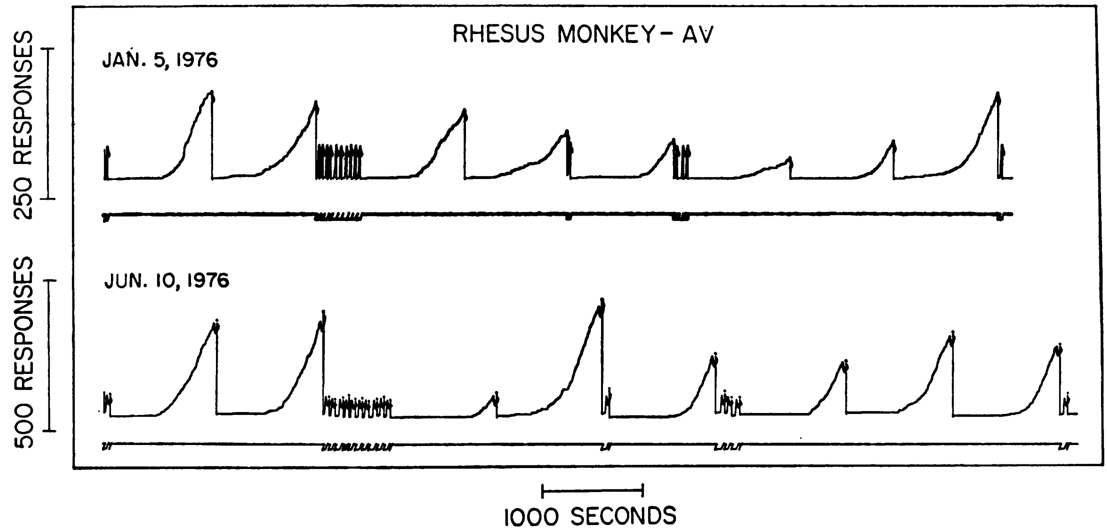

Fig. 2. Responding of Monkey AV under *mult* FI 1000-sec FR 50. Upper record (5 January 1976) illustrates two-hundredth session and lower record (10 June 1976) the last session of number collection, Session 293. In contrast to Figure 1, the pen reset to baseline after each timeout period. Also, the scale of the ordinate differed on the two sessions. In spite of the approximately two-fold difference in mean rate of responding, the *pattern* of FI responding is very similar, and very similar to Monkey AD. Monkey AV weighed 5.3 kg on 5 January 1976 and 5.0 kg on 10 June 1976.

sponses than the preceding segment, and for Monkey AV, 310 segments had more and 109 segments had no more than the preceding segments. For each subject, the numbers of segments showing more responses than the preceding segment exceeded the expectation based on equality by more than 10 S.D. units, representing an infinitesimally small probability of occurrence by chance. There was, therefore, a very significant tendency for the rate to increase from one segment to the next in individual intervals, even when the initial segment of responding was excluded. Note that the probabilities are conservative, since they are based on increases as compared to both decreases and no change combined. The mean number of consecutive segments with increasing rate per interval was 3.9 for each subject, so that, on the average, the rate was increasing over almost 40% of the interval.

Table 1

Numbers of Responses in 100-sec Segments of Individual Intervals

| *Interval No.*[a] | *Ordinal Number of Segment* | | | | | | | | | | *No. with Respond.*[b] | *No. with Increase*[c] | *No. without Increase*[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | | | |
| 1 | 0 | 0 | 1 | 6 | 39 | 55 | 63 | 83 | 86 | 86 | 8 | 7 | 0 |
| 2 | 0 | 0 | 0 | 0 | 1 | 22 | 61 | 65 | 84 | 50 | 6 | 4 | 1 |
| 3 | 0 | 0 | 0 | 0 | 0 | 3 | 47 | 67 | 73 | 86 | 5 | 4 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 33 | 45 | 3 | 2 | 0 |
| 5 | 0 | 0 | 0 | 0 | 1 | 7 | 20 | 9 | 50 | 67 | 6 | 5 | 0 |
| 6 | 0 | 0 | 0 | 0 | 10 | 18 | 43 | 38 | 61 | 67 | 6 | 4 | 1 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 8 | 2 | 1 | 1 |
| 8 | 0 | 0 | 0 | 1 | 19 | 54 | 63 | 79 | 73 | 79 | 7 | 5 | 1 |
| 9 | 0 | 0 | 0 | 1 | 2 | 0 | 12 | 2 | 58 | 72 | 7 | 6 | 0 |
| 10 | 0 | 2 | 4 | 3 | 15 | 26 | 43 | 63 | 76 | 67 | 9 | 6 | 2 |
| | | | | | | | | | | TOTALS | 59 | 44 | 5 |

[a] Ordinal number of interval of session.

[b] Number of segments during which responding occurred.

[c] Number of segments with more responses than preceding segment. (excluding initial segment of responding).

[d] Number of segments with no more responses than preceding segment.

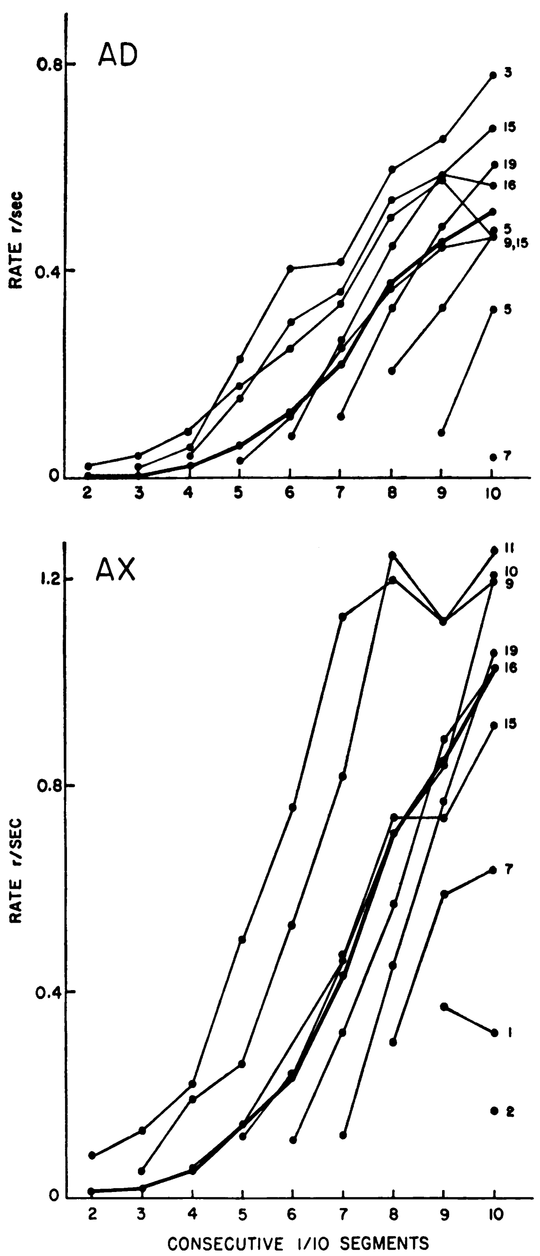

Fig. 3. Rate of responding in consecutive segments in which responding occurred, excluding the first in each interval. Each line (except the heavy line) represents the family of FIs with start of responding in the same segment. Thus, for the intervals in which responding started in the second segment, the line has eight points; when responding started in the third segment, the line has seven points, and so on until when responding started only in the ninth segment the line is represented by a single point. The number on the right gives the number of FI on which the line is based. The heavy line shows rate of responding in succeeding segments averaged over all FIs.

*The size of the increases in rates of responding.* Figure 3 shows that the continuing increases in rate were large. The numbers on the right are the number of intervals contributing to each line. Responding was initiated at some time in the segment immediately to the left of the left-most point for each line in Figure 3. If we start with the rate corresponding to the left-most point of the line, the rates in the next three segments were on the average 2, 3, and 4.5 times the rate in the first segment. This represents a 65% increase from one segment to the next over three segments, or 30% of the interval. Thus, the rate not only continued to increase after initiation of responding, but the amount of acceleration over several segments continued to be as great as when responding first started. The lines in Figure 3 are generally parallel, indicating constant acceleration over much of the interval, once responding had started. The heavy lines in Figure 3 show the mean rate in the second, third . . . tenth segments of all intervals. The averaging thus includes segments with and without responses. This line shows more concavity over segments three through seven than the lines for segregated intervals.

*The rate at the end of the interval.* When the rate of responding is plotted as a function of the number of preceding segments with responding, it can be seen that the rate increased over three to five segments, and then increases became less. The first part of the curves for both monkeys in Figure 4 is linear, reflecting the general parallelism of the curves of Figure 3, and indicating that acceleration of responding was similar whenever in the interval responding started. Consequently, when responding started as late as the seventh or eighth segment, the rate in the terminal segment was less than when responding started earlier in the interval (Figure 3).

## DISCUSSION

Once responding had started in an individual interval, rate continued to increase for an average of 40% of the interval. The rate of responding averaged more than 4.5 times greater when responding had continued through four segments than in the first segment after that in which responding started. The acceleration of responding over much of the individual intervals, apparent in the se-

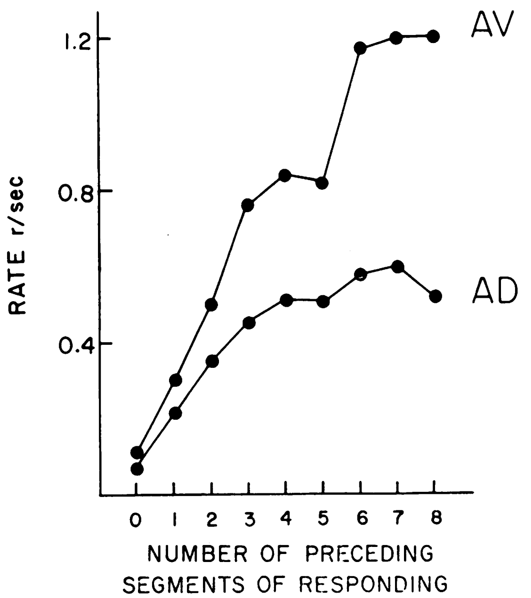

Fig. 4. Rate of responding in a segment as a function of the number of preceding segments of responding in that FI. The curves for both monkeys tend to level off in later segments, clearer with Monkey AD, suggesting that the rate reaches an asymptote.

lected cumulative records of Figures 1 and 2 is, therefore, vindicated in a more comprehensive numerical summary. In the segment when responding was initiated, initiation could occur anytime during the segment, and so the number of responses in the segment would be variable, even if the rate of responding were constant after the initiation. This first segment of responding was therefore excluded from analysis. After the first segment with responding, however, a break-and-run pattern would yield a constant rate in subsequent segments. The segregating of intervals so that only segments with responding were averaged eliminates the possibility of an apparent increase due to a decrease in the number of segments without responding in the average.

In the study of interresponse times (IRTs) shortly after the start of responding in individual FI, Shull and Brownstein (1970) found that while the first few IRTs showed a progressive shortening, the twelfth IRT was not recognizably shorter than the sixth. In the data of Table 1, each IRT was, on average, about 1% shorter than its predecessor as calculated from average rates over segments. With a 1% decline, the twelfth IRT would be only about 6% less than the sixth IRT, an inappreciable difference. But the one-hundred-seventy-fifth IRT would be only about one-seventh of the tenth IRT, which is quite enough to generate a clear scallop of the cumulative record.

Continued progress in understanding FI responding will probably require studies on average rates of responding over short periods, as well as analysis at the level of individual IRTs, especially since the value of the final IRT of the FI is less crucial in determining the pattern of FI responding than was once thought (Dews, 1969). Schneider's (1969) suggestion that FI responding may sometimes be regarded as *mult VI, extinction* should be examined further, for example by seeing whether it is influenced appropriately by a drug, such as amphetamine, that does not cause large amounts of responding during $S^{\Delta}$.

While the break-and-run pattern of FI responding undoubtedly occurs, the following should be noted. Scalloped patterns have been seen both early and late in exposure to FI schedules. As exemplified by the present results, scalloped patterns do not necessarily become break-and-run patterns as exposure is prolonged. Scalloped patterns have been seen as the prevailing pattern of cumulative records of FI responding over a wide range of parameter values up to 100,000 sec (27.75 hr) (Dews, 1965). Scalloped patterns have been seen in a variety of species: pigeons (Ferster and Skinner, 1957); mice (Wenger and Dews, 1976); rats (Skinner, 1938); cats (Dews, unpublished observations); dogs (Waller, 1961); a horse (Myers, 1960); squirrel monkeys (Kelleher and Morse, 1964); rhesus monkeys; baboons (Byrd, 1975); and chimpanzees (Byrd, 1975). A break-and-run pattern has been seen in occasional intervals in most of the preceding situations, but has been demonstrated to become the dominant pattern in only a few experiments, usually with short FIs of 300 sec or less. If the direct effect of FI schedules is to engender scalloped patterns of responding, it is easy to see, in principle, how the fortuitous association of a particular rate with occurrences of the reinforcer on a number of occasions could generate a break-and-run pattern that then comes to prevail. While such a mechanism for converting a scalloped pattern to a break-and-run pattern has not been proved to operate, it is a reasonable possibility. No one has suggested a mechanism, even in principle, whereby if the direct effect of the FI schedule is to generate a break-and-run pattern, how smooth scallops come to occur with such frequency. The break-and-run pattern does not always emerge, because there is usually insufficient consistency in the association of a particular rate with the reinforcer.

The parallel curves of Figure 3 suggest that acceleration of responding is similar whenever in the interval it starts, and that therefore it is time (or number) since the initiation of responding, and not elapsed time in the interval, that controls the rate of responding in an individual interval. The same conclusion was reached by Shull and Brownstein (1970) in studies on pigeons under FI of up to 5 min. The present findings confirm their conclusion and extend it to longer FI in a different species. There is considerable evidence, however, that responding in an interval is influenced by responding in previous intervals in a session, so that averaging takes place over a number of schedule cycles (Dews, 1970). The average rate in a particular segment of an interval is primarily determined by the elapsed time in the interval. Even though the rate in a particular segment may deviate from the average because of the rate in preceding segments, such deviations will be either in compensation for deviations in previous intervals or will be compensated for in subsequent intervals. The smooth averaged curve may therefore represent a basic relation between elapsed time in the interval and responding, even when the patterns of responding in individual intervals are as far from the smooth curve as to represent a break-and-run pattern.

An increase in average rate is tantamount to a decrease in average interresponse time (IRT). Individual IRTs were not measured in the present experiments, and the decrease in average IRT could be due to the progressive elimination of larger IRTs, as found by Shull and Brownstein (1970).

The tendency of the rate to reach an asymptote occurs only after a number of segments, and even then in convincing manner in only Monkey AD. The prevailing pattern is continued acceleration through the period of responding in the interval, with an asymptote seen only when responding started early in the interval. Does acceleration start from the very beginning of the interval? In the absence of actual responding, no direct assessment of acceleration can be made, of course, but it is interesting that at the beginning of FI, the rate of an otherwise steadily occurring concurrent response may be reduced (Skinner and Morse, 1957). Starting from a level of suppressed responding at the beginning of the FI, acceleration may have to proceed for some time before actual responding starts. Perhaps acceleration is continuous and even fairly constant from the beginning of the FI, in spite of the fact that an initial pause in responding usually occurs.

The intervals studied in the present work were of substantial duration, more than 16 min. Long intervals permit responding to be studied long after the immediate effects of the reinforcer and of changing stimuli have abated. Substantial distortions of the basic patterns of FI responding may result from such effects when the FI durations are shorter than a few minutes.

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