JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1969, 12, 191-199 NUMBER 2 (MARCH)

STUDIES ON RESPONDING UNDER FIXED-INTERVAL SCHEDULES OF REINFORCEMENT: THE EFFECTS ON THE PATTERN OF RESPONDING OF CHANGES IN REQUIREMENTS AT REINFORCEMENT[1]

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In pigeons responding under a 180-sec fixed-interval schedule of reinforcement, the frequency distribution of the duration of the final interresponse time before the reinforcer was compared with the distribution of the preceding two interresponse times. The results confirmed qualitatively and quantitatively the expected preferential reinforcement of longer interreinforcement times under fixed-interval reinforcement. Requirements at reinforcement were then changed to eliminate the preferential reinforcement of longer interresponse times. Local patterns and mean rate of responding could change, without the characteristic fixed-interval pattern of increasing responding through the interval (scalloping) being much affected. It is concluded that this characteristic pattern of fixed-interval responding does not depend crucially on effects of the reinforcer at the moment of reinforcement, but rather to effects extending over much longer periods of time than just the last interresponse time.

Under a fixed-interval schedule of reinforcement (FI) a response is followed by reinforcing stimuli only when some fixed interval of time has elapsed since the onset of a particular environmental stimulus that is present at reinforcement. With a variety of species, responses, reinforcers, and parameters, FI generates an increasing rate of responding through the interval, asymptoting to a relatively constant average rate in the terminal segment (Ferster and Skinner, 1957; Dews, 1958; Kelleher and Morse, 1968).The present experiments are part of a continuing program to measure the contribution of the various attributes of an FI schedule to the determination of the characteristic pattern (notably the scallop) and the rates of responding under the schedule. Since Skinner pointed out that "the effects of a schedule are due to the contingencies which prevail at the moment of reinforcement under it" (Skinner, 1953, p. 105), students of schedules have sought to explain *all* the effects of schedules in terms of characteristics of responding at the moment of reinforcement, despite the broader implications of the term "contingencies". An alternative view, that the effects on future responding of the occurrence of the reinforcer depends directly on the pattern of responding during considerable intervals of time preceding the moment of reinforcement, has been stated, and evidence to support it in the case of FI responding has been presented (Dews, 1962). The intervals of time are measured from the moment of reinforcement and so are temporally contingent on the moment of reinforcement. The present paper examines the effects on responding under FI of the precise temporal pattern of responding at reinforcement.

The average rate of responding in the terminal segment (say the terminal tenth) of an interval is fairly constant, though there is a considerable variation in the duration of individual interresponse times (IRTs), the times from the beginning of one response to the beginning of the next. Since the timing of the fixed interval continues independently of responding, the fixed interval is relatively more likely to end during a long IRT than during a short one (Skinner, 1938, p. 275; Anger, 1956). A general account of the necessary, mathematical consequences of interval-type schedules of reinforcement on the distribution of reinforced IRTs[2] in relation to the distribution of

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[1] Dedicated to B. F. Skinner in his sixty-fifth year. This research was supported by Grants MH 02094 and MH 07658 from the U. S. Public Health Service. I am indebted to Miss Leona M. Delaney for help with the experiments, and to Miss Frances Reagan for measurement of the polygraph records. Reprints may be obtained from the author, Dept. of Psychiatry, Harvard Medical School, 25 Shattuck St., Boston, Mass. 02115.

[2] Following customary practice, the response whose occurrence triggers the reinforcing stimuli by means of the controlling apparatus will be called the reinforced response. I have argued elsewhere that other responses may be equally entitled to the designation reinforced, in the behavioral sense, even though they do not similarly affect the hardware (Dews, 1962).

adjacent but non-reinforced IRTs has been presented by Revusky (1962). His arguments apply to FI when an IRT of *t* sec occurs, the fixed-interval is twice as likely to conclude during it as when an IRT of $t/2$ sec occurs. Generally, provided the durations of IRTs are small compared to the length of the interval, the conditional probability of an interval concluding in an IRT of duration *t* sec is directly proportional to *t*. IRTs of different durations, however, occur with different frequencies. The actual probability that the fixed interval will conclude during an IRT of a particular duration is equal to the proportion of the total time occupied by IRTs of that duration during the terminal segment of the interval. Consider the terminal segment of the interval (duration *T* sec) during which the mean rate and the relative frequencies of the various IRTs are constant. If the frequency of IRTs of duration t_i is f_i, then the probability of the reinforced response concluding an IRT of duration t_i is $f_i\ t_i/T$. Since the entire time is occupied by IRTs, $\Sigma f_i t_i$ over all values of *i* must equal *T*. If there is a large preponderance of short IRTs, most of the reinforced responses might conclude short IRTs, even though the conditional probability that an IRT of a given duration will conclude with a reinforced response is higher the longer the IRT (in direct proportion to the duration).

The quantitative consequences of these theoretical considerations have been examined. Derived and directly measured IRT distributions of three pigeons responding under an FI schedule of parameter value 180 sec (3 min) have been compared. The distributions were similar, so the hardware faithfully implemented the schedule in this regard. The magnitude of the differences between reinforced and non-reinforced IRT distributions differed considerably among the subjects. The importance of preferential reinforcement of longer IRTs in determining the characteristic pattern and rates of FI responding was then assessed by changing the distribution of the reinforced IRTs. Circumstances at the time of reinforcement affected the average rate of responding and the local patterns of responding, that is, the pattern over series of a few consecutive responses. The preferential reinforcement of longer IRTs was not, however, of importance in maintaining the characteristic general FI pattern of increasing rate through the interval. The results complement previous evidence indicating the importance of reinforcement of whole patterns of responding rather than of single responses (Dews, 1962; Dews, 1966).

MATERIALS AND METHODS

Subjects were three male White Carneaux pigeons, numbered 44, 152, and 260, with extensive and varied previous experience under a variety of schedules. The free-feeding weights were about 500, 525, and 490 g, respectively. During the experiment they were maintained at 400, 450, and 400 g respectively. The apparatus, response mechanism, reinforcer (food), and other stimuli were as in previous experiments on FI responding (Dews, 1962), and were in all matters of significance according to Ferster and Skinner (1957). The response key was transilluminated by white bulbs (GE Nova C 7 1/2). No houselight was present.

SCHEDULES

The schedules of reinforcement were FI 180-sec and variations thereof. The details are more easily presented with the following nomenclature (Dews, 1960). An elapsed time requirement of the schedule of reinforcement is designated by T followed by the requirement in seconds, *e.g.*, T 180-sec. Response requirements are designated by N followed by the number requirement. T 180-sec N 1 means that 180 sec must elapse and then one response occur whereupon the reinforcer supervenes; and so represents FI 180-sec. The schedules studied were T 180-sec N 1, T 180-sec N 2, T 180-sec N 10, and T 180-sec N 1 T 1-sec. The schedules T 180-sec N 2 and T 180-sec N 10 could be called tandem FI 180-sec FR 1 and tandem FI 180-sec FR 9 respectively; the last schedule has no familiar designation. All are diagrammed in Fig. 1. The key light was present continuously except during a 30-sec timeout of complete darkness which followed each presentation of reinforcing stimuli.

Procedure

Subjects were exposed to a schedule for a minimum of 20 sessions, consisting of 30 schedule cycles each concluded by reinforcing stimuli before definitive information for tabulation was collected. The final 20 cycles from a further 10 sessions were used in tabulation, giving a sample of 200 cycles for each subject

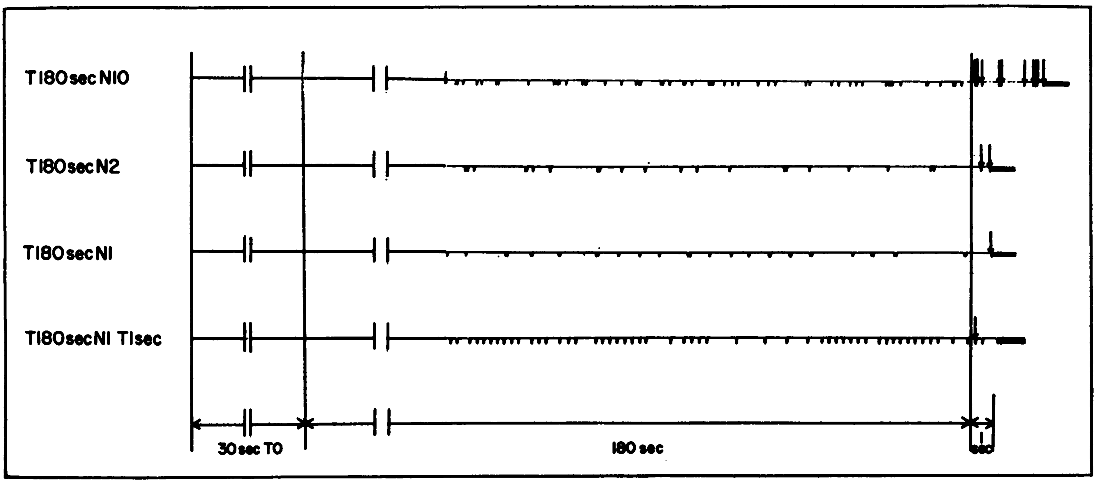

Fig. 1. Diagram of schedules. The abscissas represent time, with breaks showing omitted periods. Each schedule cycle started with a 30-sec timeout (TO) period of complete darkness followed by a 180-sec period with the key light present but with responses having no scheduled consequence. Responses are shown as brief downward deflections of the pen making the horizontal record. The key light continued until the reinforcer. The responses required by the different schedules are identified by arrows pointing to the individual responses. Finally, the first part of the period of food presentation is shown as a thickening of the line. The lines showing responses and reinforcer are polygraph records of performances on the various schedules and illustrate what was measured to obtain the distributions shown in Fig. 3, 4, and 5. The records were chosen to illustrate the schedule contingencies, *e.g.*, the possibility of continued responding in the terminal 1 sec under T 180-sec N 1 T 1-sec rather than the patterns of responding, which are shown in Fig. 3, 4, and 5. The record of T 180-sec N 1 T 1-sec, however, does illustrate the absence of short IRTs even though this particular record shows an unusually large number of responses in the 20-sec sample for this schedule. *Schedules.* T 180-sec N 10: when the key light had been present 180 sec, the reinforcer followed the tenth subsequent response. T 180-sec N 2: when the key light had been present 180 sec, the reinforcer followed the second subsequent response. T 180-sec N 1: when the key light had been present 180 sec, the reinforcer followed the first subsequent response. T 180-sec N 1 T 1-sec: when the key light had been present 180 sec, the reinforcer occurred 1 sec after the first subsequent response. Notice that the response requirements of the various schedules lead to only trivial changes in the time elapsing between onset of the key light and occurrence of the reinforcer; the difference between T 180-sec N 1 and T 180-sec N 10 in the cycles shown is about 1% of the total key-light duration.

under each procedure. Times were measured from an ink polygraph (Gerbrands Ink Writing Event Recorder) record drawn with a paper speed of 10 mm/sec (see Fig. 1). Scheduling was performed using Grason-Stadler Series 1300 Solid State Modules.

RESULTS

The characteristic pattern of FI responding, increasing rate up to the terminal rate, developed under T 180-sec N 1 (Fig. 2).

The relative frequency distributions of the durations of the three IRTs up to the reinforcing stimuli are shown in Fig. 3. For all three birds there is a deficit of short IRTs in the distribution of the last IRT before the reinforcing stimuli (L in Fig. 3) as compared to the distributions of the previous two IRTs (L-1 and L-2 respectively in Fig. 3). Short IRTs were uncommon for Birds 152 and 260, even for L-1 and L-2: they disappear altogether from the distribution of reinforced IRTs. For Bird 44, short IRTs (less than 0.1 sec) were frequent for L-1 and L-2, but short IRTs were only very infrequently concluded by reinforcing stimuli even for this bird.

Quantitative relations were examined. Panel M in Fig. 3 shows the mean of L-1 and L-2 for Bird 44. The relative frequency of responses in the different class intervals in the distribution (f_i) were multiplied by the corresponding IRT durations (t_i) to give the time occupied by IRTs of those durations ($f_i\ t_i$). The relative distribution of times in IRTs of various durations ($f_i\ t_i\ /\ \Sigma\ f_i\ t_i$) was then drawn (44 calc. of Fig. 3). Since the conclusion of the 180-sec requirement should occur in IRTs of different durations in proportion to the total time occupied by the different IRTs, the 44 calc. distribution should be the same as the distribution of reinforced IRTs.[3] The resemblance between 44 calc. and the observed distribution of reinforced IRTs for Bird 44 can be seen from Fig. 3 to be very close. Similar calculations and comparisons were made for Birds 152 and 266 with similar results, though since the difference in distribution between the last IRT and preceding ones was slight the demonstration was less dramatic. It is concluded that the preferential reinforcement of long IRTs under FI is qualitatively and quantitatively as would be expected from a program faithfully implementing the schedule.

The preferential reinforcement of a longer IRT should not occur if two responses, instead of one response, are required after the elapse of 180 sec (*i.e.*, under the schedule T 180-sec N 2), since the reinforcer occurs at the second response after the 180 sec quite independently of the time between the first and second responses (the L IRT). Detailed analyses are presented of the data of Pigeon 44; the data of Pigeons 152 and 260 showed the same effects although quantitatively the effects were much less. Under T 180-sec N 2, in fact, no preferential reinforcement of long IRTs was found; the distribution of the L IRT and the L-2 IRT were quite similar (Fig. 4). The distribution of the L-1 IRT, however, shows a strong shift towards longer IRTs; since this is the IRT during which the 180-sec interval must conclude, such a shift is according to expectations. When the number requirement was increased to 10 (T 180-sec N 10) the IRT distributions for the L, the L-1, and the L-2 became indistinguishable (Fig. 4). There was no differential reinforcement of classes of IRTs.

Another means of modifying the FI schedule to change the relations between IRTs and the occurrence of the reinforcer is to present the reinforcer at a fixed time after a response without regard to intervening responses. Under T 180-sec N 1 T 1-sec, the reinforcer was presented 1 sec after the first response occurring after elapse of the 180-sec interval (Fig. 1). There are under this schedule, strictly speaking, no terminal IRTs; the last "IRTs" are truncated by the presentations of the reinforcer, and are therefore response-reinforcer times (RRfTs). The distribution of the RRfTs

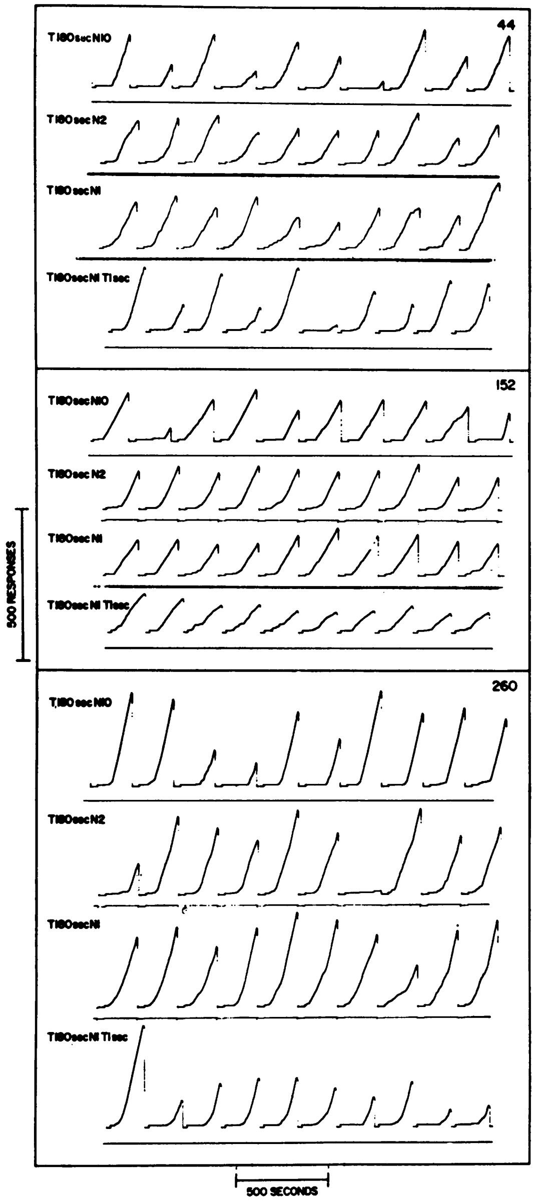

Fig. 2. Cumulative records of terminal performances under each of the schedules. Abscissa represents time, continuously through the session, including the timeout periods, which are identified by a downsetting of the response pen. The lower horizontal line on each record provides no additional information and was used merely as a help in making the chart. The details of the various schedules are given in Fig. 1 and in the text.

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[3] An additional assumption is involved here: that the distribution of L-1 and L-2 IRTs from a number of intervals in a number of sessions is the same as the distribution of IRTs during the period of the constant terminal rate in a given interval. The good quantitative agreements between observed values and calculated values justify the assumption (see below and Discussion section).

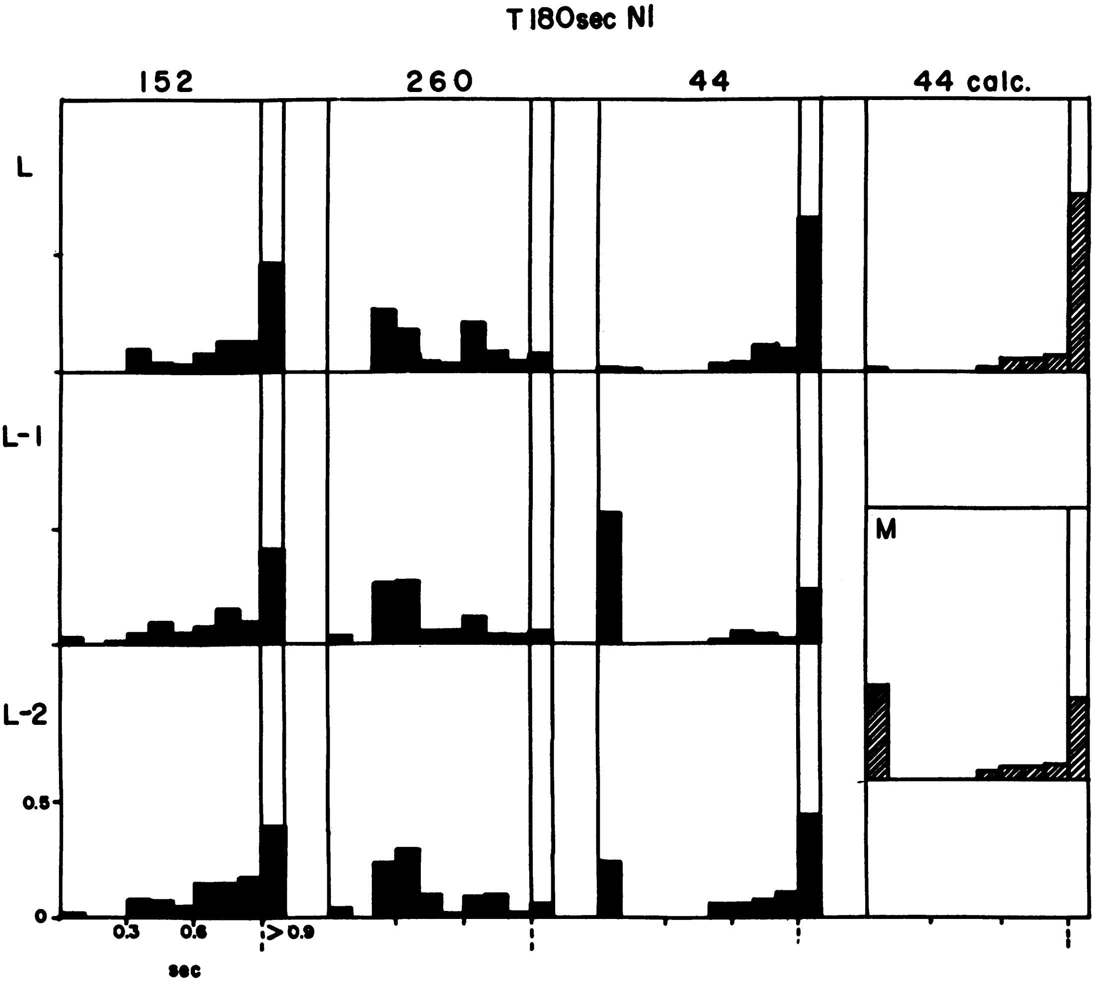

Fig. 3. Relative frequency distributions of IRTs of different durations. Abscissa: duration of IRTs in 100-msec compartments. IRTs of greater than 900 msec were pooled in the tenth compartment. Ordinate: relative frequency of IRTs. L: last IRT, *i.e.* IRT concluded by response which occasioned the reinforcer. L-1: IRT preceding L. L-2: IRT preceding L-1. M (for Bird 44): mean of distributions of L-1 and L-2. 44 calc.: proportion of total time spent in IRTs of different durations as estimated from M distribution. Notice how closely the L distribution for 44 follows the theoretically predicted distribution (44 calc.) as calculated from the independent measurements of L-1 and L-2.

is quite different from the distribution of last IRTs under the schedules previously described (Fig. 5). Again, the data of Pigeon 44 are presented.

The expected distribution of RRfTs can be calculated from the distribution of preceding IRTs. From the mean of the distributions of L-1 and L-2 (Fig. 5) the proportion of the total time spent in IRTs of different lengths was calculated, as for Fig. 2. This gives the probability that the 1-sec time period will be completed during what starts out to be an IRT of that length. But timing of the 1 sec is independent of responding so that if a reinforcer truncates an IRT that started out to be 0.4 sec long, it is equally likely to do so in the 0.0 to 0.1, 0.1 to 0.2, 0.2 to 0.3, and 0.3 to 0.4-sec class intervals. The probability of a particular IRT being truncated is therefore partitioned equally among the class intervals shorter than the IRT. The various partial probabilities for each class interval are summed to give the calculated distribution of Fig. 5. The procedure is, in a way, the converse of Anger's (1956) IRT/Ops calculation. All IRTs that would have been longer than 1 sec were, of course, truncated by the reinforcer, and were so treated in the calculation; IRTs of this length

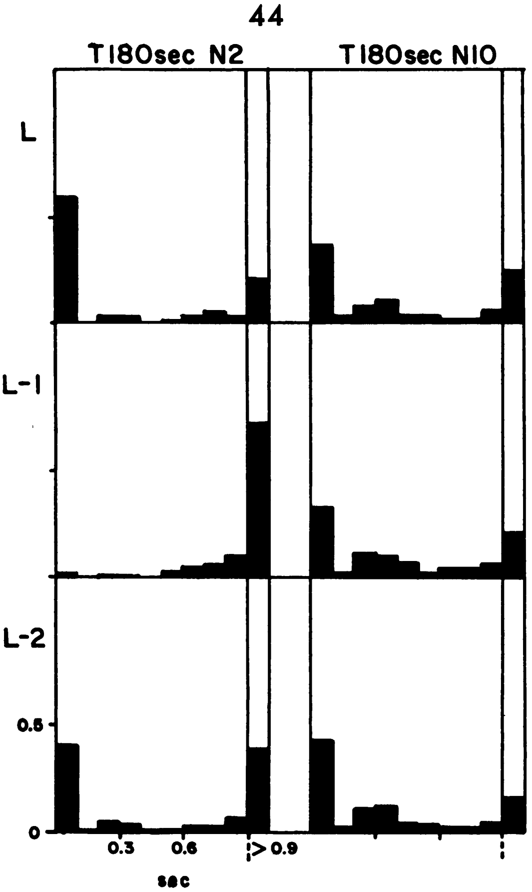

Fig. 4. Relative frequency distributions of IRTs of different lengths. Conventions as in Fig. 3. Note the deficit of short IRTs in the L-1 distribution under T 180-sec N 2, which are the IRTs during which the 180 sec must conclude. In contrast, note the similarities of the L, L-1, and L-2 distributions under T 180-sec N 10.

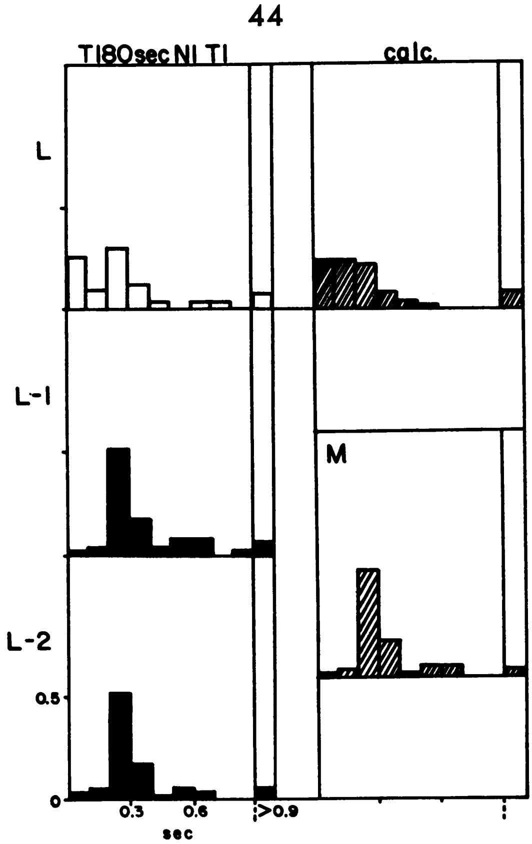

Fig. 5. Relative frequency distributions of IRTs of different lengths. Conventions as in Fig. 3 except the open bars for the L distribution draw attention to this being a response-reinforcer time distribution (RRfT) rather than an interresponse time distribution (IRT). Note the relatively flat, generally declining RRfT distribution, which is as predicted under the assumption of a random truncation of IRTs (the "calc" distribution).

occurred too infrequently to affect the distributions appreciably. The agreement with the observed distribution is fair (Fig. 5); there is a deficit in the second class interval of the observed distribution compared to the calculated. However, the total of the first three class intervals for the observed and calculated distributions is closely similar.

The effects of the changes in the occurrence of the reinforcer in relation to the final response on the general pattern of responding are shown in Fig. 2. The most striking feature is the similarity of the performances both in the patterns of the cumulative records (Fig. 2) and in the averaged data (Fig. 6). Under all schedules, a progressive increase of rate through the interval, characteristic of FI responding, occurs. Even the rate of increase is much the same under all the schedules except T 180-sec N 1 T 1-sec (Fig. 6). Under T 180-sec N 1 T 1-sec the rates of responding are uniformly less than under the other schedule, but since the rate in each segment is reduced in approximately the same proportion, the *pattern* of the changing responding is similar under all the schedules. The general pattern of FI responding is therefore not importantly dependent on the preferential reinforcement of longer IRTs nor, apparently, on any particular conditions just at the time the reinforcer is presented. The only uniform features of the schedules were the T 180-sec segment and a response requirement; the characteristic fixed-interval pattern of responding seems to de-

Table 1

Mean Rates of Responding (Responses per Second) under the Various Schedules Studied

Bird	*Schedule* *T 180-sec N 10*	*T 180-sec N 2*	*T 180-sec N 1*	*T 180-sec N 1 T 1-sec*
44	0.72	0.74	0.93	0.55
152	0.61	0.70	0.67	0.40
260	1.21	1.10	1.10	0.45
Mean	0.85	0.85	0.90	0.47

pend directly on the fixed-interval characteristic of the schedule.

The modifications of the schedule caused substantial changes in aspects of the responding other than the general pattern. While T 180-sec N 1, T 180-sec N 2, and T 180-sec N 10 engendered similar mean rates, the mean rate under T 180-sec N 1 T 1-sec was only about half of that under T 180-sec N 1 (Fig. 2 and Table). Short IRTs were reduced under T 180-sec N 1 T 1-sec (Fig. 3 and 5) even though the mean RRfT was less than 250 msec for each of the birds. Inspection of Fig. 2 suggests that change from T 180-sec N 1 to T 180-sec N 2 or T 180-sec N 10 lead to a prolongation of the initial pause in the intervals and a more abrupt acceleration to terminal rates of responding. But this suggestion does not emerge in the averaged figures (Fig. 6). Further analysis of such small but possibly significant changes in the pattern of FI responding must await better mathematical description of the pattern.

DISCUSSION

The argument of Skinner (1938, p. 275), that under a fixed-interval schedule of reinforcement ("periodic reconditioning"), if there are local variations in rate, then "a reinforced response will more frequently follow a relatively long interval" without a response, has been confirmed experimentally. Local variations in rate are clearly apparent in Fig. 1. The trend to longer IRTs for the reinforced IRTs is best described as a virtual elimination of very short (<0.1-sec) IRTs from the distribution of reinforced IRTs (Fig. 3). Such an effect followed necessarily from the actual distributions of the preceding IRTs, but the computation could not have been made without the numerical information.

In making the calculations, it was assumed that at the end of the interval the rate of responding had asymptoted, so that the distribution of L, L-1, and L-2 IRTs would have been the same if the reinforcer had not intervened. Several pieces of evidence support the assumption: the great similarities of the L-1 and L-2 distributions under T 180-sec N 1 (Fig. 3); the L and L-2 distributions under T 180-sec N 2 (Fig. 4); the L-1 and L-2 distributions under T 180-sec N 1 T 1-sec (Fig. 5) and of the L, L-1,

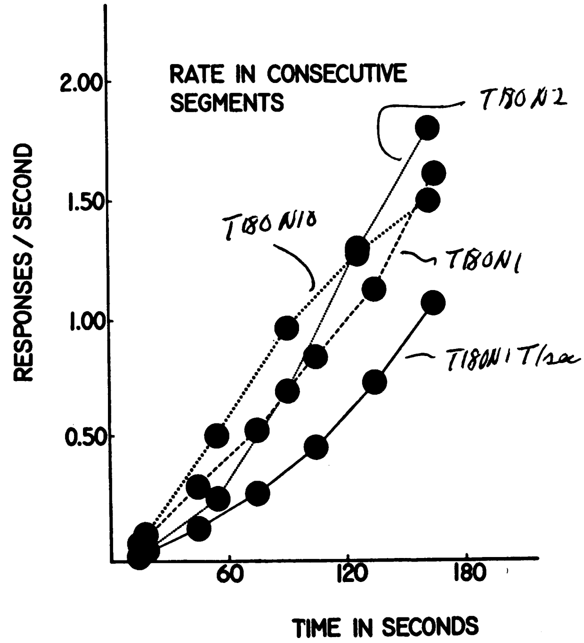

Fig. 6. Mean rates of responding in consecutive segments of intervals. Abscissa: time from start of interval. Ordinate: rate in responses per second. Heavy dotted line: T 180-sec N 10. Dashed line: T 180-sec N 1. Light dotted line: T 180-sec N 2. Solid line: T 180-sec N 1 T 1-sec. Responding in 30-sec segments of T 180-sec N 1 and T 180-sec N 1 T 1-sec and in 36-sec segments of T 180-sec N 2 and T 180-sec N 10 was accumulated over the cycles of a session and over the 10 definitive sessions on a schedule and, finally, over the three birds to obtain the graphed figures. There is no obvious difference in the progression of rates under the different modifications, nor in the rates themselves except for T 180-sec N 1 T 1-sec.

and L-2 distributions under T 180-sec N 3 (Fig. 4) all point to a constant terminal mean rate.

The distributions of the L, L-1, and L-2 IRTs under T 180-sec N 10 (tandem FI 3-min FR 9) give no support to the notion that a fixed-ratio schedule of reinforcement (FR) "favors the reinforcement of responses following relatively short intervals" (Skinner, 1938, p. 284). Under FR, the probability that an IRT will be reinforced is exactly equal to the probability of occurrence of the IRT in the terminal mean rate of responding (*i.e.*, the L distribution is the same as the L-1 and L-2 distributions in Fig. 4). Some other mechanism for the tendency of FR to lead to high rates of responding must be sought, such as a positive feedback loop (Dews, 1962).

The persistence of the FI pattern of responding under tandem FI FR schedules confirms the findings of Ferster and Skinner (1957, p. 416 *et seq*). These authors also noted an increase in overall mean rate of responding in going from FI to tandem FI FR, an effect not seen in the present series of experiments. The difference may be due to the parameter values; Ferster and Skinner worked with a long interval of 2700 sec in contrast to the 180 sec of the present experiments. Ferster and Skinner superimposed the tandem FR on very low mean rates of responding, whereas in the present experiments the tandem FR was superimposed on already quite high rates of responding (0.5 to 1.0 responses/sec). The same considerations may explain the much lower tendency for a burst and pause pattern of local responding to occur in the present experiments than in the experiments of Ferster and Skinner (1957). The grouping of responses in bursts, seen by Ferster and Skinner (1957) is an important phenomenon seen also under tandem schedules such as N 18 $\overline{\text{T 2-sec}}$ N 4[4] (an initial ratio of 18, a minimum pause of 2 sec, and a terminal ratio of 4) (Morse and Herrnstein, 1956) and under second-order schedules of reinforcement (Kelleher, 1966). All this evidence supports the present conclusion that the effect of a reinforcer in a schedule of reinforcement exerts its effects directly over much longer periods of time than the last IRT or the last few IRTs. At the same time, the change from essentially simultaneous presentation of the reinforcer at the reinforced response (under T 180-sec N 1) to an average delay between last response and reinforcer of less than 250 msec (under T 180-sec N 1 T 1-sec) lead to an approximate halving of number of responses made per interval. So, circumstance very close in time to the occurrence of the reinforcer can be very important, because of that proximity, in determining certain attributes of responding under a schedule of reinforcement.

Anger has studied the distribution of reinforced IRTs in rats responding under VI 300-sec (Anger, 1956). He chose VI to minimize systematic changes in IRT distributions with time since reinforcement (such systematic changes giving the FI scallop have been the major focus of attention in the present work). Anger used a 4-sec (or 8-sec) class interval for his IRT distributions and found that the IRT/Op distribution seemed to follow the Rf/Hr distribution for the different IRT lengths, resulting in favoring of "short" (<8-sec) IRTs. In the present work, class intervals of 0.10 sec have been used; all the IRTs would have been "short" by Anger's scale, being almost exclusively less than 1 sec. In the present work, Rf/Hr of IRTs of less than 0.10 sec were essentially zero under T 180-sec N 1, yet such short IRTs persisted. The gross differences in time scales prevent the present results from either confirming or conflicting with Anger's. Parenthetically, the importance of taking into account absolute times is obvious from these considerations. Had Anger presented his results in terms of per cent success or any other derived measure eliminating absolute time, we would have been faced with an uninterpretable and irreconcilable contradiction. As things are, it can be seen at what parameter values more experimental results are needed.

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[4] The bar over the T 2-sec ($\overline{\text{T 2-sec}}$) in this nomenclature means that the 2 sec must elapse *without* a response to fulfill the schedule requirements.

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