

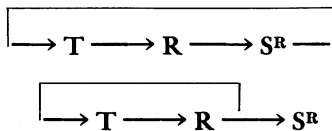
A FIXED INTERVAL SCHEDULE IN WHICH THE INTERVAL IS INITIATED BY A RESPONSE

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The fixed interval schedule described requires the animal to initiate every time interval by making a response on a bar other than the one on which it is reinforced. This response, R_A , demarcates the postreinforcement pause (S^R-R_A interval) from the fixed interval pause (R_A-R_B interval) so that these pauses may be measured separately. Twelve rats and three monkeys, working in two-bar Skinner boxes, were trained and stabilized on this schedule. The resulting performances, presented for individual animals, are analyzed in terms of (1) the relative frequencies with which the animal waits various lengths of time between consecutive responses, (2) the relative frequencies with which various rates of responding appear, (3) the change in response rate throughout the fixed interval, (4) the average length of the postreinforcement pause, (5) the relative frequencies with which the animal waits different lengths of time between the R_A and the first R_B , and (6) the average inter-response time as a function of the *rank* order in the fixed interval of the inter-response time. The joint interpretation of the several measures taken leads to the following conclusions: 1. The probability of an R_B increases throughout the fixed interval. 2. The increase is discontinuous at the first R_B , at which point the probability increases sharply. 3. The frequency distributions of R_A-R_B pauses exhibit three discrete types of behavior with no intermediate cases. 4. The (main) mode of R_A-R_B interval length usually occurs just below the fixed interval requirement.

The definition of a fixed interval schedule states that the first response following the end of a fixed time interval is reinforced, while responses made before the end of this interval go unreinforced. The interval may be initiated in a variety of ways. In his *Behavior of Organisms* (1938), Skinner describes the schedule in which every interval is initiated at the moment of reinforcement. In another method, developed by Schoenfeld, Cumming and Hearst (1957), the fixed interval recycles continuously, independent of the subject's behavior, reinforcement remaining available until claimed by a response. These two methods may be compared diagrammatically (Mechner, 1959):



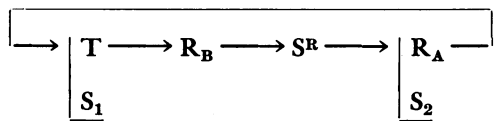
It should be noted that these diagrams show the controlling contingencies of behavior, and

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not actual instances of behavior. That is, if R is made after the elapse of T , then S^R is presented. Not: T elapses, then R is made, then S^R is presented.

The present paper describes a procedure in which every interval is initiated by a response which the animal makes on a bar other than the one on which it is reinforced:



R_A is the interval-initiating response and R_B is the class of responses of which the first response after the elapse of T is reinforced. In this procedure, R_A separates the post-reinforcement pause (S^R-R_A interval) from the fixed interval pause (R_A-R_B interval). S_1 is a light which is turned on by R_A and goes off when the reinforcement is delivered. Again, it should be noted that the diagram is of a contingency, not of actual behavior. Therefore, while it is true that R_A may occur at any time, the contingency $\left[\begin{array}{c} R_A \\ S_2 \end{array} \right] \rightarrow \left[\begin{array}{c} T \\ S_1 \end{array} \right] \rightarrow \dots$ goes into effect after S^R , and remains in effect until the R_A is made, initiating the fixed interval.

The purpose of the present paper is two-fold: to discuss some features of this procedure, and to suggest some data analysis techniques by means of which fixed interval performances in general may be described comprehensively, yet quantitatively. These data analysis techniques are applied to the performances obtained with the fixed interval procedure presented in this paper.

To establish the degree to which the performance characteristics obtained under this fixed interval procedure may have generality beyond any particular set of conditions, a variety of conditions was used: two values of fixed interval length were employed; both micro-switch and velocity-sensitive bars were used as manipulanda; monkeys as well as rats were used as subjects.

METHOD

Subjects

Twelve male rats of Charles River stock, approximately 60 days old at the beginning of training, and three male monkeys were used. Two of the monkeys, M1 and M2, were 3-yr-old *Macaca mullata*, and the third, M3, was a 3½-yr-old *Mona guenan*.

Apparatus

All 12 rats lived and worked in an apparatus called the "rat rotor," which is essentially a turntable subdivided into eight sector-shaped compartments, each permanently occupied by a rat. The periodic, automatic rotation of the turntable brings the rats successively into the testing position. The rat in the testing position has access to two bars, each 4.5 cm wide and 0.5 cm thick, which protrude 2 cm into the cage and which are situated 11 cm apart at a height of 3 cm. A dipper cup in which liquid reinforcement can be presented is situated midway between the bars.

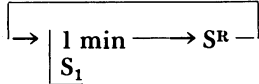
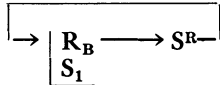
Four of the 12 rats occupied a rotor equipped with velocity-sensitive bars. These bars actuated a relay when the velocity with which they moved exceeded a preset value. Each velocity bar had a rod-shaped permanent magnet mounted vertically on the end away from the animal. This magnet was positioned inside a stationary solenoid in such a way that movement of the bar moved the magnet up and down inside the solenoid. The voltage thus generated was proportional to the velocity of the movement. For viscous damping of

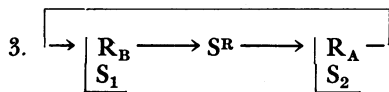
the magnet movement, both the magnet and the solenoid assembly were immersed in machine oil. This helped to reduce voltage output due to bounce or to vibrations of other origins. The positive half of the voltage output of the coil was linearly amplified, with the amplification gain set at a value where the desired velocity of bar-movement produced an amplifier output voltage adequate to fire a thyratron. The actual value of the velocity with which the rat's end of the bar had to move to fire the thyratron was within 15% of 40 cm per sec. This velocity was attained when a 4-g weight was placed on the bar. The other eight rats occupied a rotor equipped with conventional micro-switch bars. A 15-g weight on this bar was sufficient to move it through its full 3-mm excursion. This excursion was adjusted to exceed by about 5% the distance between the positions where the micro-switch made and broke.

The three monkeys worked in a 2 by 2 by 2 ft box in which they had access to two bars, each 6 cm wide and 1 cm thick, which protruded 4 cm into the cage and were mounted 35 cm apart at a height of 12 cm. A 25-g weight on this bar moved it through its full 1-cm excursion. This excursion also was adjusted to exceed the make and break positions of the micro-switch by about 5%. Midway between the bars, in a recession of the panel, was a dipper cup in which liquid reinforcement could be presented.

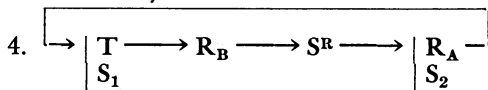
PROCEDURE

All rats and monkeys were trained according to the sequence of contingencies described by the diagrams below. Each contingency was maintained either for 3 hr or until the animal's performance under that contingency had stabilized, whichever time was longer. T was increased gradually from zero to the final desired value, which was 30 sec for the micro-switch rats and 60 sec for the monkeys and velocity-bar rats. S_1 was a small pilot light over the bar, and S_2 was total darkness.

1.  After 1 min of S_1 , then S^R is delivered and schedule recycles.
2.  If R_B in S_1 , then S^R and schedule recycles.



If R_B in S_1 , then S^R ; then S_2 and if R_A , then schedule recycles.



If R_B after T sec in S_1 , then S^R ; then S_2 and if R_A , then schedule recycles.

The animals were maintained on the final condition on a continuing basis. The four rats that used the velocity bars, R7, R8, R9, and R10, worked three consecutive hours a day, seven days a week. While food was continually available to them, they earned their entire daily water allowances in the form of reinforcements. They received 0.03 cc of water on every dipper presentation. The data analyzed below were collected over a period of from six to nine days, four months following the completion of the training outlined above.

The eight rats that worked the micro-switch bars worked 1 hr every 8 hr. In all other respects, their working conditions were the same as those of the other rats.

The three monkeys worked two consecutive hours every day. They, like the rats, earned their entire liquid allowance in the form of reinforcements, although their reinforcements consisted of Tropicana orange juice rather than of water. They received 1.0 cc of juice per reinforcement. The data for the monkeys were collected during three days, about eight months following initial training.

RESULTS AND DISCUSSION

The data analysis techniques presented in this paper were developed in order to summarize and describe fixed interval performances as economically as possible. The ideal is to include the maximum amount of information in the fewest measures. Samples of the cumulative kymograph records of the four rats that worked the velocity bars are given in the top row of graphs on the right side of Fig. 2. In these records, a vertical drop indicates the delivery of a reinforcement, and a diagonal blip indicates a response on bar A (R_A), initiating the fixed interval. The R_A blips separate and allow separate measure-

ment of two horizontal "pauses"—the post-reinforcement pause (S^R-R_A) and the fixed interval pause (R_A-R_B). But while the kymograph record furnishes an exhaustive account of the animal's bar-pressing behavior, it presents the data in a form that can neither easily nor economically be summarized by mathematical and statistical techniques.

The data presented in this paper were collected on a number of counters and analyzed by computer. While these analyses may prove on the one hand too redundant, and on the other hand insufficient for complete reconstruction of the kymograph record, they do provide more information about fixed interval performance than other sets of indices in the literature. Additional experience will undoubtedly suggest further economies.

Figure 1 shows performances of six of the eight rats that worked the microswitch bars. The four rows of graphs show the results of analyses 1, 3, 5, and 6, respectively. Figure 2 shows the performances of the three monkeys (analyses 1, 3, and 2), and of the four rats that worked the velocity bars (kymograph, and analyses 3 and 2).

1. *Relative frequency of different inter-response times (IRT's).* One inter-response time is registered every time a response is made, without regard to when in the interval it is made. This distribution (see the top row of graphs in Fig. 1) shows the proportion of times that each of several time intervals elapses between consecutive responses. The last point on the graph, which has a higher frequency than those just before it, represents all the IRT's which are 5 sec or longer. The distributions of the rats and of the monkeys are indistinguishable from one another, and all have their modes slightly below 1 sec.

2. *Relative frequency of different response rates.* A rate reading was taken at the end of short, regular intervals. The bottom row of graphs in Fig. 2 shows the proportion of these intervals in which each animal made 0, 1, 2, 3, etc. responses. Again, as in the frequency distribution of IRT's, the range of rates represented on the abscissas is unfortunately not broad enough to include the highest values that appeared. The kink in the distributions, which all four velocity-bar rats exhibit at the second or third rate category, is repeatable and statistically significant: the

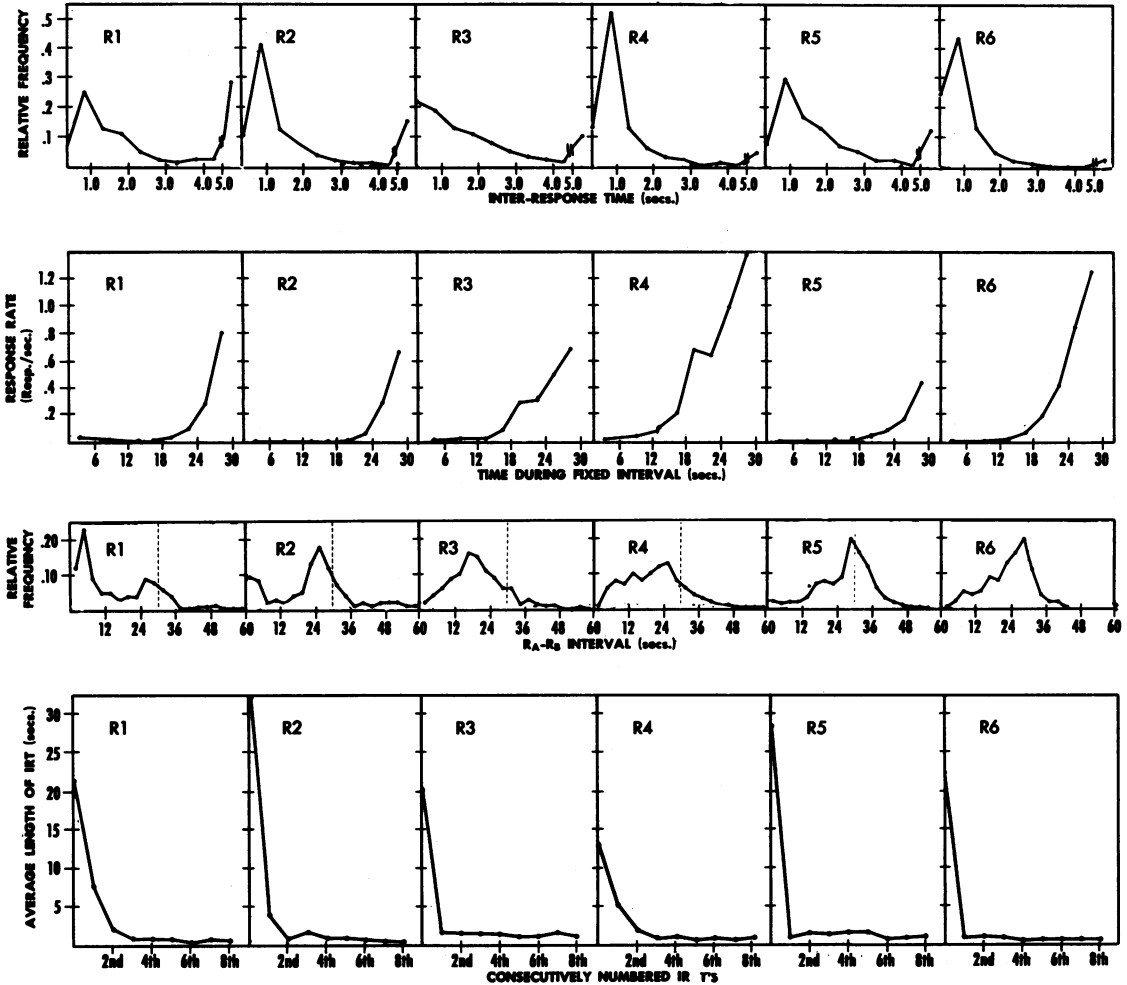


Fig. 1. The first row of graphs shows the relative frequency of different inter-response times for each of six of the eight rats that worked the microswitch bars. The next three rows of graphs show, respectively, response rate as a function of sub-interval of the fixed interval, relative frequency of different lengths of R_A-R_B interval (fixed interval pause), and average length of consecutive IR_B 's. Each column of graphs presents the data for one rat.

session-to-session variation of these functions was generally smaller than the diameter of the points on the graph.

This presentation supplements the information provided by the overall IRT distribution discussed above. For example, if an animal does not respond at all during the first half of a 1-min fixed interval, and then responds at the rate of 3 responses per sec during the second half, then its rate distribution will have one peak at 0 responses per sec and another peak at 3 responses per sec. If, on the other hand, the animal accelerates steadily throughout the interval, beginning with a rate of 0 and ending with a rate of 5

responses per sec, then every rate will be about equally represented, and the rate distribution will accordingly be flat from 0 to 5, and then drop to 0. Still another possibility is that the animal responds at some steady rate throughout the interval, without any sign of temporal discrimination. In this case, the rate distribution will have a single peak at that rate, all other rates having zero frequency.

To illustrate the usefulness of the rate distribution: suppose one wished to discriminate between these two types of fixed interval behavior: (a) the animal typically pauses for the first 30 sec of a 1-min fixed interval, and

makes 100 responses in the remaining 30 sec, and (b) the animal typically makes 200 responses distributed evenly throughout the interval, without any long pause. The frequency distribution of rates would discriminate between these two cases: if rate readings were taken every 3 sec, as in the case of the rats, case (a) would register 10 entries of 0 responses per sec during the R_A - R_B pause and 10 entries of 3.3 responses per sec during the final 100-response run, giving a bimodal distribution. Case (b) would register 20 entries of 3.3 responses per sec, and have a single peak.

The inter-response time distribution, however, would not discriminate between these two cases. The IRT distribution for case (b) would be based on 199 IRT's of 0.3 sec each; the distribution for case (a) would be based on a single IRT of 30 sec and 99 IRT's of 0.3 sec each. Since the IRT distribution shows only relative frequency, the 30-sec pause in case (a) would not be noticeable. The IRT distribution for case (b) would be almost

identical to that for case (a) except that it would be based on twice as many IRT's.

To summarize the difference between the information conveyed by the IRT distribution and the rate distribution, one could say that while the IRT distribution shows the relative number of responses made at rate r , the rate distribution shows the relative amount of time spent in responding at rate r .

For detailed analysis of rate, however, the rate distribution is inadequate, and the IRT distribution is required. If it were desired, for instance, to study the acceleration during an individual fixed interval, and to measure in all its sharpness the dichotomy in rate between the animal's initial pause and its high, steady rate thereafter, the rate distribution would be inadequate. Since rate must always be integrated over an appreciable period of time, a blurring of rates is unavoidable. Those time periods which contain the transition from the zero rate to the high rate will register an intermediate rate, thereby compromising

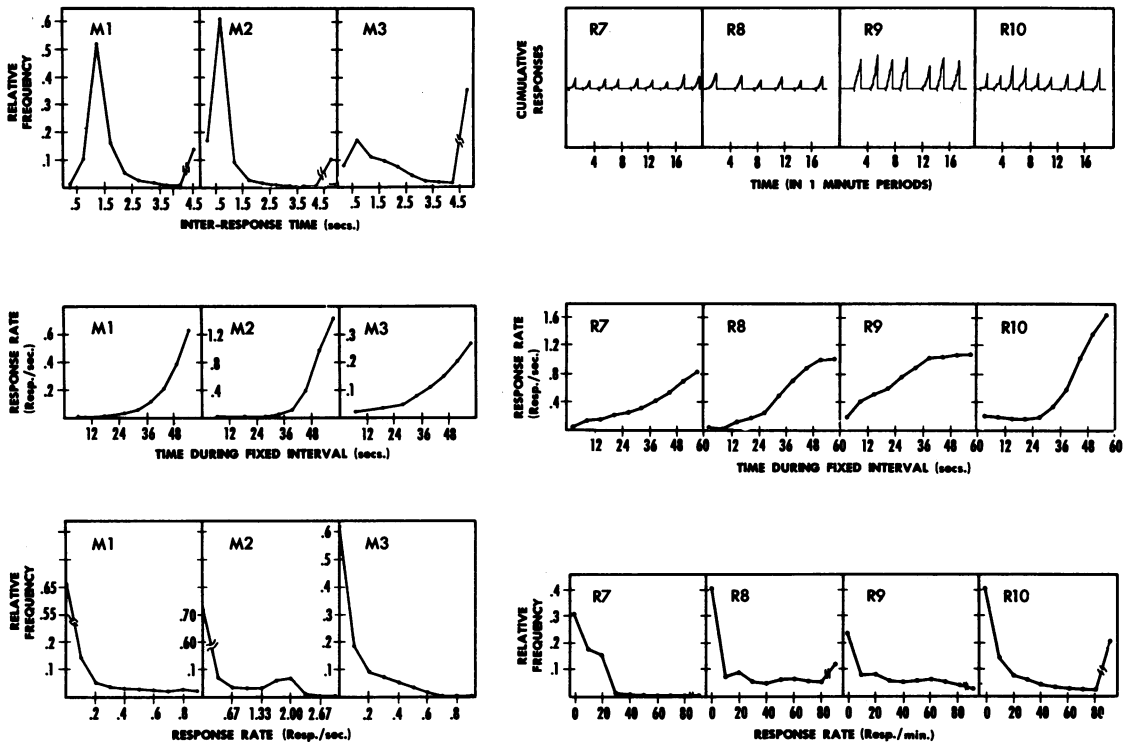


Fig. 2. The first three columns (left) present data for the monkeys. The last four columns (right) present data for the rats that worked the velocity-sensitive bars. The first row of graphs shows, for the monkeys, the relative frequency of different inter-response times, and for the rats, samples of the cumulative kymograph records. The second row of graphs shows response rate as a function of sub-interval of the fixed interval; the third shows relative frequency of different rates of responding.

the dichotomy. See, for example, the frequency distributions of rates for monkeys M1 and M3 (third row of graphs in Fig. 2), where the sampling periods were 10 sec and 5 sec respectively. This interpretation is supported by the peakedness of the IRT distributions of these monkeys. It is likely that the frequency distribution of rates is useful only when the number of sampling periods is large (say, over 20) and the average number of responses is at least three. A great deal more practice will be required to establish the effect of the interaction of these parameters on the usefulness of the rate frequency analysis.

The frequency distribution of rates for M2 is different from those for the other two monkeys. While all three monkeys have pronounced peaks at 0 responses per sec, M2 has a second peak at 2 responses per sec. The other two monkeys exhibit a wide range of rates.

3. *Average response rate.* Again, in order to integrate rate over periods short enough to yield a reasonably fine curve, the fixed interval was divided into 10 equal sub-intervals. Each sub-interval of the 30-sec fixed interval was 3 sec, and of the 60-sec fixed interval, 6 sec. (See the abscissas of the graphs in the second row of both figures.) Each point on the graphs represents the response rate for the corresponding sub-interval averaged over all the fixed intervals in the work session. That this average rate against sub-interval is often a smoothly accelerated function (see especially R1, R2, R5, and R6) does not mean that the response rates in the individual fixed intervals that made up the work session were also smoothly accelerated. That is, the smoothness may well be a result of averaging many dis-

continuous curves, the discontinuities of which occur in different sub-intervals of the fixed interval. Evidence for the discontinuity of the acceleration in the individual fixed interval will be given under Analysis 6.

The average rate functions for the monkeys (Fig. 2, line 2, left) are indistinguishable from those of the microswitch rats. The functions for the velocity-bar rats (Fig. 2, line 2, right), however, are not similar in shape to those of the monkeys and other rats. R9 is especially peculiar in that its rate function bends over, its slope approaching zero in the final sub-intervals of the fixed interval. Just what variable is responsible for this difference in rate function cannot be determined in this study.

4. *Average length of postreinforcement pause.* The procedure discussed in this paper makes possible the separate measurement of and therefore the averaging of the postreinforcement pause (the S^R-R_A interval). But the data for these animals did not show any relationship between average postreinforcement pause and length of fixed interval, and therefore are not included.

5. *Relative frequency of different fixed interval pause lengths.* Each graph in the third row of Fig. 1 shows the IRT distribution for the first IRT in the fixed interval, that is, the fixed interval pause or R_A-R_B interval. This interval is of particular interest because it is generally much longer than the other IRT's, the IR_B 's, and is sometimes regarded as evidence of temporal discrimination.

The table shows where modes appear in the R_A-R_B interval distributions of all eight microswitch rats. The data for R7 and R8

Table 1
Length of Fixed Interval Pause (R_A-R_B Interval) in Seconds

animal	0-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	27-30
R1		x							x	
R2	x								x	
R3						x				
R4									x	
R5							?			x
R6							?			x
R7		x								
R8		x				x				

Incidence of modes in the fixed interval pause distributions of the eight rats working the micro-switch bars. The fixed interval requirement is 30 sec.

are included in the table although their graphs are not shown in Fig. 1. Modes were determined visually from the graphs; no rigorous or statistical definition of "mode" was attempted. The usefulness of the present analysis is that where discrete types of performance appear, it can distinguish between them. In the present paper, three discrete types of performance were made by eight rats, each rat exhibiting either one or two of the types. The only conclusion to be drawn from the data presented here is that some variable was not under sufficient experimental control. Five of the eight rats exhibit modes just before the fixed interval requirement of 30 sec.

6. *Average IRT for successive IR_{BT} 's in the fixed interval.* The zero IR_{BT} , which is represented by the first point on the graph (bottom row of Fig. 1), is nothing more than the average R_A-R_B interval, that is, the mean of the distribution just discussed. The first IR_{BT} is the interval between the first and second R_B 's of the fixed interval, the second IR_{BT} is the interval between the second and third R_B 's of the interval, and so on. The key feature of this presentation is that it shows the pattern of rate acceleration. If the acceleration in responding is abrupt and begins with the first R_B (since the average R_A-R_B interval is almost the full fixed interval requirement), then the first IR_{BT} of the interval will be much shorter than the zero IR_{BT} , the R_A-R_B interval, and close in length to the succeeding IR_{BT} 's. If, on the other hand, the acceleration is gradual, then this function, which shows average length of successive IR_{BT} 's, will decrease more gradually.

The second row of graphs in Fig. 1 shows the average rate functions (Analysis 3). These curve upward, indicating that on the average, the rate not only increases throughout the interval, but actually accelerates. That the smoothness of the acceleration is the result of averaging is suggested by the last row of graphs, which shows the average length of successive IR_{BT} 's (Analysis 6). In general, the more an average function resembles the individual functions that comprise it, the more valuable it is. It should be noted that while a smooth curve can be the average of many discontinuous curves, a discontinuous curve cannot be the average of only smooth curves.

For animals R3, R5, and R6, the average R_A-R_B interval, represented by the first point on the graph, is considerably longer than the subsequent IR_{BT} 's, which hardly vary in length.

In the graphs of rats R1, R2, and R4, there is an indication of a gradual decrease in consecutive IR_{BT} 's. An examination of the top row of graphs in Fig. 1 (Analysis 1) may be of some use in ascertaining whether or not there is any gradual acceleration within the fixed interval. For example, the IRT distribution of R4 has its mode below 1 sec and tapers off at the higher IRT's; the frequency is already close to zero at 3 and 4 sec. So, the higher mean (5 sec) for the first IR_{BT} (second point, bottom row, animal 4) may well be accounted for by a few inordinately long first IR_{BT} 's, without being representative of the performance of any single fixed interval. The same reasoning applies to subjects R1 and R2, although in those cases, the frequencies of the higher values are due to the narrowness of the range of IRT values, and not necessarily to the actual high frequency of any given long IRT. The only sure way to resolve the question of whether or not there is any gradual acceleration at all during the individual fixed interval is to examine the median together with a measure of variation for consecutive IR_{BT} 's. A study of this type is in progress.

It should be noted that none of the other analyses can by itself yield the form of the acceleration.

Analysis 1, overall IRT distribution, looks promising; the variation around its mean can be regarded as the relative frequency of IRT's of intermediate length. The pattern of acceleration can be extracted from this function then, if one assumes that these intermediate-length IRT's occur only in the transition period from low to high rate of responding. This assumption is unjustified, however. Intermediate-length IRT's can occur any time; for example, evenly distributed throughout the terminal run. And, furthermore, the present analysis, average IRT of successive IR_{BT} 's in the fixed interval, has shown the acceleration to be abrupt. An IRT's bearing on the accelerative pattern is unambiguous only if its rank order in the fixed interval is specified. Analysis 3, average response rate failed in this respect

because it showed rate as a function of temporal rather than of rank IRT order. Whereas Analysis 6 shows the sharp rate change characteristic of the individual fixed interval, Analysis 3 shows a smooth acceleration, a result of averaging over time rather than rank order. As mentioned before, Analysis 2, frequency distribution of response rates, blurs sharp changes in rate because of the length of the time periods over which the rates are averaged.

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