

THE BEHAVIORAL EFFECTS OF SOME TEMPORALLY DEFINED SCHEDULES OF REINFORCEMENT

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The differences in behavioral effects between interval and ratio reinforcement have been pointed out by several investigators (1, 6, 9, 15), and reveal themselves most clearly in comparisons of over-all response rates, temporal patterns of cumulative-response curves, and subsequent extinction responding. In view of the different procedures followed by the experimenter and these contrasting behavioral effects, most researchers have regarded the two categories as basically distinct.

Skinner (15) has given a plausible explanation of why differences in behavior emerge from the two types of schedule. On interval schedules, long inter-response times (IRT's) are more likely to be reinforced than short IRT's, and this fact may account for the relatively low rates characteristic of interval reinforcement. On ratio schedules, however, rapid rates of responding will be more frequently reinforced than low rates, so that short IRT's have a greater probability of reinforcement than they would on a comparable interval schedule. Thus, the higher response rates obtained with ratio reinforcement may result from this contingency.

Several studies have shown that IRT distributions do, in fact, change, depending on the relative reinforcement of different IRT's. (Actually, of course, it is the response which terminates the IRT that is "reinforced.") Wilson and Keller (18), for example, found that response rates decreased as successively longer IRT's were selectively reinforced, while Sidman (14), in studying the effects of certain drugs on timing behavior, obtained IRT distributions which displayed peaks in the region of the minimum IRT reinforced.

Anger (1) has recently offered a further analysis of the effects of several different schedules on IRT distributions. He found that the probability of occurrence of different IRT's on a variable-interval (VI) schedule was closely related to the number of reinforcements per hour given each IRT class, rather than to the number

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of reinforcements per IRT for each IRT class. This large degree of control by the "reinforcements-per-hour" variable was surprising, particularly since its action in favoring short IRT's was opposed by a relatively greater frequency of nonreinforcement of these IRT's. Confirming the studies mentioned above, Anger also found that restriction of reinforcements to greater than 40-second IRT's resulted in marked decreases in response rate compared to an equivalent VI without such restriction.

Making use of some of these considerations and findings, Schoenfeld, Cumming, and Hearst (13) have suggested that both interval and ratio effects may be obtained within a single general framework which involves the manipulation of temporal variables only. The terms t^D and t^A were used to refer, respectively, to time periods during which (a) reinforcement may be given and (b) reinforcement is never given. The simplest cases arise where t^D and t^A are held constant and are alternated, and only the first response in t^D is reinforced.³

Figure 1 illustrates, for a typical case, the relationships among t^D , t^A , the organism's responses, and the reinforcing stimulus (S^R). In this example, t^D and t^A are held constant at 10 and 20 seconds, respectively, and the total 90-second sample includes three complete cycles. (Each cycle consists of one t^D and one t^A period.) Clearly, reinforcements can be "missed" on such a schedule; if no response occurs during a t^D period, the animal does not receive a reinforcement during that cycle. (Note Cycle 2.)

Two variables, which form the basis of the proposed classification of reinforcement schedules, can be derived from the foregoing definitions and restrictions on

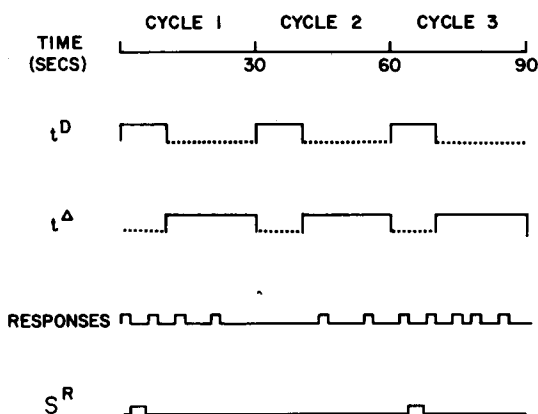


Fig. 1. Schematic representation of temporal contingencies on a 30-second cycle length ($t^D + t^A$) with $t^D/(t^D + t^A) = 0.33$. For explanation, see text.

³ Other experimenters have used the terms "limited hold" (6) and "time sample" in much the same way as t^D is defined here.

the use of t^D and t^A . Changes in either t^D or t^A affect both the total cycle length ($t^D + t^A$) and the proportion of the cycle during which a response may be reinforced [$t^D/(t^D + t^A)$], henceforth to be abbreviated \bar{T} . (In Fig. 1, the cycle length is 30 seconds, while \bar{T} is 0.33.) Manipulation of these factors, cycle length and \bar{T} , permitted the mapping of an experimental domain which included sectors expected to yield behavioral effects typical of responding under several interval and ratio schedules as ordinarily defined.

The usefulness of this sort of analysis has already been subjected to some experimental study. Schoenfeld and Cumming (12, 13) found that decreases in cycle length, with \bar{T} held constant, led to sharp increases in the key-pecking rates of pigeons for grain reinforcement. These rate increases were accompanied by changes in the temporal patterns of cumulative-response curves from ones resembling fixed-interval (FI) performance to those resembling random-ratio. An interesting follow-up involved the exposure of one subject to 6 days of extinction subsequent to its training on the several cycle lengths. Not too surprisingly, the extinction curves showed a blending of characteristics, some typical of extinction responding after a history of interval reinforcement and others typical of curves after a ratio history.

Within this context the present study sought to examine the behavioral effects of changes in \bar{T} while the cycle length was held constant, or, to paraphrase, to investigate the effects of variations in the length of a "limited hold" superimposed on an FI schedule of reinforcement. Successive reductions in \bar{T} (with cycle lengths of reasonable duration) would be expected to favor the emergence of a high response rate, since on such schedules reinforcement is likely to be more frequent following short IRT's than long IRT's. If the use of ratio schedules is considered to be a relatively crude way of selectively reinforcing high rates of responding, as was suggested earlier, then small \bar{T} values may generate effects typical of fixed-ratio (FR) and some variable-ratio (VR) schedules. In the present experiment, the effects of successive decreases in \bar{T} from its maximum value of 1.00 were examined. From the arguments above, and since at $\bar{T} = 1.00$ the schedule is FI timed by the "clock,"⁴ this procedure was expected to produce changes from FI to ratio performance.

METHOD

Subjects

Four barren White Carneaux hen pigeons approximately 7 years old were the subjects. All were maintained at about 80% (± 15 grams) of their normal or free-feeding weight throughout the study and had not been used in any experiments before the present one.

Apparatus

The experimental box in which all subjects were separately run has been described in detail by Ferster (4, 5). The response measured was key-pecking, and a 3-second presentation of grain defined a reinforcement.

Most of the necessary programming and recording devices were operated by relay circuits. A perforated-shutter arrangement was used to schedule t^D and t^A ;

⁴ Ferster and Skinner (6) state that there is little practical difference between timing the FI from the last reinforcement or from the end of the previous interval ("by the clock"), since FI schedules normally generate a substantial response rate at the time of reinforcement and the reinforced response usually occurs within a second or two of the designated interval.

this apparatus provided a range of \bar{T} values from 1.00 down to less than 0.01. Response data were taken in the form of cumulative-response curves, total number of responses and reinforcements per session, and polygraph records of the temporal distribution of response occurrences.

Procedure

The general design of the experiment involved the use of single animals as their own controls, with stable behavior (defined below) at each value of the independent variable as the criterion for moving the subject to another value.

Cycle length was held constant at 30 seconds for all values of \bar{T} . Although the birds were run 1/2 hour every day, only the data of the last 15 minutes of the session were used for analysis in order to minimize warm-up effects.

A brief preliminary period permitted habituation to the experimental box, magazine training, and differentiation of the key-pecking response (4). The experiment proper followed directly. First, each subject was run on a schedule where \bar{T} equalled 1.00 ($t^D = 30$ seconds, $t^A = 0$); this schedule is identical with a 30-second FI timed by the "clock." Thereafter, each bird was consecutively shifted to \bar{T} values of 0.35, 0.05, 0.03, 0.02, and 0.013. This order was used in preference to a randomized sequence since the birds might extinguish rapidly, as with a high FR requirement, if placed on a very small \bar{T} early in training.

As noted above, each bird was kept on a given schedule until its response rate had stabilized, as defined by the following criterion. The first 7 days on any schedule were not considered in computing stability. After the completion of the next 6 days of running, the mean of the first 3 days of the 6 was compared with that of the last 3 days. If the difference between these means was less than 5% of the total 6-day mean, the bird was said to have stabilized and was shifted to the next schedule. If the difference between submeans was greater than 5% of the grand mean, however, another experimental day was added and similar calculations made for that day and the 5 immediately preceding it. Such extensions of the experiment and calculations of stability were continued daily until the 5% criterion was achieved.

RESULTS AND DISCUSSION⁵

The effects of variations in \bar{T} can be analyzed in several ways. The arguments advanced earlier would suggest that decreases in \bar{T} are accompanied by important changes in the over-all response rate and in responses per reinforcement, as well as by changes in the appearance of cumulative-response curves and IRT distributions. The data will be discussed in that order.

Figure 2 displays individual functions relating response rate to \bar{T} . The plotted rates are the means for the last 6 days on each schedule (stability days) and have been corrected for eating time by subtracting the total amount of time the feeder was available (3 seconds per reinforcement multiplied by the total number of reinforcements) from the 15-minute test session. All birds exhibit a pronounced increase in response rate as \bar{T} decreases, with the greatest changes in slope occurring at the lowest \bar{T} values, i. e., below 0.03.

⁵ A more complete analysis of the data, including tables with comprehensive individual results and the outcome of several statistical tests, is available in the original dissertation which can be obtained on Inter-Library loan from the Columbia University Library. A microfilm copy can be purchased from University Microfilms, 313 N. First St., Ann Arbor, Michigan (Publication No. 20055).

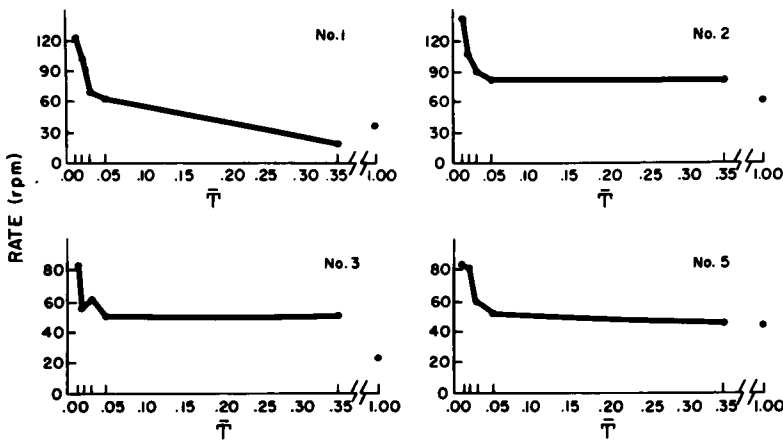


Fig. 2. Rate in responses per minute as a function of \bar{T} for each of the four subjects. Points plotted are the means for the 6 stability days on each schedule.

Since the number of "missed" reinforcements increased as \bar{T} decreased in value, the large increments in response rate depicted in Fig. 2 occur in spite of a decrease in the over-all frequency of reinforcement. In fact, these sharp increases in rate take place in the range of \bar{T} 's where the most sudden drops in number of reinforcements occur; from \bar{T} of 1.00 to \bar{T} of 0.03 the group mean number of reinforcements declines only slightly from 30.3 to 27.3 reinforcements per test session, while below 0.03 there is a rapid decrease to 20.4 and 18.5 reinforcements on the two smallest \bar{T} 's. This effect is mirrored in the data of the individual birds as well.

This relationship raises the possibility that the rate increase associated with low \bar{T} values is an artifact resulting from a decline in the number of pauses after reinforcement. An effort was made to correct for this possibility by subtracting mean pause-after-reinforcement time from total time and then recalculating response rates on this basis. Since some "pause" data was unavailable on the smallest \bar{T} used, this could only be done approximately, but the results revealed no important changes. Examination of the IRT data, which are uncontaminated by pause-time, also indicated that this factor was not a critical one (e. g., Fig. 5).

Individual curves of responses per reinforcement plotted against \bar{T} are shown in Fig. 3. The four curves exhibit the same relationship: a relatively small increase down to a \bar{T} value of 0.05 and a sharp positive acceleration with smaller values of \bar{T} .

Although these schedules are all programmed temporally, their effects do not match those obtained on interval schedules, which are also programmed on a temporal basis. Several experimenters have found that rate of responding is directly related to frequency of reinforcement on both fixed- (7, 15, 17) and variable- (3)

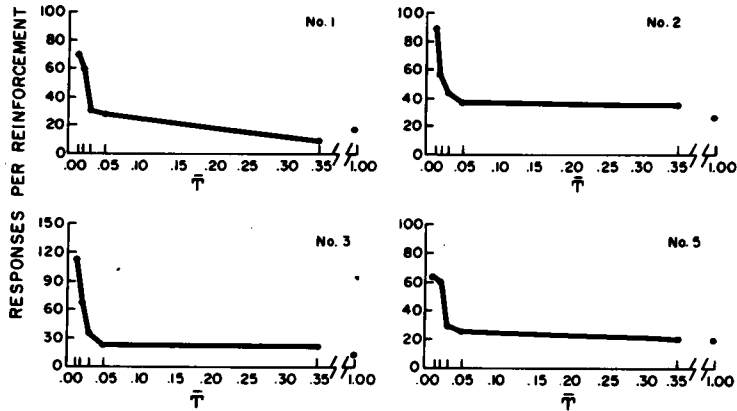


Fig. 3. Responses per reinforcement as a function of \bar{T} for each of the four subjects. Points plotted are the means for the 6 stability days on each schedule.

interval schedules (i. e., as the fixed or mean interval increases, response rate falls off), while the opposite is true in the present finding. The particular contingencies of the schedules used here, with their selective reinforcement of high rates, especially on small \bar{T} 's, already have been suggested as having several characteristics in common with ratio schedules. In both cases, as the requirements imposed on the organism become more stringent (i. e., successively higher FR's or mean VR's, or, here, smaller and smaller \bar{T} 's), response rate increases, even though the frequency of reinforcement decreases. Likewise, a rate increase accompanies an increase in the number of responses per reinforcement on both conventional ratio schedules (2, 8) and the schedules investigated here.

The data presented thus far indicate that variables similar to those under FR and some VR specifications are controlling behavior on small \bar{T} values; however, on the larger \bar{T} 's, where very few reinforcements are "missed," the controlling variables are more like those under FI.

Qualitative differences in behavior also emerged as \bar{T} was varied. Birds No. 3 and No. 5, which consistently had the lowest response rates of the four subjects on \bar{T} values below 0.35, each exhibited signs of extinction or "strain" (2, 16) on certain low \bar{T} 's; for Bird No. 3 these characteristics occurred on the 0.02 value, and for Bird No. 5 they developed on a \bar{T} of 0.013. Rates decreased noticeably during these periods, with a resultant increase in the number of "missed" reinforcements. Breaks after reinforcement were often unusually long, while the day-to-day variability in response rate was quite high and apparently was dependent on the number of reinforcements obtained in the first few minutes of each daily session. If a bird received almost no reinforcements in the first 10 minutes, its rate was likely to decrease radically in the latter half of the session. (Bird No. 3 once went almost

20 minutes without a response on the 0.02 value, despite over 5 previous months of responding at a fairly high rate.) These irregularities in behavior are characteristic, too, of the extinction-like behavior described by Skinner (16) and Boren (2) as "strain" under conditions of very high FR's, where reinforcement is too infrequent to maintain a response at high strength. Just as one might avoid "strain" in Boren's study by increasing the FR rather slowly, the same result might be achieved here through the use of smaller successive decrements in \bar{T} than were actually used.

The evidence of "strain" shown in the data also supports the notion that the controlling variables at low values of \bar{T} are similar to those under ratio schedules. In interval schedules, "strain" does not ordinarily occur, since any "tendency toward extinction is opposed by the fact that when the rate declines the next reinforcement is received in return for fewer responses" (16). This is likely to be the case for higher values of \bar{T} , e. g., 1.00 and 0.35.

Individual cumulative-response curves (e. g., Fig. 4) also showed distinct changes as \bar{T} decreased in value. For Birds No. 1, 3, and 5 the scalloping typical of FI reinforcement was apparent for \bar{T} 's of 1.00 and 0.35. (See also Fig. 5.) At \bar{T} values 0.03 and lower the records were marked by periods of responding at a very high and steady rate, usually until reinforcement was delivered. Immediately after a reinforcement, there characteristically was a pause or "break" followed by an abrupt transition to rapid responding. (See Fig. 5.) These properties are noted by Boren (2) and by Ferster and Skinner (6) as common to FR response curves. On the lowest \bar{T} values, Birds No. 3 and No. 5 typically showed periods of no responding interspersed with periods of responding at a high rate (e. g., as in Fig. 4), a finding in agreement with previous research on high "ratios" (6, 15).

The IRT data obtained in the present experiment are also worth some examination. These IRT's were measured from polygraph records taken on the last day or two of each schedule and represent time intervals between two successive response "starts" (depressions of the key); the only IRT's omitted from this sample were those during which a reinforcement occurred. No IRT records were obtained on the 0.013 schedule for any bird nor on the 0.02 schedule for Bird No. 1.

A study of the frequency of different IRT's showed that the shortest IRT class, 0-0.4 second, increased in relative frequency as \bar{T} decreased. All other IRT classes decreased in relative frequency with decreases in \bar{T} .

Anger (1) points out that "relative frequency" as an estimate of the probability of occurrence of a given IRT may not always be the most revealing measure, since it does not take into account the fact that responses have many more opportunities to occur after short intervals than after long intervals; any response after a short interval removes the opportunity for a response after a long interval. Anger corrected for this difference in opportunities by calculating the number of IRT's as a fraction of the number of opportunities for such IRT's, the "number of IRT's/number of opportunities" (IRT's/ops). This index is an estimate of the probability of response during a certain time interval given an opportunity for response in that interval. The IRT's/ops data of the present experiment indicated that on the highest \bar{T} values (i. e., 1.00 and 0.35) the separate IRT classes did not differ much in IRT's/ops; but, as \bar{T} decreased, shorter IRT's became increasingly more likely than long IRT's. (Compare 11.)

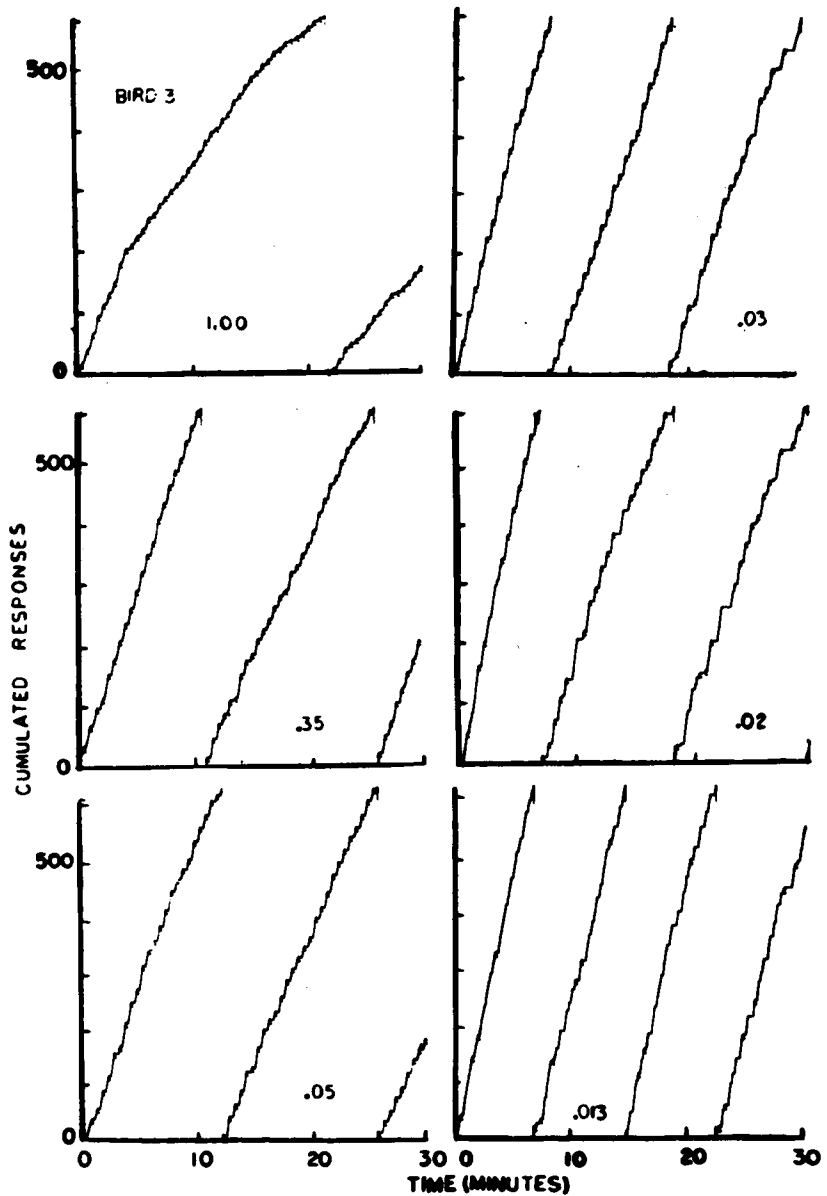


Fig. 4. Typical cumulative-response curves for Bird No. 3. In order to conserve space, the curves are displaced to the base line after approximately 600 responses have accumulated. The value of \bar{T} is shown for each curve, and reinforcements are indicated by short diagonal lines. All curves were taken from stability days on each schedule.

The IRT distributions of the present experiment were analyzed in one other way. To find out whether the decrease in mean IRT over the range of \bar{T} held both for responses immediately after reinforcements and responses just before reinforcements, the first four IRT's following reinforcement (initial rate) and the last four IRT's preceding reinforcement (terminal rate) were separately tabulated for each \bar{T} value. A total of eight IRT's per cycle was chosen because almost every cycle throughout the experiment contained at least 9 responses. Figure 5 presents the results of this analysis for the group data. Both initial and terminal IRT's 0-0.4-sec-ond increase in relative frequency as \bar{T} decreases, while all longer IRT's remain low in frequency and gradually decrease concomitantly with \bar{T} . The terminal IRT distribution is consistently above the initial at the short IRT's and below the initial at the long IRT's; the percentage differences between the two functions, however, become smaller at the lowest \bar{T} 's. Individual functions show essentially the same relationships. That is what would be expected if ratio behavior were characteristic of small \bar{T} values, since abrupt transitions to maximal response rates following pauses after reinforcement are normal under FR and VR. A more gradual acceleration of responding from its initial to its terminal value, possibly revealed in the functions for \bar{T} 's of 1.00 and 0.35, distinguishes the temporal discriminations of FI.

Several lines of evidence have been presented which are in general agreement with the implications of the proposed classification of reinforcement schedules discussed earlier. The sharp changes suggested in the rate and response-per-reinforcement data, the characteristics of the cumulative-response curves, and the differences in IRT distributions for different \bar{T} values all support the notion that important behavioral changes occur as a result of decreases in \bar{T} and that these changes represent a shift from FI to ratio performance. Though these conclusions are strongly indicated, certain reservations must be kept in mind. Skinner (15, also 6) notes that at the higher frequencies of periodic reinforcement (i. e., short fixed intervals), indirect correlations between rapid responding and reinforcement often

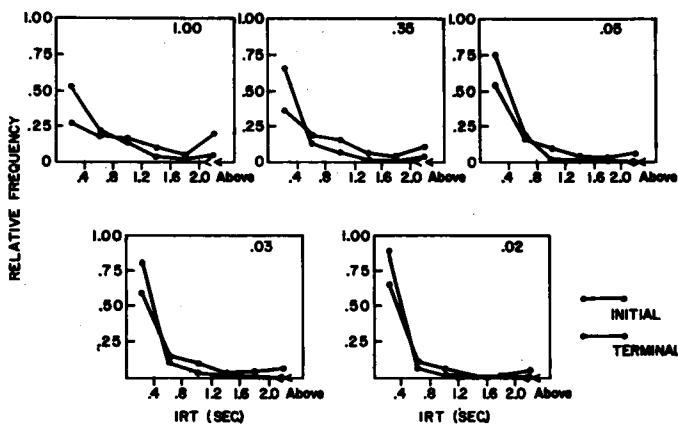


Fig. 5. Relative frequencies of initial (closed circles) and terminal (open circles) IRT's plotted separately for each \bar{T} value.

occur, and the combined result of these correlations is enough to produce curves which more usually characterize FR. In the present experiment the fixed interval was quite short, so that such indirect correlations possibly did take place. The cumulative curves for Bird No. 2, for example, on \bar{T} values of 1.00, 0.35, and 0.05, are marked by high rates and little of the scalloping ordinarily present in FI curves; the curves are more ratio-like than interval-like. The cumulative curves for the other subjects did not, however, show these same characteristics, and the pseudo-correlations of which Skinner speaks probably cannot account for the large increases in rate which occurred as \bar{T} decreased in value and more and more reinforcements were "missed." Research currently in progress with the same experimental design as used here, but with appreciably longer cycle lengths, ought to give a clearer picture of the interval-ratio relationship.

It is likely, too, that the behavior exhibited on small \bar{T} values cannot be precisely equivalent to that displayed on ratio schedules as ordinarily defined, if only because the animal, not the experimenter, here determines the "ratios" which are reinforced. Also, several studies (e. g., 10) have indicated that factors other than the differential reinforcement of high rates, frequency of reinforcement, and the discriminative function of the reinforcing stimulus, all of which were emphasized here, may also play a part in determining ratio performance. Even though subtle differences may exist between schedules defined by response counts and by manipulation of appropriate \bar{T} values, the similarities in their effects are too numerous to be minimized and suggest continuities between "interval" and "ratio" behavior which are worth further investigation.

SUMMARY

In an attempt to show how both "interval" and "ratio" behavior may be obtained within a single general framework which involves the manipulation of temporal variables only, some time-correlated operant schedules were systematically studied. On these schedules, reinforcement was available for only a limited period (t^D) every 30 seconds; if a response did not occur within this limited period, no further responses were reinforced (t^A) until the next such period was scheduled. The duration of this "limited hold" (t^D) was successively decreased throughout the experiment and the behavioral effects observed. Four White Carneaux pigeons were the subjects, while the response was key-pecking.

As the length of this limited period decreased:

(1) Response rates and responses per reinforcement increased, with the sharpest increases occurring at the shortest "holds"; at these short holds the greatest number of reinforcements was missed and two subjects evidenced "strain" similar to that often obtained on high fixed ratios.

(2) The percentage difference between initial (immediately following reinforcement) and terminal (immediately preceding reinforcement) rates decreased, with cumulative-response curves resembling "ratio" behavior appearing at short hold values.

Conclusion

Variations in the duration of the limited hold led to a change from interval-like behavior to behavior resembling that seen under ratio schedules. The data agree substantially with the proposal that both types of effect may be observed within a single framework of temporally defined variables.

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