SOME TIME-CORRELATED REINFORCEMENT SCHEDULES AND THEIR EFFECTS ON BEHAVIOR[1]

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The present study is concerned with the behavioral effects of several time-correlated reinforcement schedules.[3] In addition, it represents an attempt to enlarge upon previous findings (Brandauer, 1958; Hearst, 1958; Schoenfeld & Cumming, 1957; Schoenfeld, Cumming & Hearst, 1956) which have indicated that time-correlated schedules can duplicate the behavioral effects both of interval and some ratio schedules.

The two major independent variables of a time-correlated contingency are designated t^D and t^Δ. The term t^D specifies a time period during which an operant response may be followed by reinforcement. The term t^Δ specifies a time period in which response occurrences are not reinforced. The length of t^D and t^Δ, the sequence with which one follows the other, and the probability of reinforcement in t^D are parameters of the schedule which may be varied. In previous investigations (Brandauer, 1958; Hearst, 1958; Schoenfeld & Cumming, 1957; Schoenfeld, Cumming, & Hearst, 1956), as well as in the present one, the following restrictions were placed on t^D and t^Δ: $t^D + t^\Delta$ was held constant, t^D and t^Δ were alternated, a reinforcement was available during every t^D period, only the first response in t^D was reinforced, and the subject missed[4] a reinforcement if no response occurred during the t^D portion of a cycle (each cycle consisted of one t^D and t^Δ period).

Schoenfeld, Cumming, and Hearst (1956) have suggested that some of the different behavioral effects associated with classically defined interval and ratio schedules may be duplicated by an appropriate choice of values of $\overline{T}$ (the ratio of t^D to $t^D + t^\Delta$) and the duration of $t^D + t^\Delta$.

Extremely short $t^D + t^\Delta$ lengths, for example, duplicate a type of variable-ratio schedule which is termed random-ratio.[5] Data have been presented by Schoenfeld and Cumming (1957), for the pigeon, for $\overline{T}$ held constant at 0.05 during cycle lengths of 30, 15, 7.5, 3.75, 1.88, and 0.94 seconds. Response rates increased for all subjects as the cycle length was decreased, and the individual response curves

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[3] Equivalent terms have been limited-hold (Ferster & Skinner, 1957) or temporally defined (Hearst, 1958) schedules.

[4] The term missed reinforcement is used for descriptive purposes only and refers to an event that took place from the experimenter's, but not necessarily the subject's point of view.

[5] A random-ratio scheduling procedure specifies the probability of reinforcement for any particular response. For $t^D + t^\Delta$ lengths of perhaps less than one second for the pigeon the probability of reinforcement for any response may be considered numerically equal to the value of $\overline{T}$.

"lost their scalloped appearance below 3.75 seconds and took on the linear characteristics of random-ratio behavior free of 'breaks' after reinforcement." At the 0.94 second cycle value, the mean number of responses per reinforcement approximated 20:1, which was numerically equal to the value of $\bar{T}$ and also equalled the predicted "random-ratio" value. Brandauer (1958), using a constant cycle length of 0.001 second with $\bar{T}$ values ranging from 1.00 to 0.00167, also found that individual response curves at each $\bar{T}$ value exhibited the characteristics of random-ratio behavior. The mean number of responses per reinforcement at each $\bar{T}$ value approximated the value of $\bar{T}$.

Small values of $\bar{T}$ and cycle lengths of at least 30 seconds' duration reproduce some of the behavioral characteristics of fixed- and some variable-ratio schedules.[6] Hearst (1958), using a 30-second cycle length and $\bar{T}$ values ranging from 1.00 to 0.013, found increases in the pigeons' rate of key-pecking and the emergence of "ratio-like" behavior as the value of $\bar{T}$ was decreased.

The present study is concerned with the effects of decreases in the value of $\bar{T}$ during both a 2- and 10-minute cycle length. Its purpose, in the main, was to determine whether a transition from interval to ratio-like behavior occurs during a relatively long cycle length.

SUBJECTS

The subjects for Experiment I (2-minute cycle) were five White Carneaux hen pigeons, approximately 7 years old, four of which (experimental birds No. 1, 3, 4, and 5) were exposed to the same procedure. One bird (control bird No. 2) served as a control subject. Two additional pigeons (No. 6 and 7) were used as subjects for Experiment II (10-minute cycle). All birds were maintained at 80% (± 15 grams) of their free-feeding weight and none had been used in any previous experiment.

APPARATUS

The experimental boxes used in this study have been described in detail by Ferster and Skinner (1957). Key-pecking was the response measured, and the reinforcing stimulus consisted of a 3-second presentation of grain.

Mechanical and electrical components controlled the programming of t^D and t^Δ, the activation of the grain magazine, and the recording of responses and reinforcements. Mechanical and electronic timers provided t^D periods ranging from 0.2 second to 120 seconds ($\bar{T}$ values ranging from 0.0016 to 1.00) during Experiment I and from 1 second to 600 seconds ($\bar{T}$ values from 0.0016 to 1.00) during Experiment II. All key-pecks and reinforcements were recorded on separate fast-acting counters and a constant-speed kymograph. A wax-tape polygraph was used to obtain distributions of inter-response times.[7]

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[6] It has been suggested that the effects of these schedules may be generated by any programming technique that maintains a certain temporal spacing of reinforcements and at the same time produces a high response rate (Schoenfeld, Cumming & Hearst, 1956). Both of these conditions are fulfilled when the value of $\bar{T}$ is small (making reinforcement more likely for rapid than for slow responding) and reasonably long cycle lengths prevail.

[7] The inter-response time (IRT) is the time between two successive response occurrences. The time interval between the reinforced response and the preceding response is designated as the "reinforced IRT." It is, of course, the response terminating the "reinforced IRT" that is reinforced.

PROCEDURE

When the subjects had reached approximately 85% of their free-feeding weights, they were given punchboard training (Cumming, 1955) followed by feeder-approach training. Upon reaching the 80% weight level, each bird was given 50 continuous reinforcements for key-pecking on each of 3 consecutive days. The experiment proper began immediately after these preliminaries had been completed.

Experiment I

Each bird was run a half-hour per day (timed from the first peck) and experimentation was on a 7-day-week basis. The experimental subjects were first exposed to a schedule in which t^D equalled 2 minutes and t^Δ equalled zero ($\bar{T}=1.00$). This schedule is identical to a 2-minute fixed interval. Thereafter, each bird was successively shifted to t^D values of 6, 3, 2, 1, 0.5, 0.4, and 0.3 seconds, in that order ($\bar{T}$ values of 0.050, 0.025, 0.016, 0.008, 0.004, 0.003, and 0.002). This descending order of t^D was decided on in preference to a randomized sequence, as it was felt that the birds might extinguish rapidly if exposed to very short t^D values at the beginning of training.

Each experimental bird remained at a given $\bar{T}$ value until its response rate had stabilized, as defined by the following criterion. The first 30 days of running at each schedule were not considered in computing stability. After the completion of the next 6 days of running, the mean of the first 3 days (M_1) was compared with the mean of the last 3 days (M_2). If the difference between M_1 and M_2 was greater than 5% of the total 6-day mean (M_T), another experimental day was added and similar calculations made for that day and the preceding 5 days. These calculations were continued daily until the bird reached the 5% criterion.

After reaching stability at the 0.003 $\bar{T}$ schedule, Bird No. 1 was shifted to a variable-ratio schedule whose mean value was determined from the extinction ratio obtained during stability days at the 0.003 $\bar{T}$ value. The extinction ratio is the ratio of unreinforced to reinforced responses (Skinner, 1938). This variable-ratio schedule was in effect for 7 consecutive days, following which the bird was moved to the 0.002 $\bar{T}$ value.

After reaching stability at the 0.004 $\bar{T}$ schedule, Bird No. 5 was pre-fed to its free-feeding weight on each of 3 consecutive days of running. (The value of $\bar{T}$ was maintained at 0.004 during this period.) Further running was discontinued until the 80% weight level was again reached, whereupon the bird returned to the 0.004 $\bar{T}$ schedule for 1 week and then shifted to the 0.003 $\bar{T}$ schedule.

Bird No. 2 (the control subject) remained at the 1.00 $\bar{T}$ schedule until Bird No. 4 reached a $\bar{T}$ value of 0.004. At this point, Birds 2 and 4 were "yoked" together for both the 0.004 and 0.003 $\bar{T}$ schedules. That is, each time Bird No. 4 received a reinforcement, the following response of Bird No. 2, whenever it occurred, was also reinforced. Since no t^D restrictions were placed on Bird No. 2, this meant, in effect, that its reinforcements occurred on a variable-interval schedule whose value was determined by the number of reinforcements received by Bird No. 4. The behavioral measures obtained from Bird No. 2 were collected during the same 6-day periods in which stability was reached by Bird No. 4. Bird No. 2 was used to control for the effects of (a) changes in the number of reinforcements per session when no

t^D restrictions are placed on the schedule; and (b), prolonged running at the 1.00 $\overline{T}$ schedule.

Although it was initially intended to obtain stability data at a $\overline{T}$ value of 0.0016, Birds 1, 3, and 4 appeared to be extinguishing at this schedule. Each bird received only an occasional reinforcement per session and exhibited great irregularities in its day-to-day response rate. After approximately 2 weeks at this schedule, it was therefore decided to discontinue further running. A 3-week extinction period was then instituted for each of the birds prior to a return to higher $\overline{T}$ values. For similar reasons, a 3-week extinction period was begun for Bird No. 5 after approximately 2 weeks of running at the 0.003 $\overline{T}$ value.

Following the extinction period, Birds 1, 3, 4, and 5 were returned to $\overline{T}$ values of 1.00, 0.004, 0.008, and 1.00, respectively. Each bird remained at the schedule indicated until it had reached the same stability criterion noted previously.

Experiment II

Both birds were run for 2 1/2 hours daily (timed from the first peck) and experimentation was on a 7-day-week basis. Each subject was first exposed to a schedule in which t^D equalled 10 minutes and t^Δ equalled zero ($\overline{T} = 1.00$), then successively shifted to t^D values of 5, 4, 3, 2, and 1 seconds, in that order ($\overline{T}$ values were 0.0083, 0.0066, 0.0050, 0.0033, and 0.0016).

The same stability criterion noted in Experiment I served as the basis for moving a subject from one $\overline{T}$ value to the next.

A 1-week period of extinction was instituted for each bird after stability was reached at the 0.0016 $\overline{T}$ value. The experiment was terminated at the end of this period.

RESULTS AND DISCUSSION

The data for both experiments are discussed in the following order: (1) a) The over-all response rate, b) standard deviation of the over-all response rate, c) number of reinforcements per session, running rate, and number of responses per reinforcement; then, (2) individual cumulative-response curves are displayed which are representative of the behavior obtained at each $\overline{T}$ schedule; and, finally, (3) IRT samples taken at each $\overline{T}$ schedule are presented.

The response-rate data (both *over-all* and *running* rates) were the means of the 6 stability days at each $\overline{T}$ schedule. The running rates were obtained by subtracting the pause-after-reinforcement time from the experimental session and recalculating the response rates. Since no bird was observed to peck the key during feeder presentation, *corrected* rates were obtained by subtracting the "eating time" from each experimental session. The standard deviation of the over-all response rate, the number of reinforcements per session, and the responses-per-reinforcement data were also calculated from the 6 stability days at each $\overline{T}$ schedule.

Experiment I (2-minute cycle)

(1a) Individual curves relating the corrected over-all response rate to values of $\overline{T}$ are displayed in Fig. 1. The group curve is presented in the same figure. The

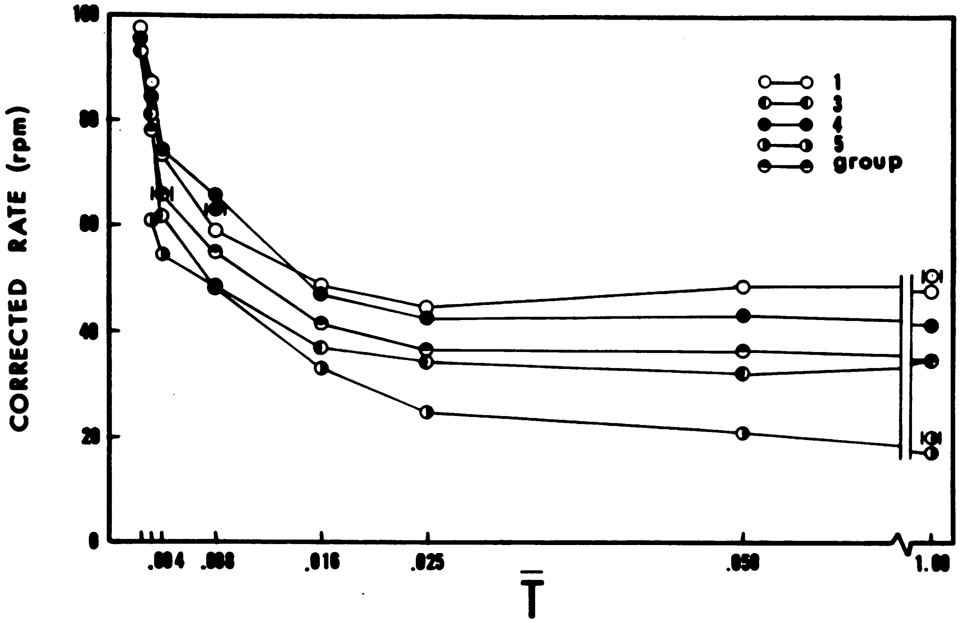

Figure 1. Corrected over-all rate in responses per minute as a function of $\bar{T}$ ($t^D + t^\Delta = 2$ minutes). Bracketed circles are recovery values.

bracketed circles are the response-rate values obtained on return to the indicated $\bar{T}$ schedule after each bird had completed its function.

Each individual curve indicated that response rate is inversely related to the value of $\bar{T}$. The individual functions consist, perhaps, of two segments, a straight line of zero slope at all $\bar{T}$ values that did not result in "missed" reinforcements, and a curvilinear segment at smaller $\bar{T}$ values. (Birds No. 1, 3, 4, and 5 began to "miss" reinforcements at $\bar{T}$ values of 0.008, 0.016, 0.016, and 0.05, respectively.) A plot of the corrected over-all rate as a function of log $\bar{T}$ was made for each individual bird for all $\bar{T}$ values that resulted in "missed" reinforcements. Each of the reduction lines so obtained were approximately linear, indicating that an equation of the form $R = a\bar{T}^{-b}$ (where R is the response rate) adequately describes the curvilinear portion of each individual function. The constants a and b were determined for each reduction line by the method of least squares. The b constant is 0.37, 0.43, 0.34, and 0.41 for Birds 1-5, respectively, indicating that the rate of descent of each of the functions is approximately the same. The major difference between individual curves is in the a constant, which represents their position on the vertical axis.

None of the redetermined rate values (bracketed circles of Fig. 1) differed significantly from the initial values obtained at the indicated $\bar{T}$ schedules (Mann & Whitney, 1947). Although each bird was returned to only one $\bar{T}$ value after the completion of its function, the close correspondence between the initial and the redetermined rates suggests that the individual functions are recoverable. This finding may be compared with data presented by Schoenfeld and Cumming (1957), who found that the recovered rates at both 7.5- and 30-second cycle values were markedly higher than the initially determined rates. These authors account for the fact that the bird *did not* return to its former rate value by noting that high response rates, once they are established under short-cycle conditions, may be "superstitiously" maintained in strength even after a return to a longer cycle length.

In the present study, however, in which a return to former rate values was obtained, 3 weeks of extinction preceded the attempt at recovery. It is likely that the increased probability of occurrence of long IRT's produced by this extinction procedure facilitated the recovery of the lower response rates associated with the larger $\bar{T}$ values. Although the effect of the delivery of the first few reinforcements following extinction was to produce a marked increase in response rate, the over-all rate during these sessions was much lower than the rate at the $\bar{T}$ schedule preceding extinction. The cumulative-response records were also "grained" in appearance, indicating large variations in rate, with long IRT's occurring at a reasonably high frequency. Larger $\bar{T}$ schedules may act at least in part, to maintain behavior through the selective reinforcement of longer IRT's than do the smaller $\bar{T}$ schedules (Anger, 1956; Ferster & Skinner, 1957). The frequent emission of long IRT's by the subject during the initial stages of return to the larger $\bar{T}$ value may therefore be an important factor in the recovery of lower response rates.

Bersh, Schoenfeld, and Notterman (1950) also concluded that "complete extinction to operant level tends to eliminate permanently differences in response strength produced by varied histories of reinforcement."

(1b) The relation between the corrected over-all response rate and its standard deviation is displayed in Fig. 2 for each of the four subjects. Each of the curves is roughly linear in appearance, with increases in the standard deviation accompanying increases in rate. Coefficients of variation, calculated for each rate and accompanying standard deviation, were approximately constant.

The possibility arose that the orderly increase in standard deviation may have been due, in part, to the nature of the stability criterion. It will be recalled that a

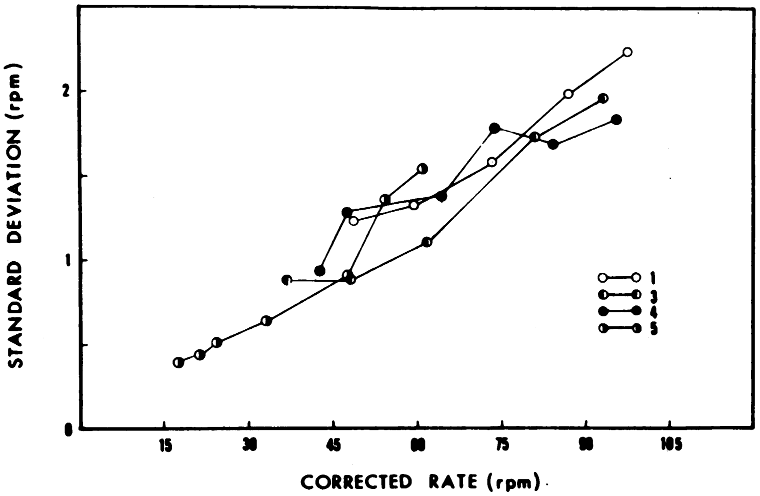

Figure 2. The standard deviation of the corrected over-all response rate in responses per minute as a function of the over-all corrected rate ($t^D + t^\Delta = 2$ minutes).

bird was considered stabilized if, after 30 days of running, $(M_1 - M_2) \leq 0.05\ M_T$. Note that the larger the value of M_T, the greater may be the difference between M_1 and M_2 that will still permit the acceptance of stability. Increases in M_T may therefore tend artificially to increase the standard deviation. In order to determine whether the increase was an artifact resulting from the nature of the stability criterion, the standard deviation was also calculated for the final 10-day period of the first 30 days of running at each $\overline{T}$ schedule. The values thus obtained were quite close to those based solely on stability days. (The same conclusion applies to the data obtained in Experiment II.) Since these 10-day periods occurred prior to any computations of stability, the stability criterion could not enter as a factor in determining the data. The close correspondence between the standard deviations calculated during stability days and during the 10-day periods preceding the computation of stability also suggests that the stability criterion incorporates a desirable feature in allowing for an increase in the spread of scores as M_T increases.

(1c) The mean over-all response rate is inversely related to the mean number of reinforcements per session. As $\overline{T}$ was decreased from 1.00 to 0.002, the group mean over-all response rate increased from 35.6 to 95.4 responses per minute, while the group mean number of reinforcements per session declined from 15.0 to 7.4. An increase in response rate accompanying a decrease in the number of reinforcements per session is also found under fixed-ratio schedules as the size of the ratio is increased (Boren, 1953). Under fixed- or variable-interval conditions (Cumming, 1955; Ferster & Skinner, 1957; Wilson, 1954) a positive relation exists between response rate and frequency of reinforcement. That is, a *decrease* in response rate accompanies a decrease in the number of reinforcements per session as the interval length is increased.

The inverse relation between over-all response rate and the number of reinforcements per session raised the possibility, however, that the rate increase associated with a decrease in $\overline{T}$ was an artifact resulting from a decline in the number of pauses after reinforcement. The pause-after-reinforcement time was therefore subtracted from the experimental sessions and the response rates recalculated. The running rates thus obtained, when plotted as a function of $\overline{T}$, were almost identical in appearance to the functions relating the over-all response rate to $\overline{T}$, indicating that the increase in response rate does not result from a decrease in the number of pauses after reinforcement. (The same conclusion applies to the data obtained in Experiment II.)

The positive relation previously noted, between rate of response and frequency of reinforcement under interval schedules, was clearly in evidence in the response records of control bird No. 2. The over-all response rate of this bird declined from 52.3 responses per minute during the 1.00 $\overline{T}$ schedule to 47.9 responses per minute when the average number of reinforcements per session was reduced from 15.0 to 12.5. The response rate further decreased to 37.2 responses per minute when the number of reinforcements per session was subsequently reduced to an average value of 9.3

The data obtained from Bird No. 2 suggest therefore that (a) the increase in response rate correlated with a decrease in $\overline{T}$ found in the four experimental subjects cannot be accounted for simply in terms of a decrease in number of reinforcements per session; and (b) neither can the increase in response rate for the four experimental birds be due solely to the passage of time. Although it was run at the 1.00$\overline{T}$ schedule until Bird No. 4 had reached the 0.004 $\overline{T}$ value, Bird No. 2 displayed no systematic changes in its behavior.

Figure 3 displays the relation between number of responses per reinforcement and $\overline{T}$. An inverse relation between the two variables is clearly in evidence. An increase in number of responses per reinforcement with an accompanying increase in response rate is also consistent with the assumption that decreases in the value of $\overline{T}$ duplicate the effects of shifting the subjects from interval to increasingly larger ratio schedules of reinforcement. There is a positive relation between the number of responses per reinforcement and response rate under fixed-ratio reinforcement schedules (Boren, 1953). Interval schedules, on the other hand, characteristically show a slight increase in the number of responses per reinforcement accompanying a decrease in response rate (Wilson, 1954). Bird No. 2, run at the variable-interval schedules noted previously, did, in fact, exhibit slight increases in the number of responses per reinforcement from 104.6 to 115.1 to 120.0 as the response rate declined from 52.3 to 47.9 to 37.2 responses per minute.

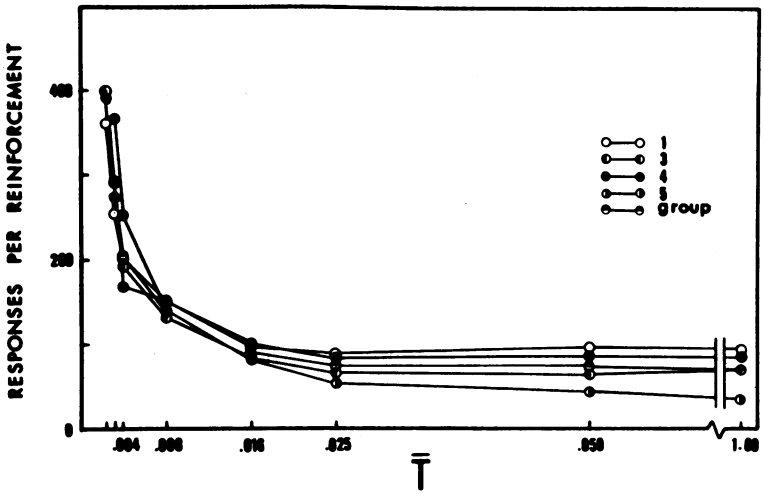

Figure 3. Mean number of responses per reinforcement as a function of $\overline{T}$ ($t^D + t^\Delta$ = 2 minutes).

(2) Representative individual cumulative-response curves selected from stability days are presented for Birds No. 1 and 4 in Fig. 4 and 5. The $\overline{T}$ value at which each curve was obtained is indicated in the upper left-hand corner of each record. Records from the 1.00 $\overline{T}$ schedule and all schedules that resulted in "missed" reinforcements are shown for both birds. Each bird shows the "scalloping" typical of fixed-interval reinforcement during the 1.00 $\overline{T}$ schedule. As the value of $\overline{T}$ is decreased, both birds show transitions to increasingly rapid accelerations to the terminal rate, within each reinforcement cycle. It is apparent from the records that the smaller $\overline{T}$ values generate "ratio-like" curves for each of the birds. The transition from the "scalloping" observed at the larger $\overline{T}$ values to the "burst" and "break"

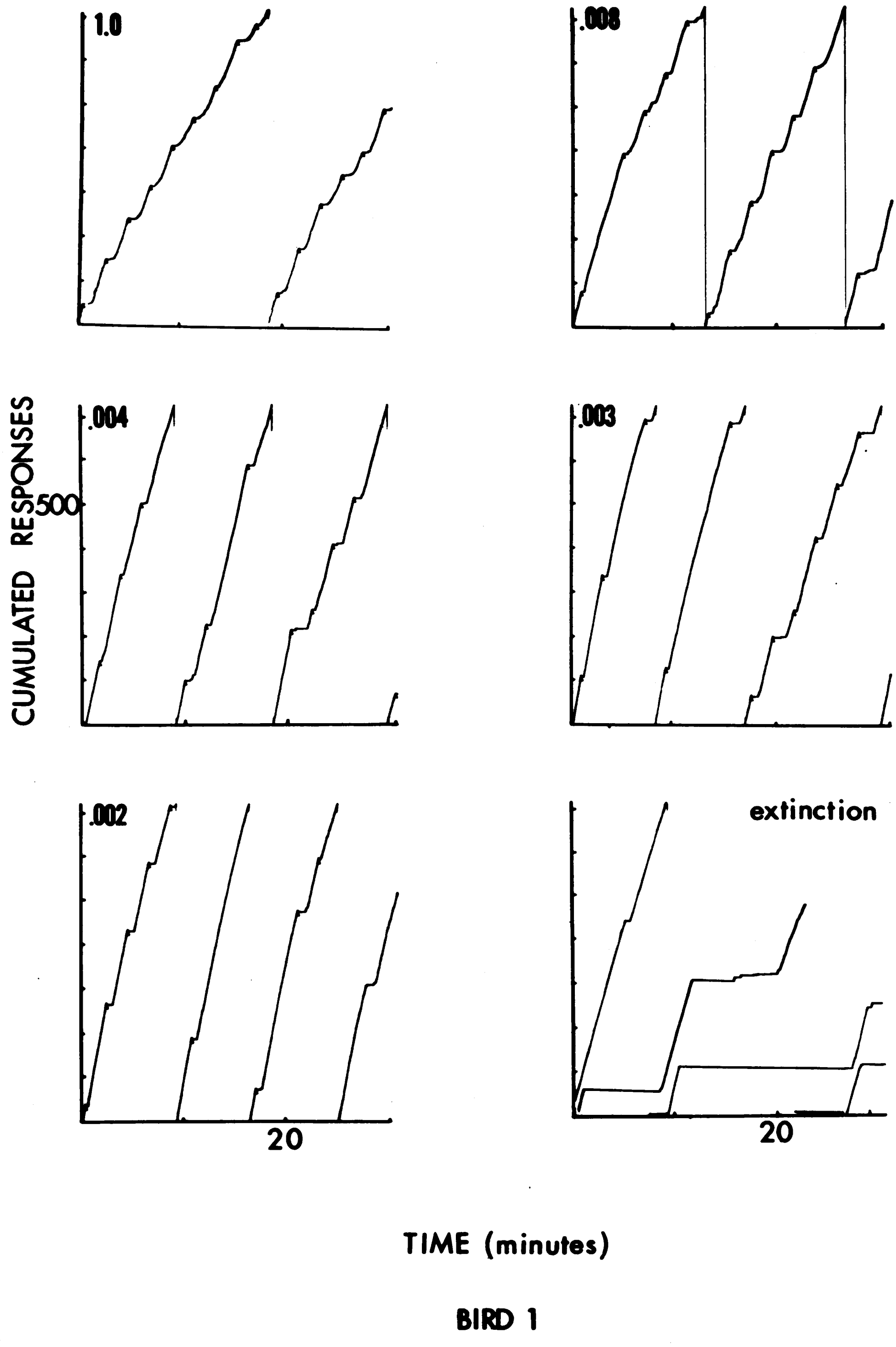

Figure 4. Representative cumulative-response curves for Bird No. 1 ($t^D + t^\Delta = 2$ minutes). Each curve is displaced to the base line after approximately 600 responses have accumulated. The value of $\overline{T}$ is shown for each record and reinforcements are indicated by short diagonal lines.

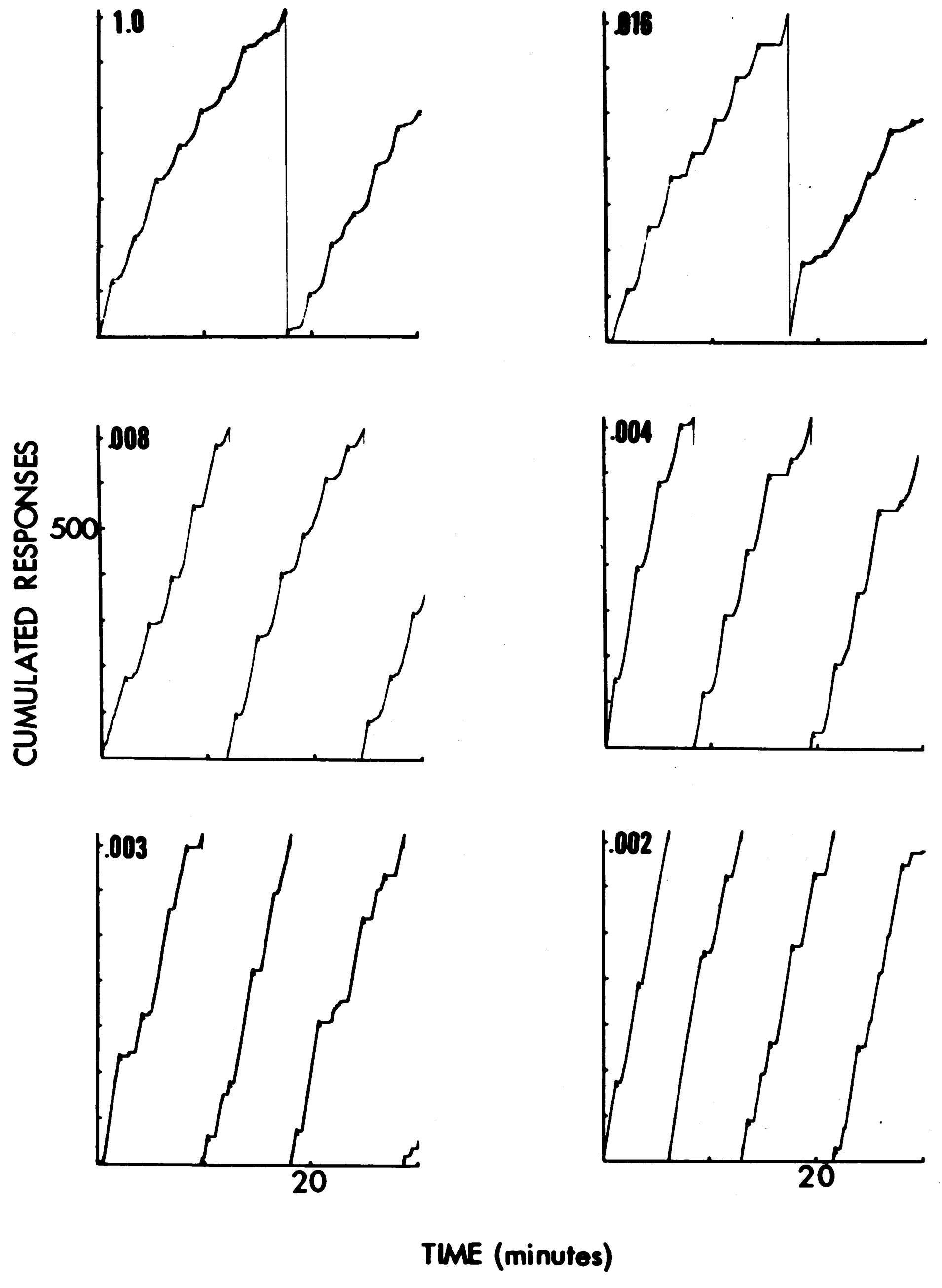

Figure 5. Representative cumulative-response curves for Bird No. 4 ($t^D + t^\Delta = 2$ minutes). Each curve is displaced to the base line after approximately 600 responses have accumulated. The value of $\overline{T}$ is shown for each record and reinforcements are indicated by short diagonal lines.

appearance at the smaller $\bar{T}$ values will be shown more clearly in the IRT analysis to be presented shortly.

The extinction record shown for Bird No. 1 in Fig. 4 closely resembles curves presented by Ferster and Skinner (1957) for extinction following ratio schedules of reinforcement. Periods of no response alternate with periods of response that reflect the rate during the preceding conditioning session. The extinction curve for Bird No. 4, which is not presented, exhibits the same ratio-like character.

The cumulative-response records obtained from Birds No. 1 and 5 on return to the 1.00 $\bar{T}$ schedule differed somewhat in appearance from the records obtained during their first exposure to this schedule. The records were less scalloped and more ratio-like in appearance. Although slow positive accelerations in rate, following a reinforcement, occasionally appeared, both birds were more likely to accelerate rapidly to the terminal rate following the pause after reinforcement. The response records of Birds No. 3 and 4, obtained on return to the 0.004 and 0.008 $\bar{T}$ schedules, respectively, were indistinguishable from the records obtained during their first exposure to these schedules. The response records for control bird No. 2 retained their scalloped appearance throughout the entire experiment.

(3) The histograms of Fig. 6 display the group IRT data obtained during the last 30-minute session (6th stability day) of each $\bar{T}$ schedule. The time interval between the delivery of reinforcement and the following response (pause-after-reinforcement) was not included in the tabulation. An increase in the relative frequency of the 0-to-0.4- and 0.5-to-0.8-second IRT classes and a decrease in the relative frequency of the other four IRT classes is in evidence as $\bar{T}$ is decreased below a value of 0.025. Since the 1.00, 0.05, and 0.025 distributions are practically identical, the data suggest that the transition from interval to ratio-like behavior begins somewhere in the neighborhood of a $\bar{T}$ value of 0.016.

Anger (1956) points out that the use of relative frequency as an estimate of the probability of occurrence of a given IRT does not take into consideration the fact that there are more opportunities for responses to occur after short than after long intervals. He suggests correcting for this difference in opportunities by calculating the ratio of the number of IRT occurrences as a fraction of the number of opportunities for such IRT's (IRT's/ops). This ratio is an unbiased estimate of the probability of response during a given time interval given an opportunity for response in that interval. The filled circles of Fig. 6 show the relation between the group IRT's/ops data and IRT class. The peak of the IRT's/ops distribution occurs in the 1.3-to-1.6-second class for $\bar{T}$ values of 0.05 and 0.025. At the 0.016 $\bar{T}$ schedule there is an abrupt shift of the peak to the 0.5-to-0.8-second class. The peak of the distribution remains in this class and becomes more pronounced as $\bar{T}$ is further decreased.

Figure 7 shows the group data of the distribution of the first four IRT's following reinforcement (initial rate) and the last four IRT's preceding reinforcement (terminal rate). Pauses after reinforcement were not included in the initial rate tabulation. The data indicate that the peak in the initial rate IRT distribution occurs in the "over 2 seconds" IRT class at the 0.05 and 0.025 $\bar{T}$ schedules. A second peak appears in the 0.5-to-0.8-second class at the 0.016 schedule and becomes more pronounced as $\bar{T}$ is further decreased. The peak in the terminal rate IRT distribution occurs in the 0.9-to-1.2-second class at the 0.05 $\bar{T}$ schedule and shifts to the 0.5-to-

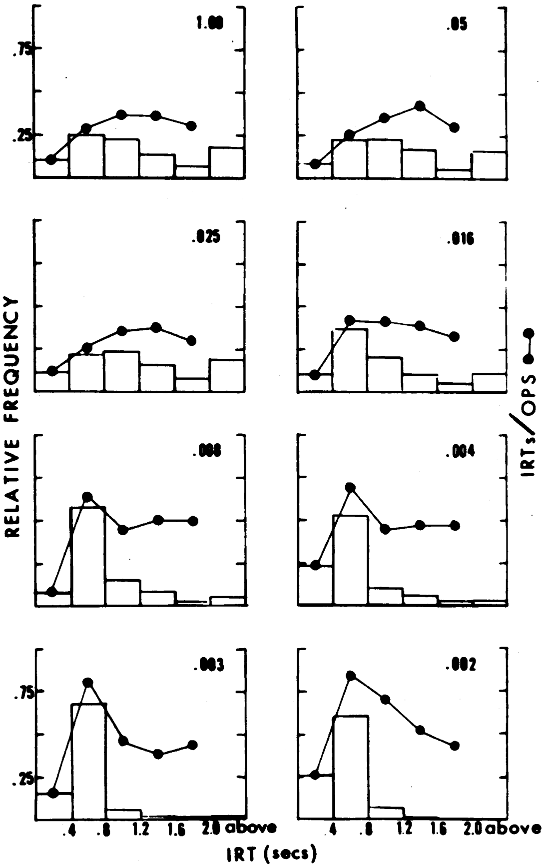

Figure 6. The relative frequency of different IRT classes at each $\bar{T}$ value ($t^D + t^\Delta$ = 2 minutes). The filled-circle functions are the IRT's/ops of different IRT classes.

0.8-second category at the 0.008 schedule. Clearly, the initial as well as the terminal rates increase as $\bar{T}$ is decreased. The terminal-rate distribution lies above the initial-rate distribution in the shorter IRT classes at all values of $\bar{T}$, but the percentage difference between the two functions decreases at the smaller $\bar{T}$ values (at the 0.002 value the curves superimpose), indicating an increasingly rapid acceleration to the terminal rate at these schedules. The distributions at the 1.00, 0.05, 0.025, and 0.016 $\bar{T}$ schedules indicate a more gradual acceleration in number of responses from the initial to the terminal value, which is similar to the scalloping obtained under interval conditions.

Two other findings in this study are of some interest: the effects of pre-feeding upon behavior during a $\bar{T}$ schedule that generates ratio-like behavior and the effects upon behavior of changing from a $\bar{T}$ schedule to a comparable variable-ratio schedule.

The effect of 3 days of pre-feeding to the free-feeding weight upon the behavior of Bird No. 5 during a $\bar{T}$ schedule of 0.004 was to lengthen the average pause-after-reinforcement time from 80.7 seconds to 122.4 seconds. This difference was significant at the 0.01 confidence level (Mann & Whitney, 1947). The cumulative-response records during this period were steplike in appearance. Responding, when it did occur, was at the same rate as prior to pre-feeding. The effects of satiation upon behavior at this $\bar{T}$ schedule duplicate the effects of satiation upon ratio rather than interval schedules (Ferster & Skinner, 1957; Sidman & Stebbins, 1954).

Moving Bird No. 1 from a $\bar{T}$ schedule of 0.003 to a comparable variable-ratio schedule produced no discernable changes in its behavior during the 7-day period in which the VR schedule was in effect. A comparison of the response rates and pauses after reinforcement indicated no significant differences between the 0.003 $\bar{T}$ schedule and the VR schedule (Mann & Whitney, 1947). Cumulative-response records obtained under both schedule conditions were indistinguishable. It is not

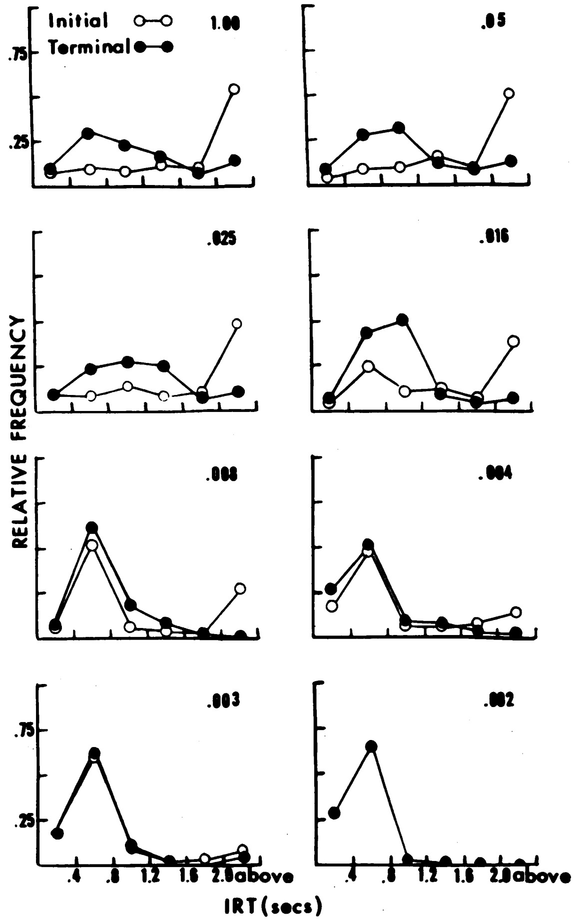

Figure 7. Relative frequency of initial and terminal IRT's at each $\bar{T}$ value ($t^D + t^\Delta =$ 2 minutes).

possible to say whether further running at the VR schedule would have generated different effects on behavior, but the data do suggest that the same variables are involved in the control of behavior during both the $\overline{T}$ and the corresponding VR schedule.

Experiment II (10-minute cycle)

(1a) Figure 8 displays individual curves relating the corrected over-all response rate to values of $\overline{T}$. The response rates of both birds increase as $\overline{T}$ is reduced from 1.00 to 0.0033 and then decrease at the smallest $\overline{T}$ value. (Both birds began to "miss" reinforcements at a $\overline{T}$ value of 0.0066.) The data indicate that a nonmonotonic function relates the response rate to $\overline{T}$ when $t^D + t^\Delta$ is equal to 10 minutes. A similar relation between response rate and $\overline{T}$, when $t^D + t^\Delta$ equals 2 minutes, is also suggested by the response records of the subjects during the 0.0016 $\overline{T}$ value.

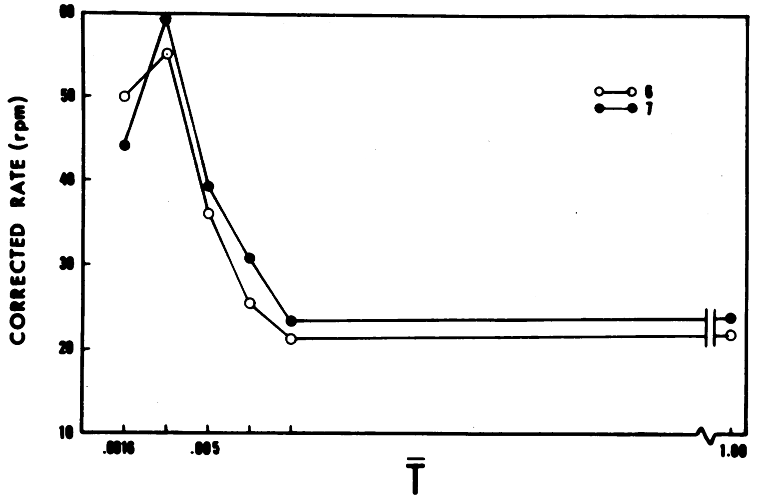

Figure 8. Corrected over-all rate in responses per minute as a function of $\overline{T}$ ($t^D + t^\Delta$ = 10 minutes).

(1b) The relation between the over-all response rate and the standard deviation is shown in Fig. 9 for both subjects. Each of the curves is again quite linear in appearance with increases in standard deviation accompanying increases in rate. The slope of the estimated mean curves of Fig. 2 and Fig. 9 are approximately equal, suggesting perhaps, that the standard deviation of the over-all rate is simply a constant proportion of the over-all rate.

(1c) The data indicate that the over-all response rate is inversely related to the mean number of reinforcements per session for all values of $\overline{T}$ up to 0.0033. As $\overline{T}$ was decreased from 1.00 to 0.0033 the group mean over-all response rate increased from 23.2 to 57.4 responses per minute, while the group mean number of reinforcements per session declined from 15 to 7.7 At the 0.0016 value the response rate and

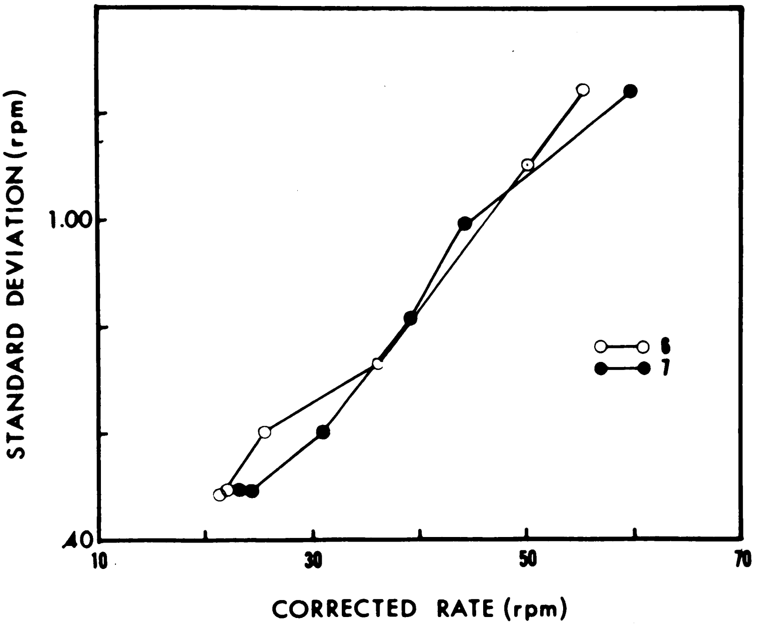

Figure 9. The standard deviation of the corrected over-all response rate in responses per minute as a function of the over-all corrected rate ($t^D + t^\Delta = 10$ minutes).

the frequency of reinforcement decreased to 47.1 responses per minute and 5.9 reinforcements per session, respectively.

Figure 10 displays the relation between number of responses per reinforcement and $\overline{T}$. An inverse relation between the two variables is exhibited by Bird No. 6, while Bird No. 7 shows a maximum in the function at the 0.0033 $\overline{T}$ value.

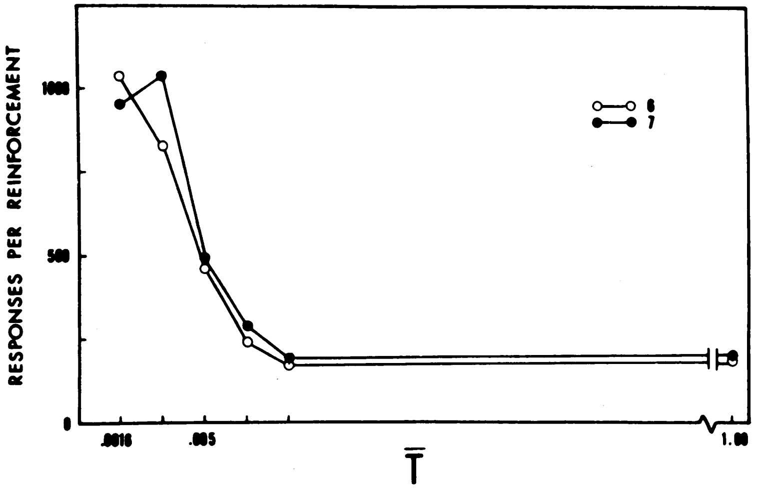

Figure 10. Mean number of responses per reinforcement as a function of $\overline{T}$ ($t^D + t^\Delta = 10$ minutes).

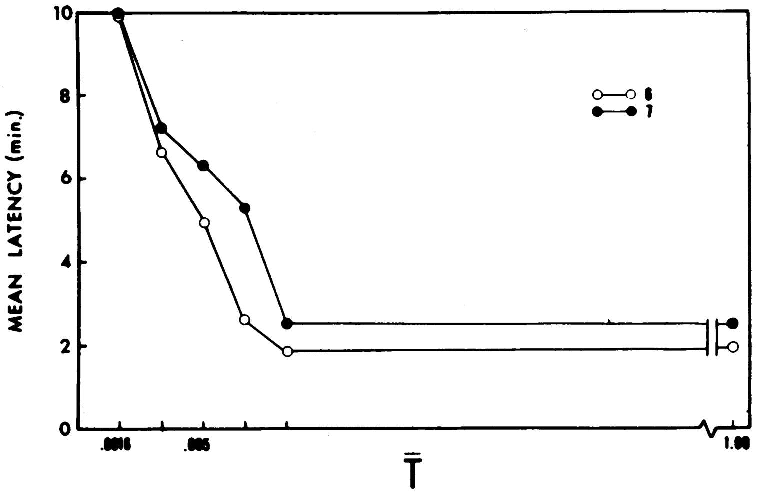

Figure 11. The mean pause after reinforcement (latency) as a function of $\overline{T}$ ($t^D + t^\Delta = 10$ minutes).

(1d) The data of Fig. 11 indicate a systematic increase in the duration of the mean pause after reinforcement (latency) as $\overline{T}$ is decreased. (No such increase in latency was found in the response records of Experiment I.)

(2) Representative individual cumulative-response curves selected from stability days are presented in Fig. 12 and 13. The 0.0083 records are not shown as they were quite similar to the 1.00 records. Both birds display the "scalloping" typical of fixed-interval reinforcement during the 1.00 $\overline{T}$ schedule. As the value of $\overline{T}$ is decreased, transitions to progressively rapid accelerations in number of responses occur within each reinforcement cycle, generating records that are "ratio-like" in appearance. The extinction records, again, closely resemble curves presented by Ferster and Skinner (1957) for extinction following ratio schedules of reinforcement. Periods of rapid response that approximate the rate obtained during the previous conditioning sessions alternate with periods of no response that begin rather abruptly.

(3) The histograms of Fig. 14 display the group IRT data obtained during the last stability day at each $\overline{T}$ schedule. An increase in the relative frequency of the 0-to-0.4- and 0.5-to-0.8-second IRT classes and a decrease in the relative frequency of the remaining four IRT classes is in evidence as $\overline{T}$ is decreased to a value of 0.0033. An increase in the four largest and a decrease in the two smallest classes is noted at the 0.0016 value, indicating a decrease in running rate at this schedule. Since the 1.00 and 0.0083 distributions are practically identical, the data suggest that the transition from interval to "ratio-like" behavior during a 10-minute cycle length begins somewhere in the region of 0.0066.

The filled circles of Fig. 14 show the relation between the group IRT's/ops data and the IRT class. The peak of the distribution occurs in the "above 2 seconds" class for $\overline{T}$ values of 1.00 and 0.0083, and abruptly shifts to the 0.5-to-0.8-second

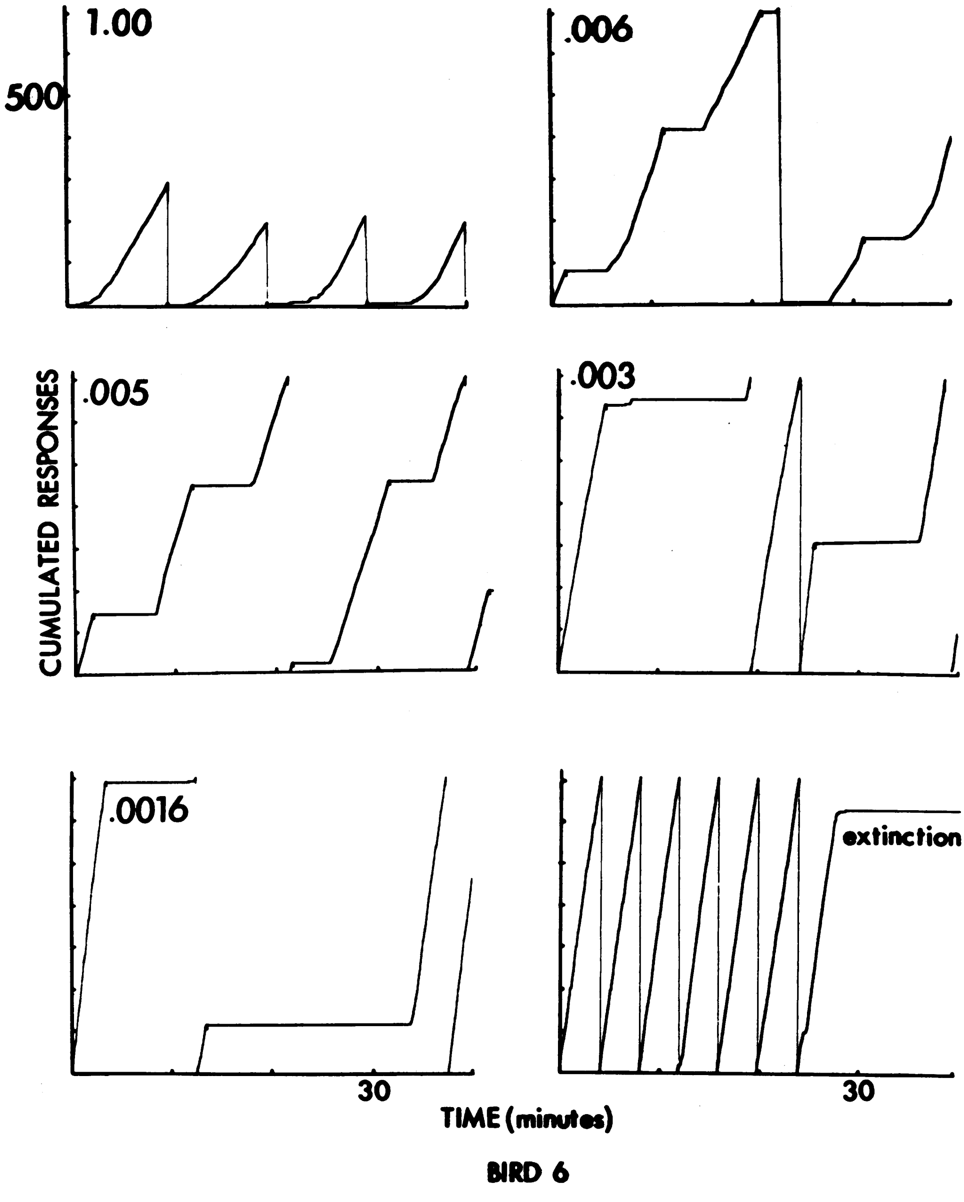

Figure 12. Representative cumulative-response curves for Bird No. 6 ($t^D + t^\Delta = 10$ minutes). Each curve is displaced to the base line after approximately 600 responses have accumulated except for the 1.00 schedule, where the curve returns to the base line after each reinforcement. The value of $\overline{T}$ is shown for each record and reinforcements are indicated by short diagonal lines.

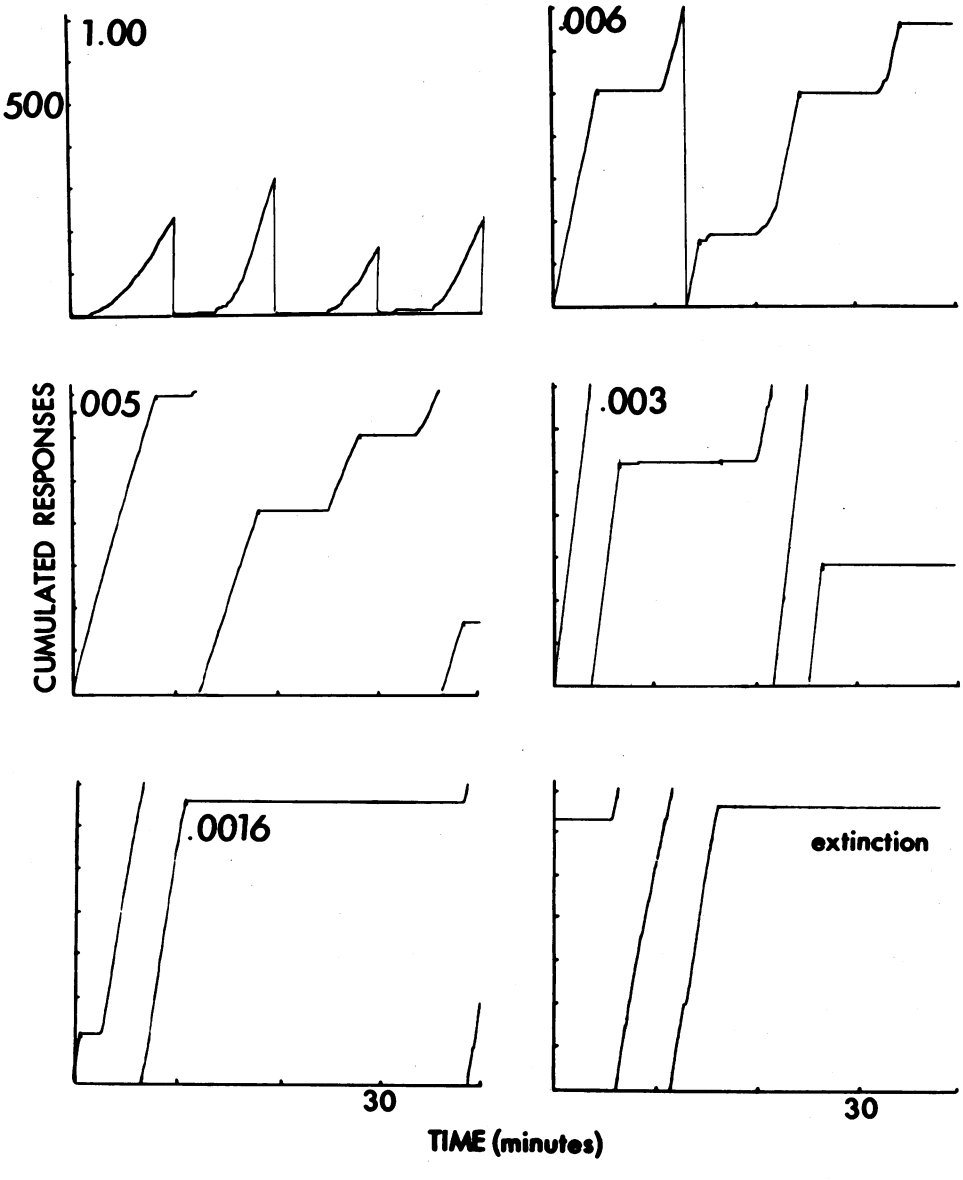

Figure 13. Representative cumulative-response curves for Bird No. 7 ($t^D + t^\Delta = 10$ minutes). Each curve is displaced to the base line after approximately 600 responses have accumulated except for the 1.00 schedule, where the curve returns to the base line after each reinforcement. The value of $\overline{T}$ is shown for each record and reinforcements are indicated by short diagonal lines.

class at the 0.0066 value. The peak remains in this class, becomes more pronounced as $\overline{T}$ is further decreased to a value of 0.0033, and then is lowered somewhat at the 0.0016 schedule.

Figure 15 presents the group data of the first four IRT's following reinforcement (initial rate) and the last four IRT's preceding reinforcement (terminal rate). Latencies were not included in the initial rate tabulation. Similar to the data of Fig. 7, initial and terminal rates increase as $\overline{T}$ is decreased (except for the smallest $\overline{T}$ value, where both initial and terminal rates decrease somewhat); and the percentage difference between the two functions decreases at the smaller $\overline{T}$ values.

The data presented for Experiments I and II have been in substantial agreement with the hypothesis that some time-correlated schedules of reinforcement duplicate the behavioral effects of interval and some ratio schedules of reinforcement. The increase in response rate accompanying both a decrease in number of reinforcements per session and an increase in number of responses per reinforcement, the characteristics of the cumulative-response curves, the changes in the initial and terminal IRT distributions at the different $\overline{T}$ values, the effects of pre-feeding, and the effects of changing from a $\overline{T}$ to a comparable VR schedule all support the notion that decreases in the value of $\overline{T}$ result in a transition from interval to "ratio-like" behavior. At this point the determination of any behavioral differences that may exist between ratio schedules and time-correlated schedules that generate ratio-like effects must wait upon a fine-grain analysis of ratio schedules that are equated with time-correlated schedules on the basis of number of responses per reinforcement.

SUMMARY

The two major variables of a time-correlated schedule are designated t^D and t^Δ. The former specifies a time period during which a response occurrence may be reinforced; the latter, a time period during which no response occurrences are reinforced. In the present experiments, $t^D + t^\Delta$ equalled 2 minutes and 10 minutes, respectively, t^D and t^Δ were alternated, and only the first response in t^D was reinforced. The independent variable was the value of $\overline{T}$ (the ratio of t^D to $t^D + t^\Delta$), which was successively decreased throughout each experiment.

White Carneaux hen pigeons served as subjects and the response measured was key-pecking.

The following results were obtained:

Experiment I (2-minute cycle)

(1) Response rates and responses per reinforcement increased as $\overline{T}$ was decreased. An equation of the form $R = a\overline{T}^{-b}$ (where R equals response rate) adequately described the relation between response rate and $\overline{T}$.

(2) Good recoverability of data was obtained on return to former $\overline{T}$ values.

(3) The response rate and standard deviation of the response rate were linearly related.

(4) Individual cumulative-response curves indicated that the smaller $\overline{T}$ values generated "ratio-like" behavior.

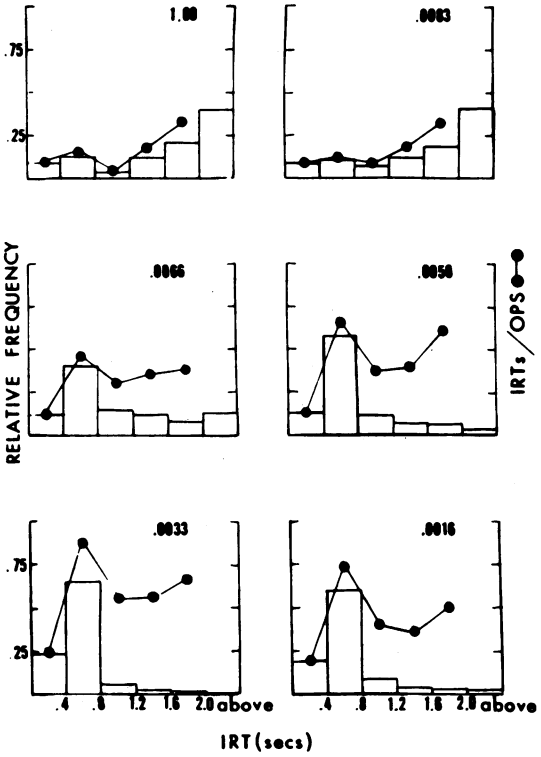

Figure 14. The relative frequency of different IRT classes plotted at each $\overline{T}$ value ($t^D + t^\Delta = 10$ minutes). The filled-circle functions are the IRT's/ops of different IRT classes.

(5) The percentage difference between initial (immediately following reinforcement) and terminal (immediately preceding reinforcement) rates decreased as $\overline{T}$ decreased.

(6) The effects of pre-feeding during a $\overline{T}$ schedule that generated "ratio-like" behavior duplicated the effects of satiation upon ratio schedules.

(7) Moving one bird from a $\overline{T}$ schedule to a comparable variable-ratio schedule produced no discernable changes in its behavior.

Experiment II (10-minute cycle)

(1) The response rate was nonmonotonically related to the value of $\overline{T}$. An inverse relation between responses per reinforcement and $\overline{T}$ was found for one bird, and a nonmonotonic relation for the other.

(2) The results of Paragraphs (3), (4), and (5) of Experiment I were also obtained in this experiment.

CONCLUSION

Decreases in the value of $\overline{T}$ in both studies led to systematic changes in several aspects of behavior. In addition, the data indicate that decreases in the value of $\overline{T}$,

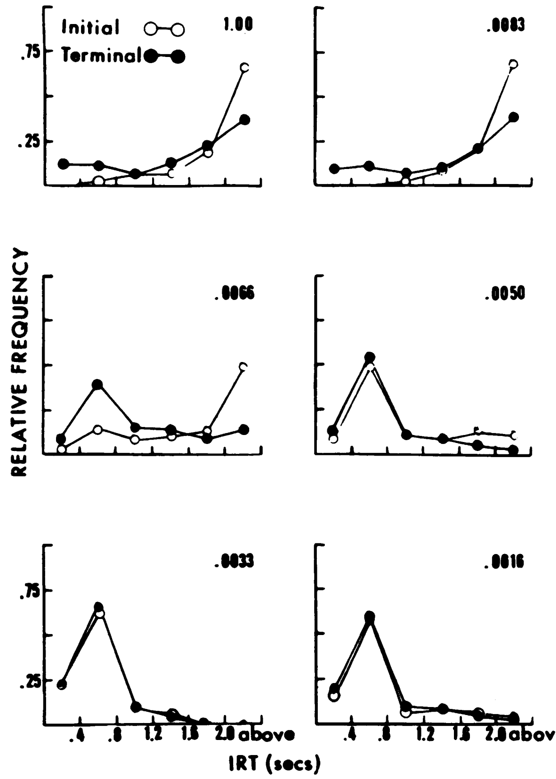

Figure 15. Relative frequency of initial and terminal IRT's at each $\overline{T}$ value ($t^D + t^\Delta = 10$ minutes).

during both a 2-and-10-minute cycle length result in a transition from interval to "ratio-like" behavior.

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