CLUSTERING IN THE OUTPUT OF BEHAVIOR[1]

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Pigeons exposed to fixed-interval schedules of 3, 5, 15, 40, and 120 minutes all maintained considerable variability in daily response rates for as many as 104 sessions. However, variations did not occur at random. Instead, rate in a session appeared dependent on those occurring previously. The series displayed a wave-like form arising because a group of high rates was followed by a group of low rates and *vice versa*. These sequential relations produced a curve having irregular periodicity, sometimes superimposed on a declining or rising linear trend. Whether grouping of response rates stemmed from experimental or extra-experimental sources was not determined. If the phenomenon was either totally or partially produced by the schedule itself, it suggests that response rate is determined by a combination of positive and negative feedback. Control by factors extrinisic to the experiment itself implies that response rate may be influenced by some rhythmic physiological process.

Key words: fixed-interval schedule, first-order deviation, sequential dependency, steady-state performance, regulation, rhythms, pigeons

The fixed interval (FI) was the first schedule of intermittent reinforcement to be studied in detail. To investigate conditioning and extinction repeatedly, Skinner (1933) followed one response at regular intervals with food while intervening responses had no consequences. Presumably, the response was being conditioned periodically, hence the designation of the arrangement as "periodic reconditioning". Eventually, this label was replaced by "fixed-interval schedule" (Ferster and Skinner, 1957) as emphasis shifted from the acquisition and loss of responding to the stable behavior emerging with prolonged exposure to the schedule.

What is the steady-state behavior with FI schedules? Although often overlooked in favor of implications that performance is stereotyped and repetitive, the existing information actually suggests change and variability. Skinner originally observed that the FI schedule established variable overall response rates in successive sessions (first-order deviations from a steady response rate), rate changes in successive intervals within sessions (second-order deviations), variable rates within individual intervals (third-order deviations), and grouping of individual response (fourth-order deviations). The third-order deviation, or temporal patterning of responses as it is now more commonly known, is generally recognized as characteristic of FI performance. Second-order deviations also have been confirmed, and even have motivated quantitative analysis and theory (Dews, 1970; Herrnstein and Morse, 1958; Zeiler, 1977). Experiments conducted subsequent to Skinner's have suggested that the fourth-order deviations—the tendency for responses to be clustered—actually may be a general characterictic of performance under all schedules of intermittent reinforcement, rather than being restricted to FI schedules (Blough, 1963; Blough and Blough, 1968).

Only suggestive data are available about total output in successive sessions (the first-order deviations). Skinner (1933, p. 310, Figure 3; or 1938, p. 120, Figure 29) showed rate over a series of sessions, but the figure does not lend itself to quantitative analysis. Rates are cumulated over sessions, and Skinner drew a smooth curve through the points that totally obscures the individual entries. Two features discussed were a tendency for rate to decline,

and the occurrence of occasional sessions in which rate was lowered, thereby giving rise to a series of shallow scallops in the curves. Cyclicities, therefore, appeared in the context of a slowly declining rate. Skinner implied that the changes were unimportant, however, it is not clear whether this judgement pertained to theoretical significance or to the magnitude of the effects.

Other data are those of Gollub (1964) for 21 sessions following transition from other schedules to FI. The most evident feature was considerable variability that Gollub attributed to the recent history with other conditions. The assumption was that erratic overall rates under FI were representative of a transition period, rather than of steady-state perform-ance.

Thus, the existing literature does not lend itself readily to evaluations of possible sequential effects or even to assessment of the magnitude of overall rate differences between successive sessions. The present purpose was to provide a quantitative description. Original data describe the daily overall response rates with FI schedules having parameter values from 3 to 120 min.

METHOD

Subjects

Eleven White Carneaux pigeons were maintained at 80% of their free-feeding weights. All had different but extensive experimental histories involving a variety of simple and second-order schedules and discriminative stimuli. The 11 birds comprised five conditions, each involving a different FI schedule.

Apparatus

The experimental chambers were four single-key units modified slightly from that described by Ferster and Skinner (1957). The 2-cm diameter response key (R. Gerbrands Co.) was operated by a minimum force of 0.2 N and could be transilluminated by two 7-W lamps. A 5-cm square aperture centered 8 cm below the key provided occasional access to Purina Pigeon Checkers, the birds' standard diet. During feeder cycles, a 1.1-W white lamp illuminated the aperture. White noise and a continuously operating exhaust fan masked extraneous auditory input.

Procedure

The five conditions differed in the parameter value of the FI schedule and in procedural detail, because the data typically derived from conditions that served as baseline sessions for other experiments. Under all except the longest FI schedule, sessions were conducted five days per week (Monday to Friday).

Birds P-40, P-59, P-122, and P-127 were exposed to an FI 3-min schedule for 63, 55, 43, and 41 sessions respectively. Sessions continued for 30 fixed intervals. The only illumination was provided by amber keylights during interfood intervals or by the aperture light during the 3-sec feeder cycles. The 3-min intervals were timed from the end of the preceding food delivery. In this and all other groups, the first interval was timed from the start of the session.

Birds P-2, P-46, and P-106 were exposed to an FI 5-min schedule for 104, 102, and 100 sessions respectively. Sessions continued for 30 fixed intervals. A white houselight (GE 25T10/1F in series with a 300-ohm resistor) and blue keylights were on throughout each interval and during the 4-sec feeder cycles. Each food delivery was followed by a 10-sec period with the chamber dark. Fixed intervals after the first were timed from the end of this blackout period.

Birds P-102 and P-103 had an FI 15-min schedule for 47 and 51 sessions respectively. Each session involved 15 food presentations. The only illumination was provided by a green keylight during the fixed intervals and by the aperture lamp during the 4-sec feeder cycles. All intervals after the first were timed from the end of the previous food delivery.

Birds P-107 and P-136 were exposed to an FI 40-min schedule for 38 and 40 sessions respectively. Sessions continued for 11 food presentations. During the intervals, illumination was provided by a white houselight (GE 25T10/1F) and a blue keylight, both wired in series with a 300-ohm resistor. The only illumination during the feeder cycles was provided by the white aperture lamp. Each interval after the first was timed from the end of the previous food delivery.

Birds P-107 and P-136 then were exposed to an FI 120-min schedule for 41 sessions. Except for the number of sessions per week, the details of the procedure were the same as with

the FI 40-min schedule. Because each session required at least 22 hr, and because only one experimental chamber was used, the two birds were studied on alternate days. No sessions were begun on weekends, so each bird had a cycle of one week with two sessions, followed by one week with three sessions.

All birds were given supplementary feeding immediately after each session to bring them to the 80% weight. They also were fed on Saturdays, and Birds P-107 and P-136 were fed on weekdays when they were not studied under the FI 120-min condition. Because no bird was fed on Sunday, an extra ration given on Saturday ensured that each would be at the appropriate weight on Monday. Water was always available in the living cage.

Experimental chambers were cleaned every Saturday. Key pressures were checked daily and were adjusted when necessary. Living cages were cleaned on the same night each week.

RESULTS

Figures 1 and 2 show response rate in each session. Rate was computed by dividing the total number of responses in the session by total session time, excluding feeder cycles and blackouts. Each bird displayed substantial variability in rate: only the longest interval failed to produce at least some sessions with rates higher than 0.50 responses per second, and all resulted in at least some rates lower than 0.30 responses per second. This was the case even if the first several sessions are excluded, as they might be on the assumption that they represented initial adaptation periods. With the first seven sessions excluded for P-103 and the first two excluded for the other birds, the highest rates differed from the lowest by factors ranging from 1.5-fold to more than 3.0-fold for the individual subjects.

Cumulative records provide evidence that the rate differences were not due to grossly disrupted performance or to some aberrant individual intervals occurring within a session. Figures 3, 4, and 5 display performance in two entire sessions for one bird under the shortest (3 min), medium (15 min), and longest (120 min) FI values. The pairs of records were representative examples of high- and low-rate sessions for each bird, and they also were

representative of the other subjects and schedules. All of the records indicated that normal FI performance occurred. The most prevalent pattern of responding was a pause followed by positive acceleration to the terminal rate (scalloping). Although instances of an abrupt transition from pausing to a maintained steady rate (break-run pattern) occurred occasionally as well, it was less common than was the positive acceleration. These patterns were maintained throughout training, with no evidence for any change, even when a condition was maintained for more than 100 sessions.

These records show that sessions characterized by low overall response rates were not the outcome of unusually extended periods without responding, nor were high overall rates artifacts of particular individual intervals. Although variability in output typified the individual intervals in both types of session, rate enhancements or depressions responsible for the overall rates tended to encompass many of the individual intervals and could not be considered temporary disruptions.

Consideration of Figures 1 and 2 indicates that for the most part, only some of the variability in rate across successive sessions could be attributed to a linear trend. For all of the birds, the magnitude of rate changes in successive sessions exceeded that characterizing the difference between the first and last sessions. Figures 1 and 2 indicate oscillations in response rate throughout training. The graphs do not show, however, whether these oscillations were orderly or random.

Quantitative techniques exist for analyzing oscillations and possible periodicities. One such analysis--autocorrelation—was conducted on the present data (see Weiss, Laties, Siegel, and Goldstein, 1966, for a description of autocorrelational analysis). Autocorrelation measures the relation between successive observations in a time-ordered series. The autocorrelation coefficient is calculated like the Pearson product-moment correlation (r), except that the pairs of observations entering into the computation are taken from a single series. Each observation is paired with one occurring a certain distance later in the series, where "lag" describes the displacement between the two members of the pair. So, with 10 observations, at lag 1 observation 1 is paired with observation 2, 2 is then paired with 3, *etc.;* at lag 2 observation 1 is paired with 3, 2 is paired with

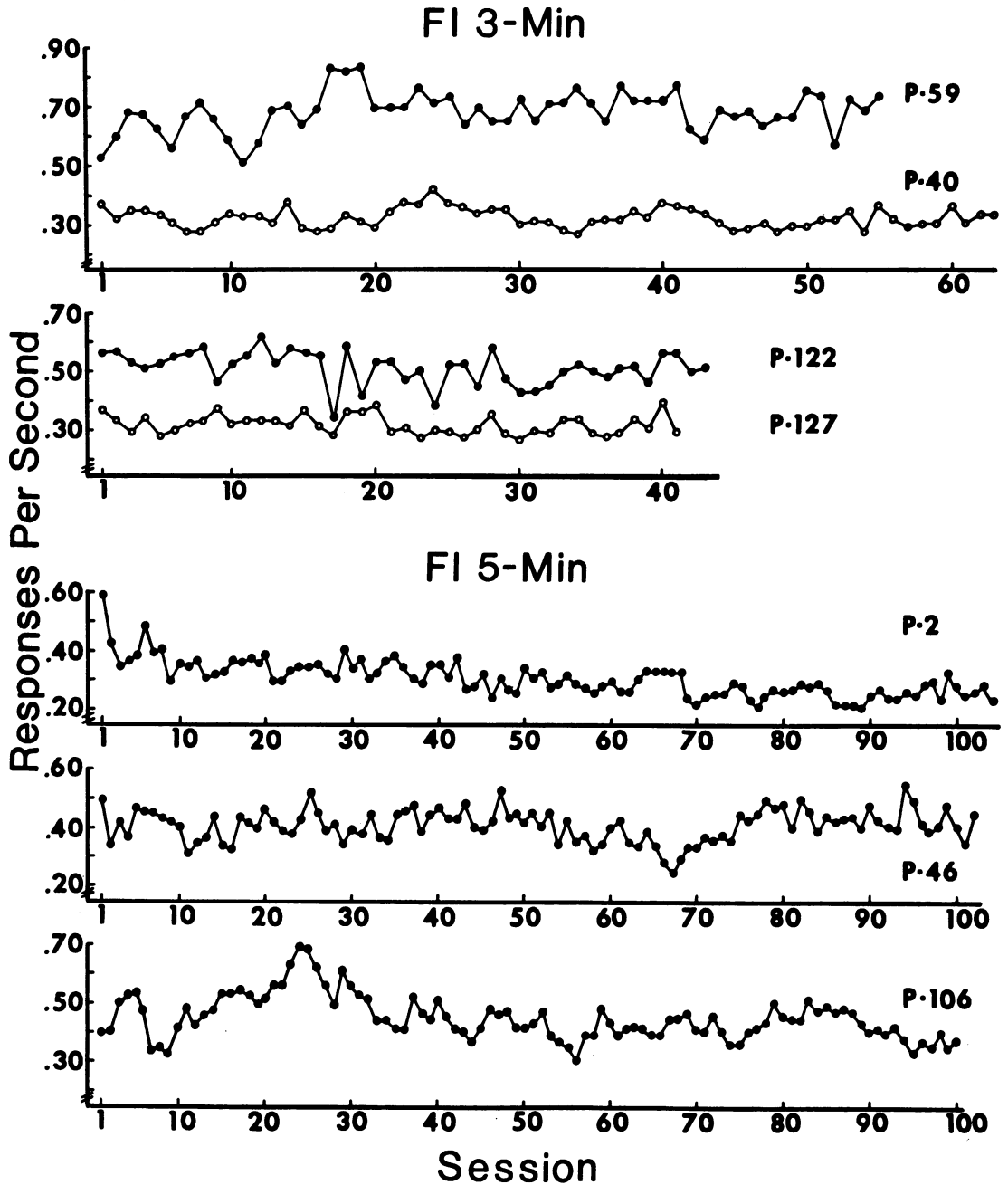Fig. 1. Response rate in each session.

4, 3 with 5, and so forth. The coefficient may range between −1.0 and +1.0, indicating negative and positive relations respectively.

Autocorrelation applied to the present data indicated the extent of the relation between response rate in one session and that in the other sessions. Stationarity of each series was ensured by removing linear trends, as sug-gested by Weiss *et al.* (1966). The autocorrela-tions were calculated for all lags from 1 to 10 over 50 sessions for P-2, P-46, and P-106 and over 30 sessions for the other birds. Al-though moderate coefficients occurred occa-sionally (*e.g.,* P-40 had a coefficient of +0.59 at lag 6), no consistencies appeared across birds. The only generality was that the three
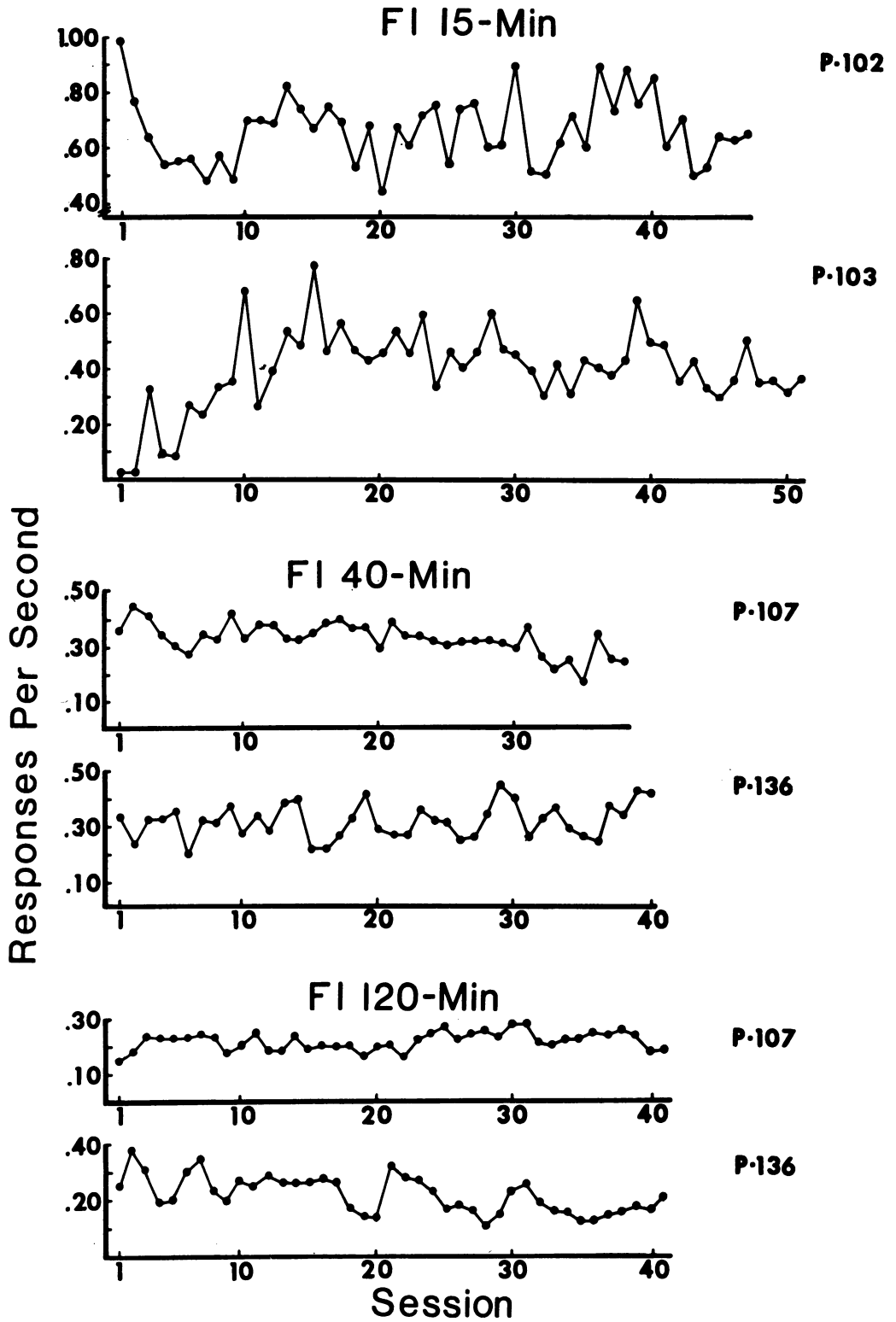
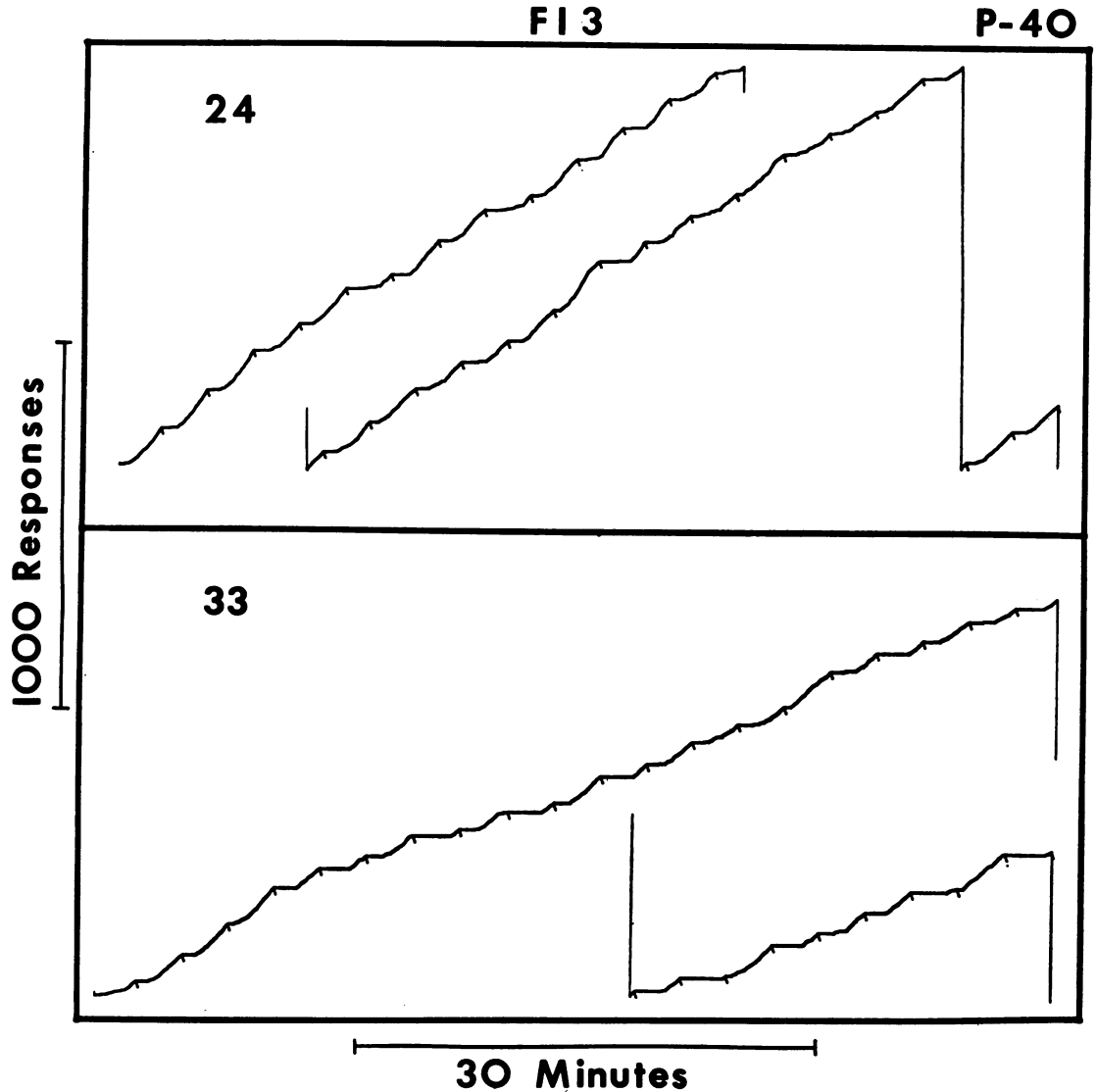Fig. 2. Response rate in each session.

Fig. 3. Cumulative records of two complete sessions for P-40. The session number is shown in the upper left of each panel. The response pen offset during each food delivery and reset after 1100 responses.

birds with the FI 5-min schedule had a positive correlation at lag 1 (from +0.41 to +0.61) that decreased to near 0.00 by lags 3 to 5. For these birds, response rate in a given session usually was similar to that of the immediately preceding session, but this relation decayed as sessions became more separated.

Consistently substantial autocorrelation coefficients (or other measures such as spectral or Fourier analyses) require more precise periodicities than typified the present data. A less-stringent analysis determined the possibility of another sort of sequential dependency. The

runs test (Siegel, 1959, pp. 52-58) is a statistical technique for determining whether the order or sequence of a series of observations is random. With two possible events, A and B, a run is defined as a succession of identical events (*e.g.*, A events) preceded and followed by a different event (a B event). The total number of runs indicates whether or not the sample can be considered as composed of a random series. If either very few or very many runs occur, observations are not independent. The runs test results in a Z-score. If Z is 1.96 or larger, the data are significant at
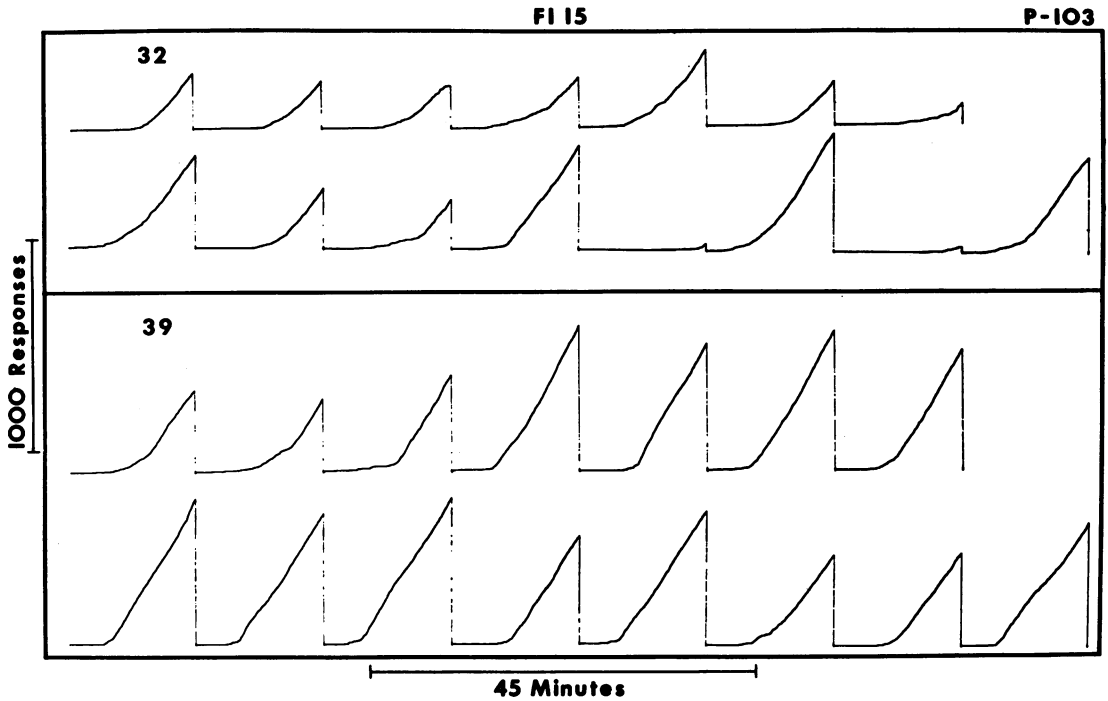
Fig. 4. Cumulative records of two complete sessions for P-103. The session number is shown in the upper left of each panel. The response pen reset after each food delivery.

the 0.05 level, and the sign of the Z-score indicates too few (negative sign) or too many (positive sign) runs than would be expected due to chance fluctuations.

The runs test was applied to the present data by classifying each session in terms of whether the response rate exceeded or was below the mean rate for all of the sessions (the means appear in Table 1). (Since the runs test does not require equiprobable events, the mean was a convenient measure.) The first two sessions were excluded from all calculations. The Z-scores are shown in Table 2 as Z(mean). In 10 of the 13 analyses, Z was sig-

Table 1

Summary Data: Response Rate

| Schedule	Bird	(Resp/Sec) Mean	(Resp/Sec) Median	Standard Deviation (Resp/Sec)	Best Fit Linear Regression Equation Y =
FI 3-min	P-40	0.33	0.32	0.03	$-0.0002X + 0.335$
	P-59	0.70	0.70	0.06	$+0.0003X + 0.680$
	P-122	0.51	0.51	0.06	$-0.0012X + 0.534$
	P-127	0.31	0.30	0.03	$-0.0005X + 0.325$
FI 5-min	P-2	0.30	0.29	0.05	$-0.0012X + 0.365$
	P-46	0.41	0.42	0.06	$+0.0001X + 0.401$
	P-106	0.45	0.44	0.07	$-0.0004X + 0.453$
FI 15-min	P-102	0.63	0.63	0.11	$+0.0017X + 0.588$
	P-103	0.41	0.42	0.13	$-0.0025X + 0.512$
FI 40-min	P-107	0.32	0.32	0.06	$-0.0032X + 0.382$
	P-136	0.31	0.31	0.06	$+0.0011X + 0.290$
FI 120-min	P-107	0.22	0.22	0.03	$+0.0001X + 0.213$
	P-136	0.22	0.21	0.07	$-0.0033X + 0.285$
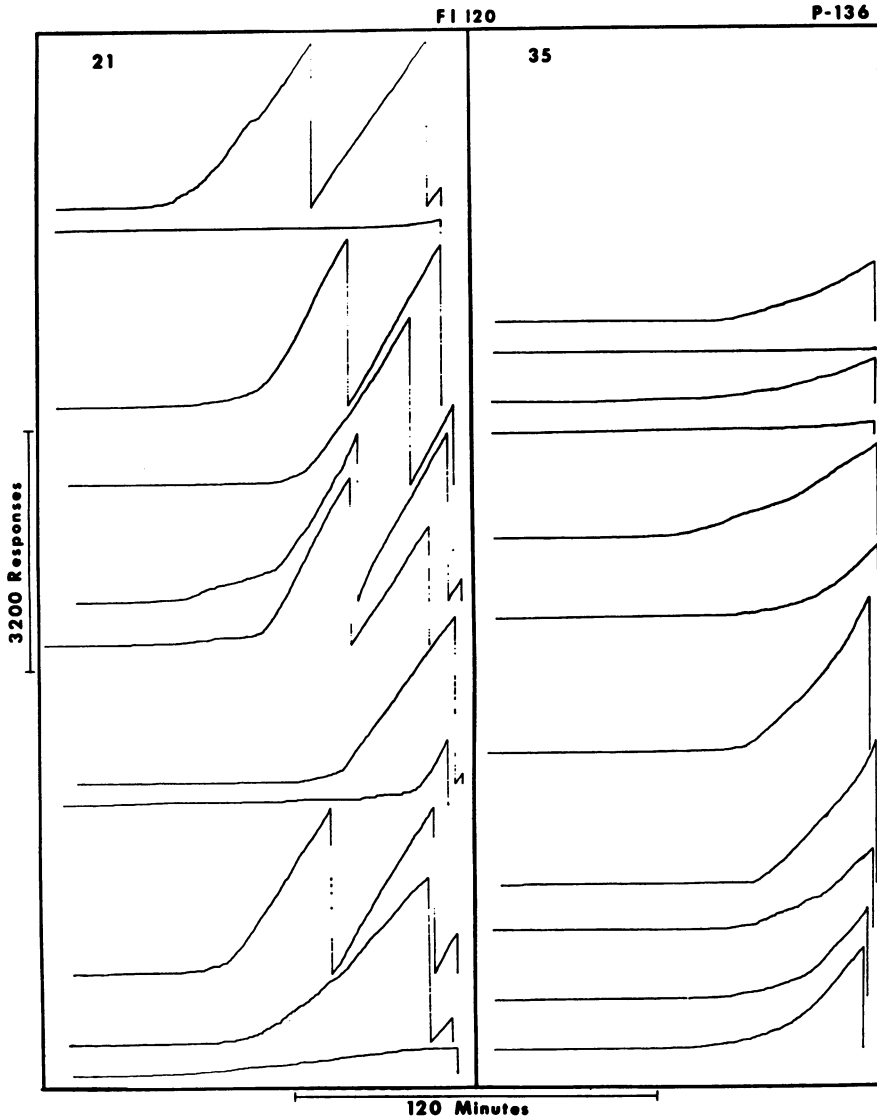
Fig. 5. Cumulative records of two complete sessions for P-136. The session number is shown in the upper left of each panel. Successive intervals of each session are arranged with the first at the top and the last at the bottom: they are arrayed in the order of occurrence. The response pen reset after 2200 responses and after each food delivery.

nificant ($p < 0.05$), and in all 13 cases it was negative. This meant fewer runs (fewer transitions from rates above the mean to below and *vice versa*) than would be expected from a random distribution.

Because erratic sessions early in training or a trend for rate to decrease or increase over the course of training would inflate the value of Z, the runs test was repeated. Now the reference point was the linear function providing the best fit to the data (see Table 1,

regression equation). Each data point was transformed into a deviation from the rate predicted from this function, with the sign indicating whether the point was larger or smaller than the predicted value. The following initial sessions were excluded, because they seemed to represent transitions, rather than being part of the subsequent function: P-59, Sessions 1 to 19; P-106, Sessions 1 to 32; P-103, Sessions 1 to 7. These recalculated scores appear in Table 2 as Z (best-fit). Twelve

Table 2

Analysis of Runs: Probability of Runs and Z-Scores

| Schedule	Bird	Run Length						Z (Mean)	Z (BestFit)
		1	*2*	*3*	*4*	*5*	*6+*		
FI 3-min	P-40	0.37	0.21	0.16	0.00	0.05	0.21	−3.1	−3.1
	P-59	0.53	0.11	0.00	0.21	0.05	0.11	−2.3	−1.7
	P-122	0.40	0.30	0.20	0.05	0.05	0.00	−0.6	−1.1
	P-127	0.53	0.18	0.12	0.06	0.00	0.12	−1.1	−1.0
FI 5-min	P-2	0.24	0.21	0.21	0.03	0.21	0.09	−6.8	−2.6
	P-46	0.42	0.19	0.10	0.03	0.13	0.13	−3.8	−3.6
	P-106	0.11	0.39	0.17	0.06	0.11	0.17	−5.0	−3.6
FI 15-min	P-102	0.53	0.18	0.06	0.00	0.06	0.18	−2.0	+0.1
	P-103	0.40	0.13	0.07	0.20	0.07	0.14	−2.4	−1.2
FI 40-min	P-107	0.50	0.19	0.00	0.19	0.13	0.00	−2.3	−1.0
	P-136	0.35	0.18	0.35	0.12	0.00	0.00	−1.0	−0.3
FI 120-min	P-107	0.25	0.33	0.00	0.17	0.08	0.16	−2.7	−3.3
	P-136	0.27	0.09	0.27	0.09	0.09	0.18	−3.4	−3.1
Chance		0.50	0.25	0.13	0.06	0.03	0.03		
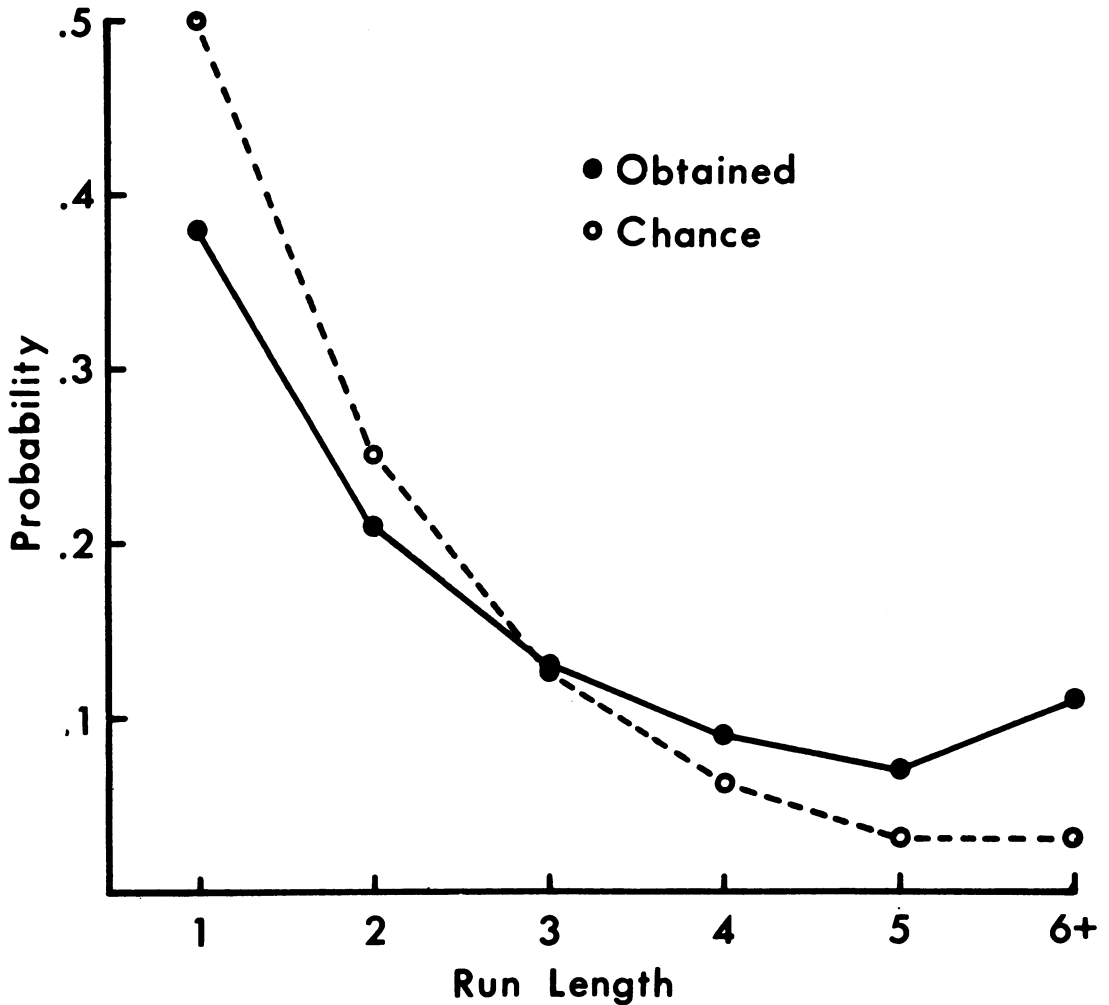
Fig. 6. Probability of a run of each length. The filled points and solid line depict the averages over the 13 observations, and the open circles and dashed lines depict the probability expected on the basis of chance.

of the 13 Z-scores remained negative, but four that previously attained statistical significance now failed to do so.

With two equiprobable events, the chance probability of a run of one is 0.5, that of a run of two is 0.25 (0.5^2), that of a run of 3 is 0.13 (0.5^3), etc. Table 2 shows the chance probabilities of runs of various lengths and the actual probabilities of these runs for each bird. The mean, rather than the median, rate was the reference point, because the two corresponded closely (see Table 1) and the mean seemed more consistent with the preceding analyses, even though it is not defined in terms of equiprobability. Figure 6 shows the frequency of runs averaged across subjects and schedules. Significantly fewer runs of one and significantly more runs of five and six occurred than would be expected by chance ($t > 2.2$, $df = 12$, $p < 0.05$). In short, rates were less likely to alternate and more likely to remain on the same side of the mean for extended sequences than would occur if responses in successive sessions were independent of each other.

The fixed laboratory routine raised the possibility that cyclic effects might have arisen in some way from handling and housekeeping procedures or perhaps from the five-day-on (Monday to Friday) two-day-off (weekend) schedule. Two considerations make this possibility unlikely. First, a "Monday effect" of abnormally enhanced or depressed rates would lead to more orderly cyclicities than actually occurred. This, of course, is equally true of any other strong bias attributable to experimental or laboratory routine. The second consideration derives from statistical analyses based on day of the week. Sessions were divided into blocks of five (beginning on Monday). Within each block, the sessions were ranked by response rate, with the highest rate assigned a rank of 1, the next a rank of 2, and so forth. The result was that each day of the week had a set of n ranks ranging from 1 to 5, with n representing the number of full weeks of experimentation. Then, chi-square tests for differences between replicated treatments (Wilcoxon, 1949, pp. 7-8) were conducted to compare the sums of ranks for each replication. These tests indicated the probability that the obtained differences occurred by chance. The probabilities for the individual subjects ranged from $p > 0.10$ to $p > 0.98$, with the average being $p > 0.41$. To determine whether differences might appear across all of the subjects, the ranks for days for the individual subjects were combined, and the test was applied to the grouped data. Now, the probability of all differences occurring by chance was $p > 0.98$. Thus, neither individual nor grouped data suggested systematic effects of particular days, and thereby implied that the cyclicities in response rate were not determined by artifacts attributable to the laboratory schedule.

DISCUSSION

Overall response rate was not constant in successive sessions of exposure to an unchanging fixed-interval schedule. In any group of several sessions, sequences of similar rates were followed by a shift to a higher or lower rate, and the new level was likely to be maintained before another change occurred. The result was a series of response rates displaying an irregular but wavelike character.

Reanalysis of Gollub's (1964) data with rats given 21 sessions under an FI 2-min schedule revealed similar tendencies. Runs tests based on the mean rate for all 21 sessions or for only the last 19 sessions yielded negative Z-scores for every subject (-0.4, -0.7, -1.6, -3.0). Once again, therefore, fewer transitions from high to low rates and *vice versa* occurred than would have happened if performance in successive sessions was independent.

Cumming and Schoenfeld (1960) maintained a schedule for at least 190 sessions. Their schedule involved recurring cycles of a period in which the first response produced food (t^D) and a period in which responses had no scheduled effect (t^Δ). The $t^D + t^\Delta$ cycle duration was 30 sec, and $\overline{T}$, the proportion of the cycle occupied by t^D, was 0.05. The arrangement would be an FI schedule ("FI by the clock", cf. Hearst, 1958) if $\overline{T} = 1.00$, because the first response emitted at regular time intervals would produce food. When $\overline{T}$ is less than 1.00, the response must occur during the t^D period if food is to be obtained. Therefore, in Cumming and Schoenfeld's procedure, a 1.5-sec period of food availability occurred every 28.5 sec. Hearst (1958) showed that this schedule produces responding more characteristic of ratio than of interval schedules, in that a brief pause was followed by an abrupt shift

to a high response rate. When $\overline{T} = 1.00$, Hearst described the performance as more interval-like, in that the transition from pausing to the terminal response rate was less abrupt and response rate was lower.

When runs tests based on deviations from the straight line best fitting the session-to-session rates (first seven sessions excluded) were conducted on Cumming and Schoenfeld's data, the Z-scores for the six pigeons ranged from −5.2 to −8.2. The probability of a run of one approximated chance (0.50) for each bird, but runs of two occurred less often than chance, and runs of four or longer occurred more often. If this schedule indeed closely resembles FI, it extends the present conclusions to shorter parameter values than were studied now; if it is basically different from FI, Cumming and Schoenfeld's data indicate that session-to-session cyclicities in overall response rate are not confined to FI schedules.

In addition to displaying cyclicity, some of the present pigeons had the rate decline over sessions noted by Skinner (1933) and also found by Cumming and Schoenfeld (1960) with time-correlated schedules. The decrement did not appear in all subjects; indeed, some of the present birds showed a slight tendency for rate to increase. When progressive changes did occur, they happened in the context of cyclic increases and decreases in session-to-session rate. Actually, differences in rate in successive pairs of sessions typically were larger than those between the first and last of all the sessions (first and last points of each panel in Figures 1 and 2), even for subjects showing systematic decline or increase. In short, any linear trend was superimposed on continuing cyclicity.

The characteristic pattern, although not sufficiently regular to be described quantitatively, can be outlined in less-precise terms. A series of sessions with high rates was followed by a series with low rates and *vice versa*. This produced peaks and troughs, thereby generating a wave-like or oscillating pattern of irregular period length. A rhythmic character emerged from the alternation between groups of high- and low-rate sessions, with the groups or clusters themselves varying in size.

What is responsible for the grouping of response rates? Although the data as yet provide no answer, the source must be either extra-experimental or factors arising within the reinforcement schedule itself, or some combination of the two. Alterations in many states occur periodically and have been shown to affect behavior (*cf.* Luce, 1971), so perhaps rate changes stem from such physiological rhythms. If so, the cyclicities would not arise directly from the fixed-interval schedules themselves. However, it may be significant that output levels in successive intervals also are grouped (*cf.* Dews, 1970), just as are output levels between sessions. Cyclicities across sessions lend themselves to speculation about changes in physiological state, but such an account seems less compelling as an explanation of similar wave-like oscillations in response rate within sessions. Such considerations suggest the possibility of schedule control over both types of clustering. Perhaps the rate emitted in one session or interval in some way determines the rates occurring subsequently according to two processes. The first, a tendency to repeat the preceding output level, would operate to generate a series of consistent rates (clusters). The second would be responsible for rate changes. Perhaps a series of high rates actually represents deviations from some optimal output level that eventually generates a compensatory radically lower rate and *vice versa*. These two processes would seem to be closely related to positive and negative feedback systems.

Whatever the explanation may be, the data show that stable performance does not necessarily mean unchanging output between sessions or changes that can be attributed to minor uncontrolled fluctuations in controlling variables. Accurate description and meaningful theorizing must take into account that steady-state performance is not synonymous with unvarying responding. Unchanging experimental conditions may generate behavior that continuously changes and may even assume a rhythmic character.

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