

*TEMPORAL CONTROL BY PROGRESSIVE-INTERVAL
SCHEDULES OF REINFORCEMENT*

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Progressive-interval performances are described using measures that have proven to be successful in the analysis of fixed-interval responding. Five rats were trained with schedules in which the durations of consecutive intervals increased arithmetically as each interval was completed (either 6-s or 12-s steps for different subjects). The response patterns that emerged with extended training (90 sessions) indicated that performances had come under temporal control. Postreinforcement pausing increased as a function of the interval duration, the pauses were proportional to the prevailing duration, and the likelihood of the first response within an interval increased as the interval elapsed. To assess the resistance of these patterns to disruption, subjects were trained with a schedule that generated high response rates and short pauses (variable ratio). When the progressive-interval schedule was reinstated, pausing was attenuated and rates were elevated, but performances reverted to earlier patterns with continued exposure. The results indicated that temporal control by progressive-interval schedules, although slow to develop, is similar in many respects to that for fixed-interval schedules.

Key words: progressive-interval schedule, variable-ratio schedule, fixed-interval schedule, patterns of responding, postreinforcement pause, history effects, lever press, rats

In a paper entitled, “The Sleeping Giant: Reinforcement Schedules,” Zeiler (1984) commented on the declining status of reinforcement schedules. For many years, schedules “were virtually the definition of operant conditioning . . . the major unique contribution of the behavior-analytic approach to the field of learning . . . the most powerful independent variables ever seen in psychology.” More recently, however, “they no longer appear to be of much interest to researchers: Goliath is sleeping” (p. 485). Zeiler attributed both the rise and the fall of interest in schedules to the descriptive, atheoretical quality of much of the research. Experiments over the years have yielded a wealth of information about the control exerted by different scheduling procedures. The continued usefulness of such efforts appeared to be doubtful, however, in the absence of an agreed-upon set of principles that might link the different schedules and their variants.

Not too much seems to have changed since Zeiler’s article (for some recent developments, see the special issue on behavior dy-

namics, *JEAB*, Vol. 57, No. 3, 1992), and it certainly is not our purpose to question the need for broad theories of schedules. We do question the implication that empirical investigations have been so exhaustive that further descriptive research is unnecessary. One measure of the need is Lattal’s (1991) comprehensive review of schedule methodologies. His presentation reveals that despite the considerable attention that has been given to some schedules, the behavioral consequences of others remain obscure. The gap in the literature about one of them—the progressive-interval schedule of reinforcement—is what prompted the present investigation.

Progressive-interval (PI) schedules fall within the class whose defining characteristic is a changing response requirement (usually an increase) following each reinforcement. Of the various possibilities, the progressive-ratio schedule (the ratio increases as the schedule progresses) has been studied over the years, beginning with the original research of Hodos and Kalman (1963). By comparison, the interval counterpart, in which the durations of the intervals increase, has met with neglect. The only information provided by Lattal (1991) was from a study by Harzem (1969) that formed part of a broad treatment of temporal control. Harzem’s data illustrated some essential features of PI performances, most notably that postreinforce-

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ment pausing increased as the schedule progressed, but his analysis was limited, and the method and results were presented in abbreviated form.

The question might still be asked in light of Zeiler's (1984) comments: Why bother to attempt a more comprehensive description of PI performances? After all, this schedule represents only one of the myriad of contingencies to which experimental subjects can be exposed within the laboratory. One answer is that progress toward the worthy goal of theoretical integration relies on already available information about the characteristic patterns of behavior generated by each schedule. Another is that reinforcement schedules are essential for research in other areas for which they serve as baselines, as in the study of drug effects, stimulus control, and human-nonhuman differences.

Apart from Harzem's (1969) seminal research, we could find only one other experiment that sheds some light on characteristic PI response patterns. Dougherty, Cherek, and Roache (1994) recently used the PI schedule with human subjects to investigate the effects of smoked marijuana. As in Harzem's rat study, a general finding was that postreinforcement pausing increased and response rates decreased as the schedule progressed. Moreover, these changes were retarded under drug conditions, thus supporting the conclusion that smoked marijuana produces overestimation of elapsed time. We note two other lines of research that have some bearing on PI performances. Several experiments have included PI schedules within choice paradigms (e.g., Hackenberg & Himeline, 1992; Jacobs & Hackenberg, 1996). However, the reports have not provided information on performances once the PI schedule was chosen. Also relevant is research employing cyclical interval schedules (e.g., Higa, Thaw, & Staddon, 1993; Innis & Staddon, 1971). Comparisons with PI schedules are difficult, however, because the sequences are nonmonotonic (i.e., repeating sequences of increasing and decreasing intervals occur within the session).

Dougherty et al.'s (1994) experiment with humans is instructive when considered from the standpoint of whether more schedule research is needed. Research under the controlled conditions of the animal laboratory

often provides models that guide extensions to human performances. For example, the theoretical implications of research on human performance on fixed-interval (FI) schedules have revolved around discrepancies with nonhuman performances on the same schedule (e.g., Lowe, 1979). In the case of PI schedules, however, the research with humans appears to have outstripped the animal model, insofar as the only published information available to Dougherty et al. was limited to the single experiment reported by Harzem (1969).

Given this dearth of information, the present purpose was straightforward: to describe PI performances using measures that have proven to be successful in the analysis of FI schedules (Baron & Leinenweber, 1994, 1995). The essential question concerns the nature of the control exerted by the schedule. Studies of FI schedules have indicated that responding is controlled by the temporal contingencies. The procedural links between PI and FI schedules suggest that corresponding response patterns might occur; that is, a pause followed by accelerated responding (the so-called FI scallop), with the duration of the pause increasing as a function of the interval duration. Less apparent is the rate of change as the durations of the intervals are progressively increased. Working with FI schedules, Dukich and Lee (1973) found that pauses were a constant proportion of the interval durations, whereas Lowe, Harzem, and Spencer (1979) found decreasing proportions with increasing intervals.

A good part of our experiment was devoted to attainment of steady-state performances (we quickly discovered that adjustment to PI schedules by rats is slow; a total of 90 training sessions was required before reasonably stable performance was achieved). During a subsequent phase, we assessed the persistence of response patterns using procedures similar to those of recent studies of conditioning histories (Baron & Leinenweber, 1995; Cohen, Pedersen, Kinney, & Myers, 1994; Wanchisen, Tatham, & Mooney, 1989). According to Nevin's behavioral momentum model (Nevin, 1979), response strength can be indexed by the resistance of the behavior to changes from disruptive sources. In the present experiment, initial PI training was followed by exposure to a schedule that typically gener-

ates short pauses and high response rates (a variable-ratio [VR] schedule). The PI schedule then was reimposed and recovery was observed.

METHOD

Subjects

Five experimentally naive male albino rats (Sprague-Dawley derived) were 5 to 6 months old at the start. They were housed individually with free access to water and were maintained at 80% of their free-feeding weights. Illumination within the vivarium followed a 16:8 hr light/dark cycle.

Apparatus

Single-lever rodent chambers (Grason-Stadler, E3125a; 29 cm by 24 cm by 19 cm) were enclosed in sound-attenuating chests. The lever, which required a minimum force of 40 g (approximately 0.4 N) to operate, was centered on the front wall, 9.5 cm above the grid floor. Directly below was a cylindrical opening into which a 0.05-ml dipper could be raised. General illumination was provided by a 3-W lamp mounted behind a translucent screen on the right wall. Extraneous sounds were masked by both white noise and the ventilating fan. Programming and recording equipment was controlled by microcomputers located in an adjacent room.

Procedure

Lever-press responses were reinforced with liquid food consisting of reconstituted skimmed milk sweetened with 18 g of granulated sugar per 950 ml (1 quart) of water. Delivery of the reinforcer was accomplished by raising the dipper for 3 s accompanied by a tone that replaced the white noise. During preliminary training, all animals were trained to drink the milk from the dipper, and the lever-press response was shaped. The experiment proper involved three phases. During the main phase, extended training was given with PI schedules. Subsequent conditions involved exposure to a VR schedule and, then, retraining with the original PI schedule.

Baseline. The first interval of the PI schedule was always 30 s, and succeeding intervals increased in steps of either 6 s or 12 s until 18 intervals were completed. Thus, for rats in

the PI 6-s condition (R12, R53, R54), the sequence was 30 s, 36 s, 42 s, and so on, to a final value of 132 s, and for rats in the PI 12-s condition (R27 and R58), the sequence was 30 s, 42 s, 54 s, and so on, to a final value of 234 s. The PI schedule was introduced gradually. Initial training involved FI schedules of increasing durations to the final value of FI 30 s, followed by PI schedules with increasing steps until the final values (6 s or 12 s, depending on the animal) were reached.

Sessions were usually conducted 5 to 6 days per week. At the start of the session the test chamber was dark and silent except for the sound of the ventilating fan, and the lever was inoperative. Subsequent initiation of the PI schedule was accompanied by activation of the lever, illumination of the chamber light, and continuous white masking noise. When the session ended after completion of the last interval, the lever was deactivated and the chamber light and white noise were turned off. The PI 6-s sessions usually were completed within 28 min, and the PI 12-s sessions were completed within 45 min (the shortest possible durations for the two schedules were 24.3 and 39.6 min, respectively).

Training with the baseline PI schedules was continued for 90 sessions. When we ended the baseline phase, our assessment was that performances, although still containing some irregularities, were sufficiently stable to reveal characteristic response patterns. Moreover, we did not anticipate that additional training would quickly lead to further changes.

Variable-ratio phase. Following the 90th PI session, animals were trained under a VR 20 schedule (20 responses were required on the average for delivery of the milk reinforcer). During shaping sessions, the average ratio was increased in a series of steps beginning with VR 3 to the final value of VR 20. The VR 20 schedule contained seven ratios, ranging from 5 to 35, arranged in an irregular sequence. Sessions ended when 40 reinforcers had been delivered. Training with the VR 20 schedule continued for 50 sessions.

Recovery phase. During the final part of the experiment, the original PI schedules were reinstated for an additional 50 sessions. Other details were as described for the baseline phase.

Table 1

Mean response rates (responses per minute; standard deviations in parentheses) for Sessions 61 through 90 of the baseline phase, Sessions 46 through 50 of VR training, and Sessions 1 through 50 of the recovery phase. The rats' identification numbers are followed by the size of the PI increment, either 6 s or 12 s.

Sessions	R12-6	R53-6	R54-6	R27-12	R58-12
61-70	14.0 (2.3)	5.7 (1.4)	9.0 (2.7)	14.0 (2.6)	11.6 (3.0)
71-80	14.7 (4.6)	6.9 (1.3)	9.3 (3.4)	16.3 (4.3)	13.9 (2.3)
81-90	11.8 (2.5)	5.8 (1.2)	8.2 (1.1)	16.5 (3.6)	13.6 (3.1)
46-50	104.8 (9.9)	73.8 (5.2)	103.0 (7.5)	103.1 (7.6)	72.0 (11.9)
1-10	27.1 (5.7)	34.6 (11.0)	43.0 (12.3)	28.2 (8.8)	22.7 (17.3)
11-20	19.1 (5.0)	23.5 (4.8)	32.9 (5.7)	15.1 (5.5)	11.5 (4.7)
21-30	13.7 (2.5)	16.7 (3.2)	23.9 (4.1)	16.8 (4.3)	9.3 (3.1)
31-40	9.9 (1.6)	14.7 (3.8)	16.6 (2.3)	14.7 (3.3)	7.7 (2.1)
41-50	13.1 (3.7)	11.3 (2.4)	9.5 (4.4)	14.4 (3.3)	5.5 (1.8)

RESULTS

Overall Response Rates

Average response rates across entire sessions were used to track the stability of individual performances. These values, summarized in Table 1, provide a global picture of changes during the course of the experiment. Performances were variable during the early sessions of training (not shown), but a reasonable degree of stability had been attained by Sessions 61 to 90 of the baseline phase. Table 1 also shows that animal-to-animal variations in overall rates were not consistently related to the size of the PI increment (6 s vs. 12 s).

The interposed VR schedule induced high steady response rates (70 or more responses per minute), and elevated rates persisted when the PI schedule was reintroduced, most notably for the animals with the lowest pre-VR rates (R53 and R54). With continued exposure to the PI schedule, response rates returned to the earlier levels. Finally, recovery was somewhat slower under the 6-s condition. When the experiment ended after 50 recovery sessions, 3 animals had reached their baseline performances (R12, R54, and R27), 1 was still higher (R53), and 1 was considerably lower (R58).

Postreinforcement Pausing

Pauses were recorded to the nearest second, as measured from the end of the reinforcement period (dropping of the dipper) to the first lever press. These values are plotted in Figure 1 (6 s) and Figure 2 (12 s) as a function of the increasing intervals within

each session. Data are from the end of the baseline phase and from the first, second, and fifth blocks of recovery sessions. Each point depicts the median value of the 10 instances of the interval within the 10-session block. To aid interpretation, two lines have been added to each panel: The diagonal line denotes the programmed duration of each of the 18 intervals (100%) and the lower line denotes the midpoints of the intervals (50%).

At the end of the baseline phase, all animals paused for increasing durations as the schedule progressed. Variation can be seen within the rising functions; however, most of the individual values reached or exceeded the interval midpoints. In addition, the arrays of points generally followed a linear trend, which indicates that the pauses were proportional to the length of the intervals. The top part of Table 2 shows the proportion of variance accounted for by the linear trends (r^2) in pausing. Values of r^2 exceeded chance expectations ($p < .05$) for both baseline and terminal recovery sessions, and the linear fit was close in most (but not all) of the cases. Table 2 also includes the mean pause durations across all 18 of the intervals, and the durations are also expressed as proportions of the interval. During the baseline phase, the average pause occupied at least half of the intervals (range, 55% to 72% for the 5 animals). Although average pausing and r^2 values varied from animal to animal, the differences did not appear to be related to the size of the PI increment.

Changes in pausing during the subsequent

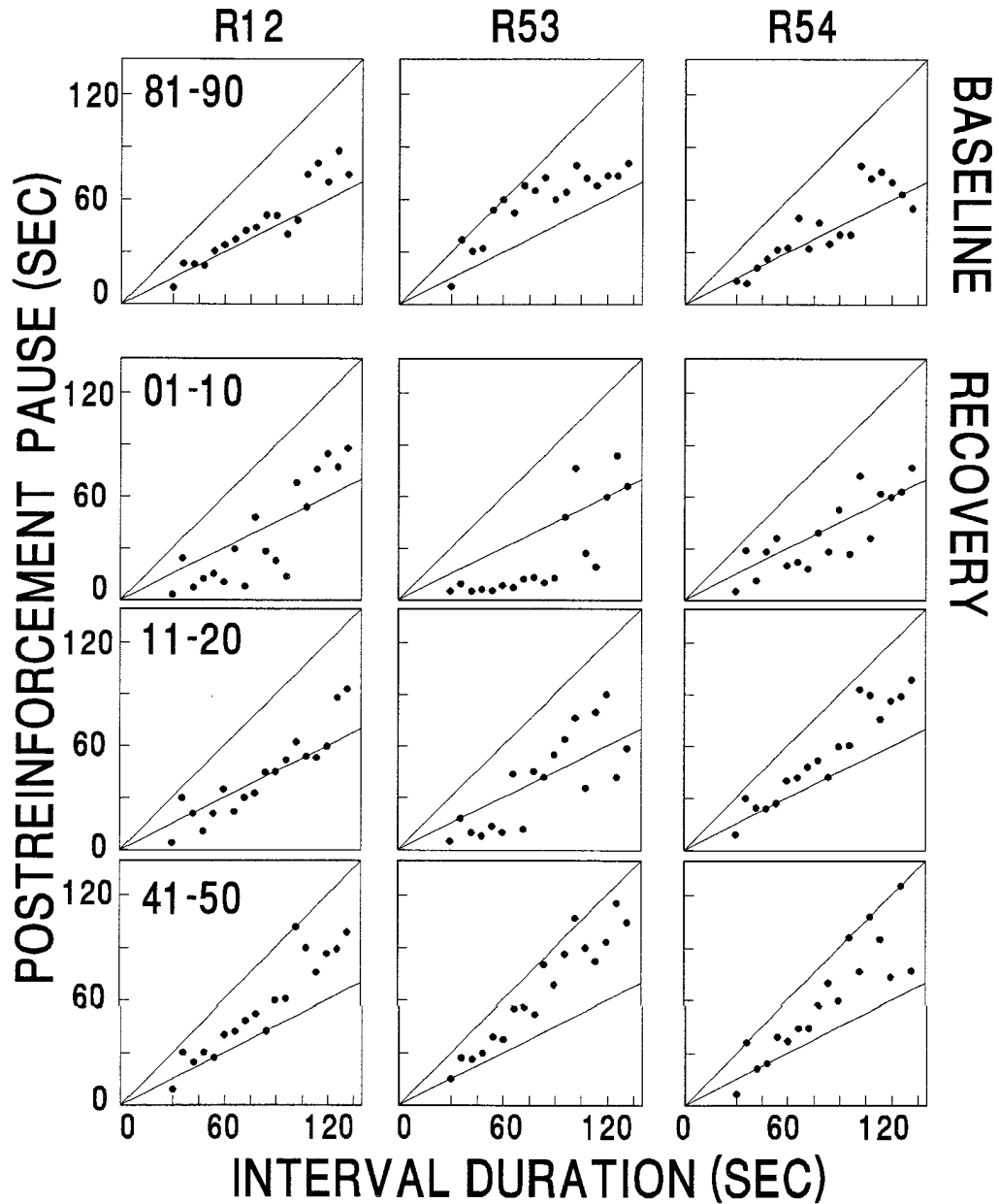


Fig. 1. Postreinforcement pauses as a function of interval duration. Points represent median durations for Sessions 81-90 (baseline) and Sessions 1-10, 11-20, and 41-50 (recovery). Data are from R12, R53, and R54 (6 s).

recovery phase (Figures 1 and 2) paralleled those already described for response rates. The short pauses that characterized VR performances carried over to the PI schedule, particularly during the early intervals of the session (an exception is R58, whose pauses became less regular but not necessarily short-

er). With continued exposure, pause durations increased toward the levels observed at the end of the baseline phase. Comparison of the final recovery functions with performances during the earlier baseline phase indicates that pauses occupied a larger proportion of the intervals (see also the summary

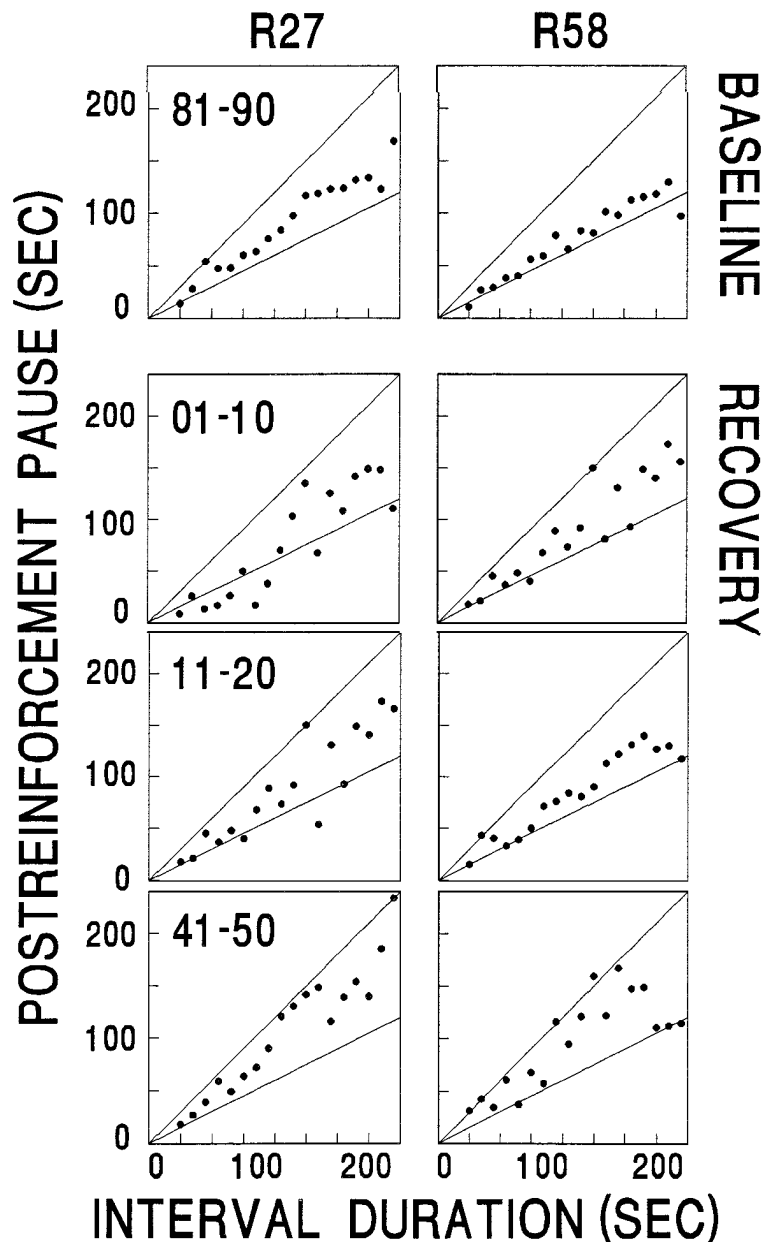


Fig. 2. Postreinforcement pauses as a function of interval duration. Points represent median durations for Sessions 81-90 (baseline) and Sessions 1-10, 11-20, and 41-50 (recovery). The lines within the panels indicate the scheduled durations and midpoints of the intervals. Data are from R27 and R58 (12 s).

values in Table 2). When the experiment ended, average pausing encompassed at least two thirds of the intervals (range, 69% to 81%). By this point, the animals had completed a total of 140 sessions of exposure to the PI schedule.

Within-Interval Responding

The analysis of postreinforcement pausing was supplemented with two measures that are used to quantify response patterning: the quarter life and the index of curvature (Lat-

Table 2

Postreinforcement pause (PRP) and quarter-life (QL) durations. Summarized are the proportions of variance accounted for by the linear functions (r^2) and the mean durations for the 18 intervals expressed as seconds (mean proportions of the intervals are in parentheses). The rats' identification numbers are followed by the size of the PI increment, either 6 s or 12 s. For R12, R53, and R54, the mean duration for the 18 intervals was 81 s, and the intervals increased from an initial value of 30 s to a final value of 132 s in 6-s steps. For R27 and R58, the mean duration for the 18 intervals was 132 s, and the intervals increased from 30 s to 234 s in 12-s steps. Data are from the final 10 sessions of the baseline and recovery phases.

Subject	Baseline (Sessions 81-90)		Recovery (Sessions 41-50)		
	r^2	Seconds	r^2	Seconds	
PRP	R12-6	.89	46.8 (.58)	.89	56.0 (.69)
	R53-6	.75	58.4 (.72)	.92	64.9 (.80)
	R54-6	.75	44.1 (.55)	.79	60.6 (.75)
	R27-12	.95	89.7 (.68)	.91	107.1 (.81)
	R58-12	.92	74.6 (.57)	.64	96.8 (.73)
QL	R12-6	.97	62.6 (.77)	.98	63.4 (.78)
	R53-6	.94	66.2 (.82)	.98	66.0 (.81)
	R54-6	.91	56.3 (.70)	.88	61.8 (.76)
	R27-12	.99	109.7 (.83)	.98	112.1 (.85)
	R58-12	.94	95.2 (.72)	.87	111.1 (.84)

tal, 1991). The quarter life identifies the duration (or proportional duration) in the interval at which one quarter of the total number of responses has been completed. Thus, a proportion of .25 corresponds to undifferentiated responding within the interval (one quarter of the responses has been completed in one quarter of the time), and larger values up to a limit of 1 correspond to increasing concentrations of responses in the latter part of the interval. The index of curvature is more comprehensive than the quarter life because it is based on rate differences in successive segments of the interval. The index increases from 0 (a linear pattern) towards 1 as the response function becomes more positively inflected.

Quarter-life durations are plotted in Figure 3 (6 s) and Figure 4 (12 s) using the same format as for the previously presented pause data. Occasionally, the actual interval exceeded the scheduled interval; in those cases, the quarter life was calculated as the scheduled interval plus 25% of extra time. Values from baseline sessions paralleled those for pausing: Quarter-life durations increased as the sched-

ule progressed, and the increasing functions approximated a linear pattern. The bottom half of Table 2 shows that the linear fit was close in all cases ($r^2 > .90$) and that the quarter lives encompassed from 70% to 83% of the intervals. Recovery of baseline performances also followed the same time course as for the pause data. By the end of the recovery phase, all animals had reached or exceeded the levels that had been observed at the end of the baseline phase.

Index-of-curvature values from terminal baseline and recovery sessions are summarized in Table 3. To simplify the analysis as well as to smooth over irregularities, data were blocked in groups of three intervals. Table 3 indicates that most of the values fell in the upper middle part of the positive range (between .50 and .70), thus indicating an intermediate level of positive inflection. Although there were irregular tendencies for higher curvature values during the later intervals of the progression, these changes were small and unreliable. The absence of systematic interval-to-interval differences in curvature is consistent with the finding of proportionality for the pause and quarter-life measures. Another similarity is that all animals had more or less recovered their baseline performances when the experiment ended.

Conditional Probabilities of Pause Terminations

Temporal control by an interval schedule can also be described by the conditional probability of the response that terminates the postreinforcement pause, that is, the first response within the interval. With temporal control, the first response should become increasingly probable as the interval elapses (Hatten & Shull, 1983). Each interval was subdivided into six equal time bins for this analysis, and pause durations were classified accordingly. A seventh bin was reserved for instances in which the latency of the first response exceeded the duration of the interval. The resulting frequency distributions then were used to derive the conditional probability that a pause would be terminated within a given time bin (the number of terminations within that bin divided by the number in that and all longer bins).

The connected points in Figure 5 (6 s) and

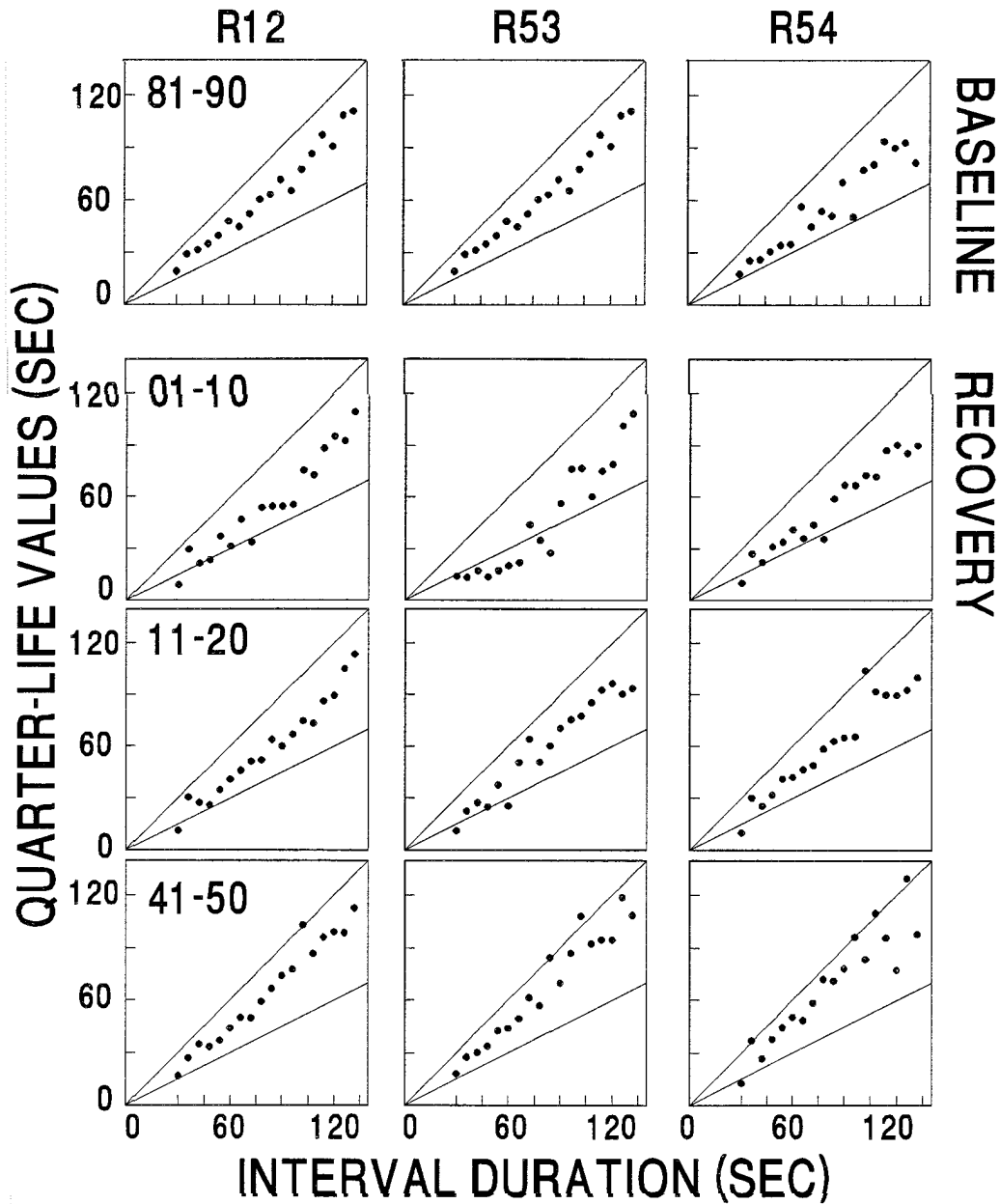


Fig. 3. Quarter-life values as a function of interval duration. Points represent median durations for Sessions 81-90 (baseline) and Sessions 1-10, 11-20, and 41-50 (recovery). The lines within the panels indicate the scheduled durations and midpoints of the intervals. Data are from R12, R53, and R54 (6 s).

Figure 6 (12 s) depict the conditional probabilities of pause terminations; the histograms show the relative frequencies on which the conditional values were based. To accumulate sufficient values for a probability analysis, the data were grouped into blocks of 10 days (cf. Figures 1 and 2) and three consec-

utive intervals (e.g., 30, 36, and 42 s for Intervals 1, 2, and 3 of the 6-s schedule). Probabilities were not plotted when a bin contained fewer than four entries or for the seventh bin (shaded bars), where the probability was always 1.

The analysis of the baseline data indicated

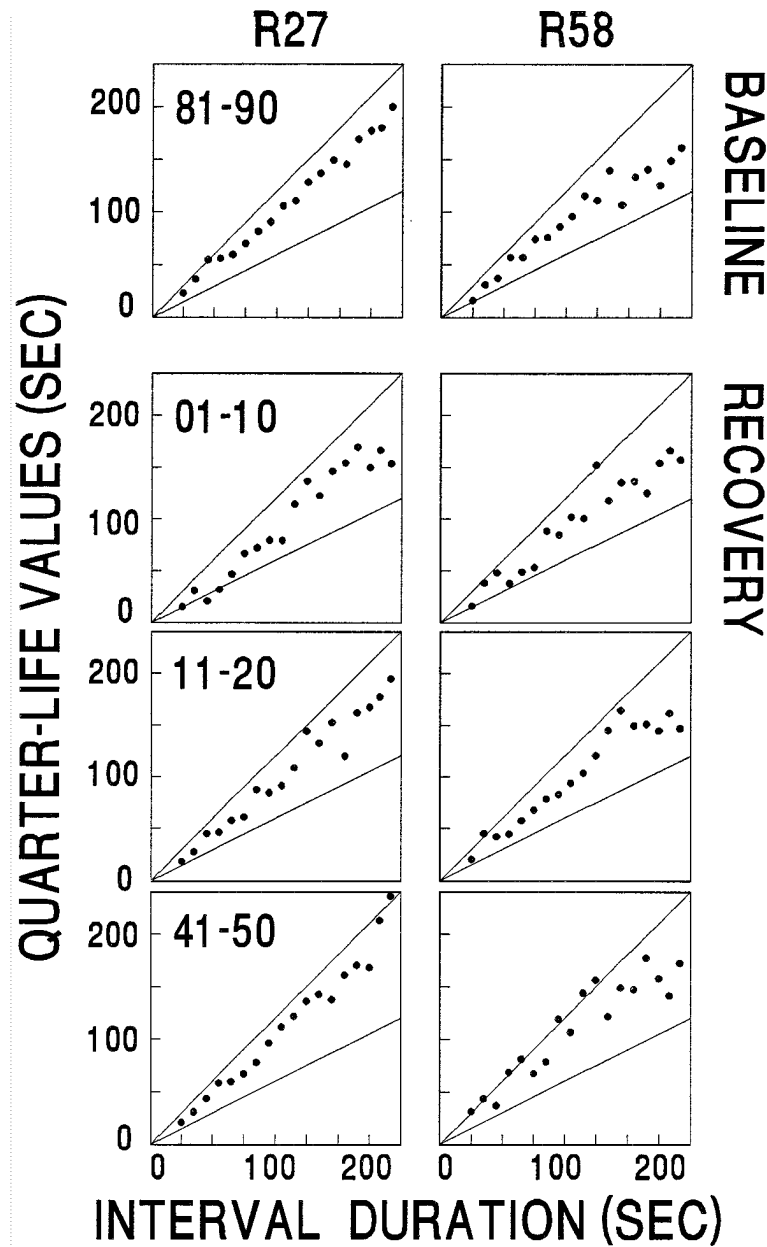


Fig. 4. Quarter-life values as a function of interval duration. Points represent median durations for Sessions 81-90 (baseline) and Sessions 1-10, 11-20, and 41-50 (recovery). The lines within the panels indicate the scheduled durations and midpoints of the intervals. Data are from R27 and R58 (12 s).

that conditional probabilities increased as a function of elapsed time within the intervals (Figures 5 and 6). Although variations across the range of intervals can be seen, taken as a whole the functions appear to be similar (the largest irregularities occurred for Intervals 1, 2, and 3). Subsequent effects of the VR train-

ing were also consistent across animals and conditions. During the earliest block of recovery sessions, the rising functions were replaced by irregular patterns in which probabilities sometimes declined. With continued exposure to the PI schedule, performances reverted to the earlier rising functions. Sub-

Table 3

Mathematical index of curvature values derived from performances during the final 10 sessions of the baseline (BL) and recovery (Rec) phases. Values are averages of blocks of three consecutive intervals. The rats' identification numbers are followed by the size of the PI increment, either 6 s or 12 s.

Intervals	R12-6		R53-6		R54-6		R27-12		R58-12		Median	
	BL	Rec	BL	Rec	BL	Rec	BL	Rec	BL	Rec	BL	Rec
1-3	.58	.56	.49	.57	.44	.47	.65	.52	.48	.54	.49	.54
4-6	.41	.55	.48	.61	.52	.59	.62	.52	.56	.58	.52	.58
7-9	.53	.61	.52	.59	.48	.62	.67	.62	.60	.61	.53	.62
10-12	.54	.68	.65	.61	.53	.62	.68	.34	.60	.52	.60	.61
13-15	.65	.63	.61	.69	.64	.59	.70	.42	.57	.56	.64	.59
16-18	.64	.74	.56	.65	.54	.41	.72	.51	.52	.51	.56	.51

jects varied in the extent to which original baseline performances were recovered, and for several of the animals the concentration of values in the last bin exceeded previous performances.

Cumulative Records

Finally, we considered the cumulative records that were routinely collected during the course of the experiment. The records displayed in Figure 7 (6 s) and Figure 8 (12 s) include a typical record from Sessions 86 through 90 of the baseline phase (A), typical records from the 1st and 11th recovery sessions (B and C, respectively), and a typical record from Sessions 46 through 50 of the recovery phase (D). The baseline records illustrate the three local response patterns that have been used to characterize FI performances: scalloped patterns (the response rate accelerates within the intervals), break-and-run patterns (an initial postreinforcement pause is followed by sustained responding), and single-response patterns (a single response within the interval occurs after the interval has expired). The extent to which any one of the patterns predominated varied from animal to animal and session to session. The clearest evidence of scalloping was in the records of R12 and R27; the break-and-run and single-response patterns were more common among the other animals.

The records from the recovery phase give details of the changes induced by the interposed VR schedule. During the first recovery session, response rates were elevated, and pausing was absent during the earliest intervals of the progression. However, pausing reappeared during later intervals. With con-

tinued exposure to the PI schedule, rates declined and pausing became more prominent. Although these changes continued to the end of the experiment, it is difficult to determine whether baseline performances were recovered. The impression from the records is that the scalloped patterns seen earlier were replaced by the break-and-run and single-response patterns.

DISCUSSION

The postreinforcement pause is a commonly used measure of temporal control by FI schedules, and a number of experiments have shown that the pause increases as the interval is increased (e.g., Dukich & Lee, 1973; Lowe et al., 1979). Results were similar in the present study of PI schedules, that is, a schedule in which interval durations change within rather than between sessions. We also found that the rising pause functions were linear, thus indicating that the pauses occupied a constant proportion of the increasing intervals (Figures 1 and 2). Constant proportions were observed in Harzem's (1969) investigation; however, our values were larger (50% or more of the intervals vs. about 30%). Increased pausing also was the rule in Dougherty et al.'s (1994) experiment, but their human subjects did not consistently maintain constant proportions. These differences from the previous studies may be attributed to a number of factors. Among other things, our experiment involved the smallest PI increments and the most extended training procedures.

Increased pausing as a function of interval duration has also been reported for FI sched-

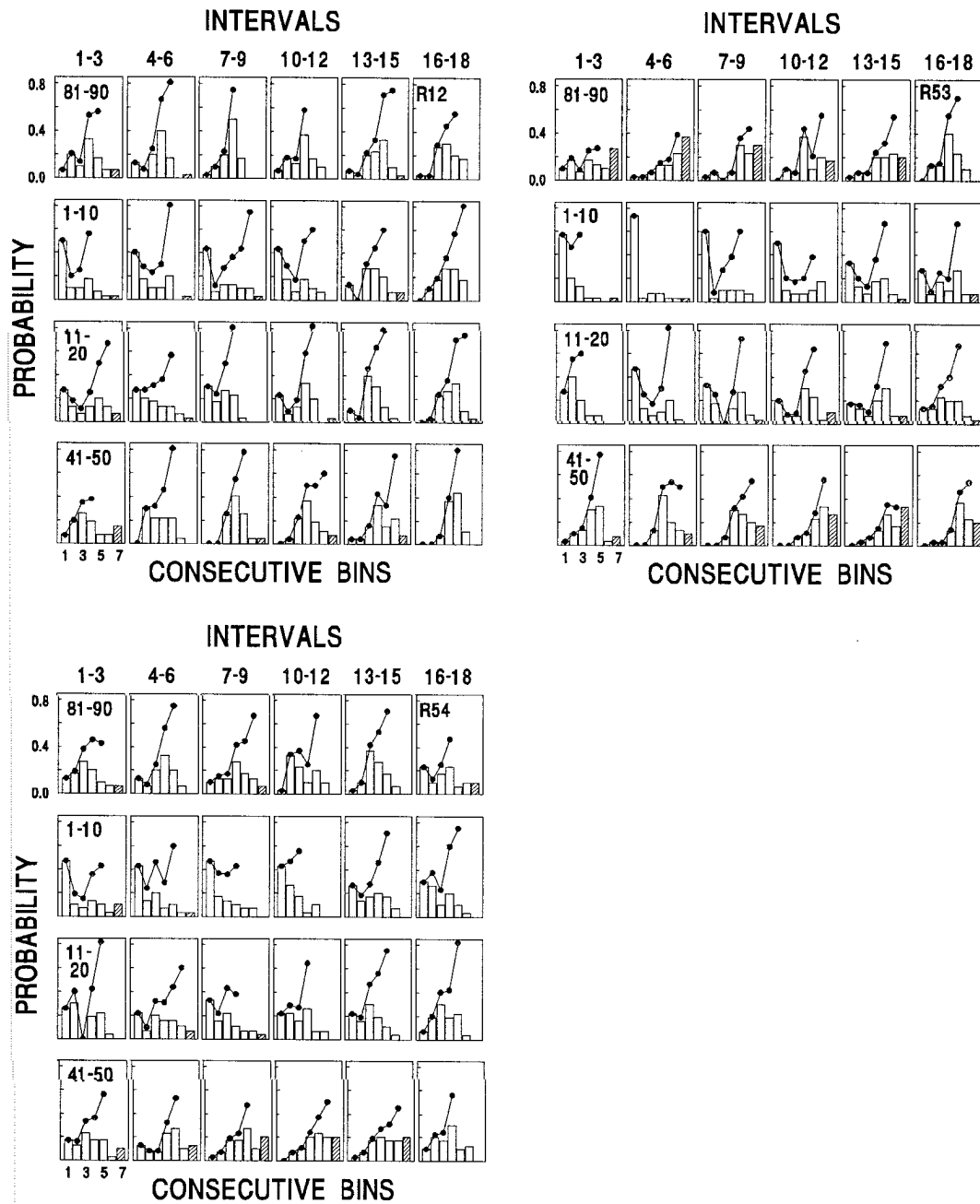


Fig. 5. Conditional probabilities of pausing terminations. Data are from Sessions 81–90 (baseline) and Sessions 1–10, 11–20, and 41–50 (recovery). The lines depict pauses as conditional probabilities (i.e., pause terminations per opportunity), and the histograms show the relative frequencies on which the conditional values were based. Data are from the 6-s condition for R12 (top left), R53 (top right), and R54 (bottom left).

ules. Dukich and Lee (1973) trained rats to stability at each of several FI durations and found that pauses occupied about two thirds of the intervals, regardless of interval dura-

tion (a value not too different from the present results). By comparison, somewhat different results were obtained in a study of FI responding by Lowe et al. (1979). Although

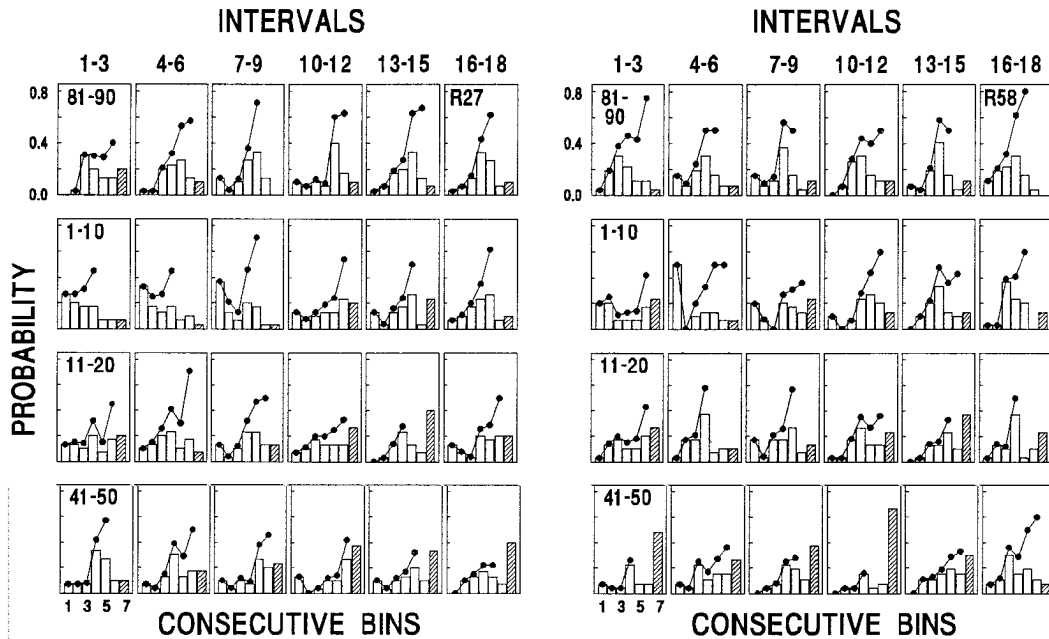


Fig. 6. Conditional probabilities of pausing terminations. Data are from Sessions 81–90 (baseline) and Sessions 1–10, 11–20, and 41–50 (recovery). The lines depict pauses as conditional probabilities (i.e., pause terminations per opportunity), and the histograms show the relative frequencies on which the conditional values were based. Data are from the 12-s condition for R27 (left) and R58 (right).

pauses were longer at the longer FI durations, proportions declined rather than remaining constant (the decrease was a power function with fractional slope). Lowe *et al.* attributed the difference to the fact that they studied the FI values in a random sequence, whereas Dukich and Lee had used an ascending order. The present finding of proportionality with a schedule that contained increasing intervals (albeit within sessions rather than between blocks of sessions as in the Dukich and Lee experiment) may seem to fit Lowe *et al.*'s interpretation. However, we doubt that this is the entire story. Innis and Staddon (1971) observed the performances of pigeons under cyclical PI schedules (schedules in which the increasing sequence was followed by a decreasing one). Although the intervals were ordered rather than random, their data also indicated a power function rather than the proportional relationship found by Dukich and Lee and the present experiment.

The finding that pausing under PI schedules was proportional to the prevailing interval duration points to temporal control rather than control by some other variable (e.g., fa-

tigue, deprivation). This conclusion is buttressed by the other analyses: (a) Quarter-life values increased in a linear manner; (b) index-of-curvature values were similar across the intervals; and (c) conditional probabilities of the first response within the interval increased as a function of elapsed time. Such findings in studies of FI schedules have been used to support temporal accounts of responding. Parallel outcomes with PI schedules suggest a common process, but one with the added feature that performances are regulated in accord with continually increasing interval durations.

The regularities in PI performances are somewhat surprising in light of the special demands of the schedule. Gibbon (1979) reanalyzed some of Harzem's (1969) data, and he also found the performances to be remarkable in that "the progressive schedule requires that subjects hold 'in memory' the rule for incrementing successive intervals" (p. 287). Although a more behavioral account may be desirable, our study does not take us much beyond the speculation that the duration of the just-completed interval somehow provides the necessary timing cues for

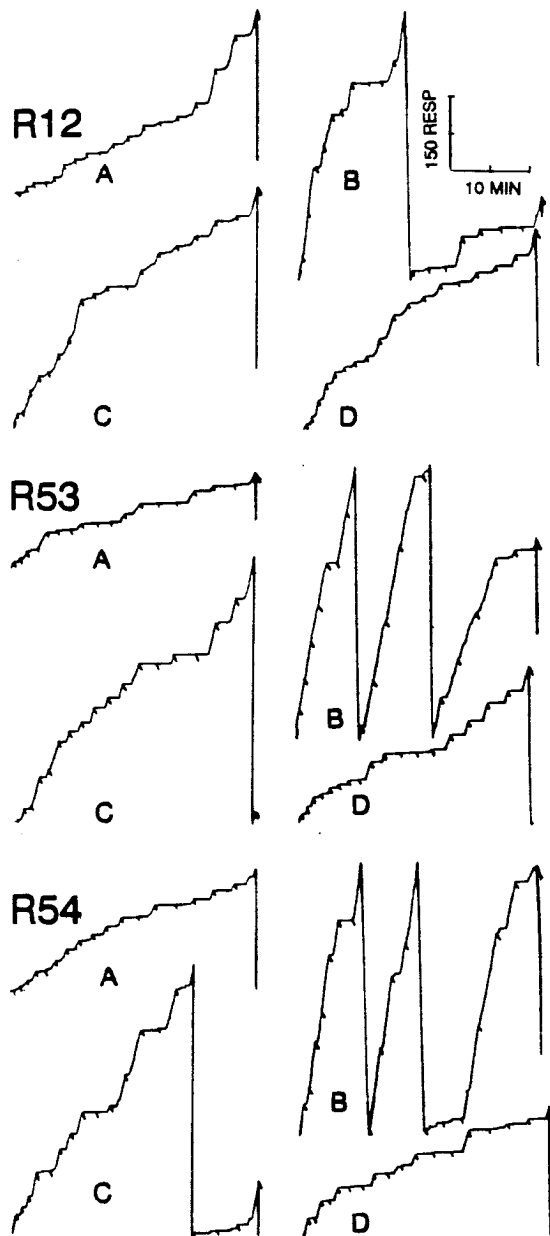


Fig. 7. Cumulative records from a baseline phase session (A), from Recovery Session I (B), from Recovery Session 11 (C), and from a final recovery session (D). Records are from R12, R53, and R54 (6 s).

pausing and responding within the current interval.

The various similarities between PI and FI performances make PI schedules a candidate for investigations that ordinarily would employ FI schedules. The obvious advantage is

that PI schedules allow simultaneous study of a wide range of intervals. In Dougherty et al.'s (1994) drug study, for example, this feature helped to establish the generality of temporal overestimation across a range of different time intervals. But two cautions are indicated by the present results: First, the not-well-understood progressive feature of PI schedules undoubtedly complicates interpretations; and second, the amount of training required for stable behavior may be excessive for some purposes. This latter consideration is especially important for research with humans and may have contributed to Dougherty et al.'s failure to observe proportionality.

A comment about the cumulative records is in order. By comparison with the orderly picture presented by the averaged data, results from the cumulative records—a faithful rendition of the animal's moment-to-moment responding—were considerably less regular. The progressions of increased pauses are difficult to discern, and the proportionality of the response patterns is not apparent. We have discussed the discrepancies that emerge when cumulative records of FI performances are compared with more molar depictions (Baron & Leinenweber, 1994). In particular, the picture painted by probabilistic analyses (which cannot be conducted unless the data are aggregated) typically reveals scalloped patterns, whereas such patterns are less frequent in cumulative records. These analytic problems are heightened when research turns to PI schedules. A procedure that confronts a subject with an interval of a given duration only once per session is hardly conducive to the development of stable local performances that mirror molar trends.

The second part of the experiment sheds further light on PI performances by examining the persistence of the established PI patterns following exposure to a schedule that generated high rates and short pauses. When the PI contingencies were reinstated after VR training, response rates were elevated for the initial recovery sessions, particularly during the early part of the progressions. Noteworthy is the much lesser influence of the VR history on relative responding within the intervals. The cumulative records from the first recovery session (Figures 7 and 8; Record B) illustrate the difference: The characteristic patterns of accelerated responding can be

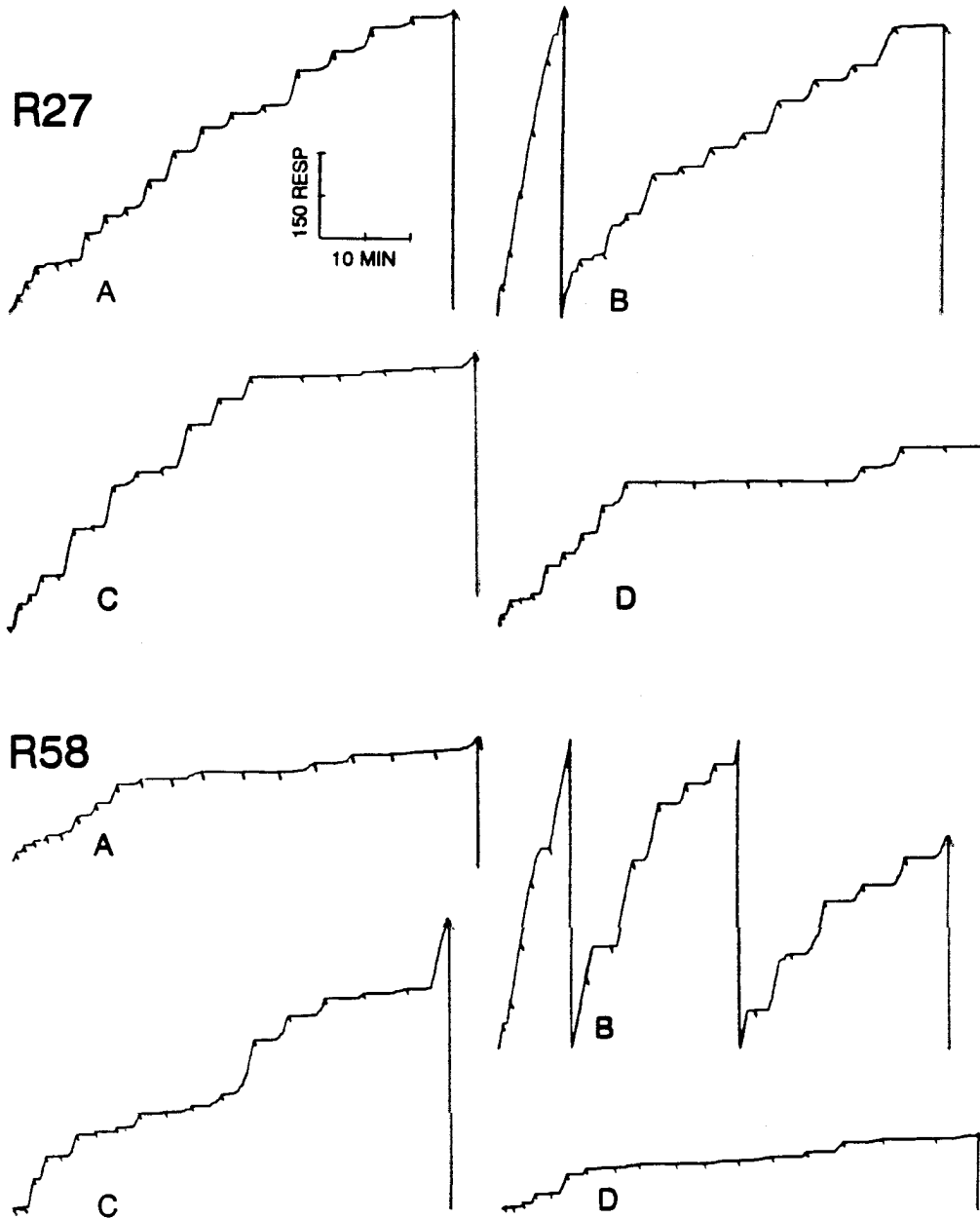


Fig. 8. Cumulative records from a baseline phase session (A), from Recovery Session I (B), from Recovery Session II (C), and from a final recovery session (D). Records are from R27 and R58 (12 s).

seen superimposed on the heightened absolute rates. In discussing similar findings when VR training preceded an FI schedule (Baron & Leinenweber, 1995), we proposed that the FI schedule was exerting its control on response units that were formed during the VR training (response bursts) rather than on in-

dividual responses. This account seems to be appropriate for the present findings as well.

Although recovery from the effects of the VR schedule followed an orderly progression, not all of the changes are easily understood. Noteworthy was that pausing reached levels that exceeded those reached before the VR

schedule was introduced. Wanchisen et al. (1989) reported similar findings in an experiment with VR training and an FI baseline. Performances, as gauged by the other measures (quarter life, index of curvature), were also more extreme. In general, responding during the recovery phase was less regular than had been the case during the terminal baseline sessions.

The effects of the VR history have a bearing on recent discussions of whether results from animal models can be replicated in experiments with humans (Baron & Leinenweber, 1995; Cohen et al., 1994; Wanchisen et al., 1989). Anomalous human performances are well known in the case of FI schedules. Whereas rats and pigeons respond in ways that are consistent with the temporal contingency (response probabilities increase as the interval elapses), humans often respond in a persistent, undifferentiated manner (Weiner, 1970). Wanchisen et al. attributed these differences to historical factors. They proposed that rats given a VR history would manifest human-like FI performances, and their experimental results appeared to support this view. However, our systematic replication of their procedures, together with more detailed data analyses, yielded results not unlike the present ones (Baron & Leinenweber, 1995). Although VR histories induced high FI and PI rates in our experiments, continued temporal control, as shown by accelerated rates within the intervals, was apparent during the early recovery sessions, and baseline performances eventually were recovered (see also Cohen et al.). By comparison, human subjects usually respond in an undifferentiated manner at the start of FI training, and performances do not change much despite continued exposure to the schedule (Weiner).

The present results, together with those from Dougherty et al.'s (1994) experiment with humans, point more toward control by the current contingencies than to long-standing influences of historical factors. Our findings indicated that the disruptions caused by the VR history were relatively short lived. In addition, the human subjects in Dougherty et al.'s experiments were also sensitive to the temporal contingencies: Pausing by both rats and humans increased systematically with increasing interval durations (the human increases were not proportional, however).

This correspondence between humans and nonhumans is striking when considered in the light of the many experiments that have shown discrepant performances under FI schedules. Considered together, these results with PI schedules attest to the utility of animal models of schedule-controlled performances. They also pose a challenge to the view that conditioning histories provide the key to differences between humans and nonhumans.

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