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EFFECTS OF A VARIABLE-RATIO CONDITIONING HISTORY ON SENSITIVITY TO FIXED-INTERVAL CONTINGENCIES IN RATS

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We investigated the possibility that human-like fixed-interval performances would appear in rats given a variable-ratio history (Wanchisen, Tatham, & Mooney, 1989). Nine rats were trained under single or compound variable-ratio schedules and then under a fixed-interval 30-s schedule. The histories produced high fixed-interval rates that declined slowly over 90 sessions; differences as a function of the particular history were absent. Nine control animals given only fixed-interval training responded at lower levels initially, but rates increased with training. Despite differences in absolute rates, rates within the intervals and postreinforcement pauses indicated equivalent development of the accelerated response patterns suggestive of sensitivity to fixed-interval contingencies. The finding that the histories elevated rates without retarding development of differentiated patterns suggests that the effective response unit was a burst of several lever presses and that the fixed-interval contingencies acted on these units in the same way as for single responses. Regardless of history, the rats did not manifest the persistent, undifferentiated responding reported for humans under comparable schedules. We concluded that the shortcomings of animal models of human fixed-interval performances cannot be easily remedied by including a variable-ratio conditioning history within the model.

Key words: schedule history, fixed-interval schedule, variable-ratio schedule, temporal patterning of behavior, response units, human/nonhuman differences, lever press, rats

Animal models have made important contributions to the understanding of human operant conditioning. Basic processes are identified and studied in the animal laboratory where highly controlled experiments are possible. The principles are then extrapolated to the behavior of humans. For example, animal-based principles of operant conditioning are widely used to interpret the behavior of humans in complex natural environments. The principles are at the basis of the behavior modification procedures commonly employed within clinical, educational, and other applied settings. Moreover, the principles have been supported by results of laboratory experiments that used humans rather than nonhumans as the subjects.

Because experiments with humans have usually supported the animal model, discrepant outcomes attract special attention. A case in point is the body of research on human reactions to fixed-interval (FI) schedules of reinforcement (e.g., Lowe, 1979; Perone, Galizio, & Baron, 1988; Weiner, 1969, 1970). The expected response pattern, often seen in experiments with rats and pigeons, reflects the temporal contingency: The animal pauses after delivery of the reinforcer and then responds at an accelerated rate during the remainder of the interval. Experiments with humans, by comparison, have not provided consistent evidence of temporal control. The human subject typically responds in a persistent, undifferentiated manner within the intervals, usually at a high rate (e.g., one to three key presses per second), and these response patterns do not change much despite continued exposure to the schedule (e.g., Weiner, 1969, 1970). To be sure, special procedures may bring performances more in line with the expectations of the model (e.g., instructions about the schedule). Nevertheless, it remains a puzzle as to why human subjects should be so resistant to control by a schedule to which nonhumans so readily adapt.

Wanchisen, Tatham, and Mooney (1989) suggested a plausible basis for these anomalous results. In their view, the animal model is not so much incorrect as it is incomplete. This is because the model is derived from research with experimentally naive subjects, whereas research with humans usually employs adults

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with extensive and varied extraexperimental conditioning histories. Of particular relevance is that these histories include instances in which the response of button pressing (the common response in these experiments) has been reinforced on a variable-ratio basis (i.e., reinforced on a schedule in which the contingency involves completion of a number of responses rather than expiration of a period of time). Such a history could be expected to generate high response rates and interfere markedly with temporal control when FI schedules are subsequently introduced in the laboratory.

Wanchisen et al. (1989) put this account to the test in a straightforward experiment with rats. Subjects assigned to the history condition received variable-ratio (VR) training (the conditioning history) and then were exposed to an FI schedule (the current schedule). Other control subjects were naive when the FI schedule was introduced. Their initial results supported the hypothesis. By comparison with the control subjects, the history animals responded at much higher overall rates and manifested briefer pauses following the reinforcer (for similar findings, see Freeman & Lattal, 1992; Urbain, Poling, Millam, & Thompson, 1978; Weiner, 1964).

But outcomes were more complex on the question of whether subsequent performances also approximated those of human subjects. Wanchisen et al.'s (1989) analyses of cumulative records (their Figures 2, 3, and 4) led them to conclude that their account received some support: The VR history had altered the normal development of FI patterning and thus may have produced something akin to what has been observed in experiments with humans. The naive rats "progressed predictably through the standard FI behavioral patterns, showing scallops, then low rates, some with break-runs," whereas the history animals did not provide consistent evidence of scalloping at any point in the experiment; they "emitted primarily high- with some low-rate patterns; this is more characteristic of adult human performances" (Wanchisen et al., 1989, p. 177). Mazur (1994), in his widely used learning textbook, concurred with this interpretation; he cited Wanchisen et al.'s results with rats as a model of the adult human's "long and complex history of exposure to reinforcement schedules outside the laboratory" (p. 189).

The picture changes, however, when one considers Wanchisen et al.'s (1989) data on overall response rates (within-interval changes in rates were not reported) and postreinforcement pauses (their Figure 5). With exposure to the FI schedule, the history animals developed considerable sensitivity to the new contingencies. Their initially elevated rates declined, and their postreinforcement pauses lengthened. When the experiment ended, the earlier differences in favor of the control subjects were no longer apparent (see Freeman & Lattal, 1992, for similar findings with pigeons). Thus, a key ingredient was missing in the performances of the rats: an analogue to the finding with humans that the undifferentiated high rates usually seen at the start of the experiment persevere more or less indefinitely (or, at least, to the limits of the experiment).

Wanchisen et al.'s (1989) study calls for further examination of the effects of ratio histories on FI performances. Their conclusions about the nature of rate variations within the intervals (the "scallop") relied heavily on cumulative records. Perhaps a clearer picture would emerge from a quantitative treatment. Wanchisen et al. did attempt a quantitative analysis of within-interval performances using Fry, Kelleher, and Cook's (1960) mathematical index of curvature, but the outcomes are difficult to interpret. They stated that history–control differences were absent, but they did not present actual values nor did they make clear whether any of the subjects showed differentiated performances with this index. In any case, the index is inappropriate when applied to intervals containing only a few responses (as correctly pointed out by Wanchisen et al.; see also Fry et al.); this is likely with intervals as short as the 30-s durations in their experiment.

We decided that a useful approach would be simply to replicate Wanchisen et al.'s (1989) experiment. A few modifications were introduced: (a) We gave the rats greater exposure to the FI 30-s schedule to gain a fuller picture of changes. (b) We concentrated the analyses on quantitative assessments of within-interval changes in performances; measures included local rates within the intervals, pause distributions, and the quarter-life index of response patterning (Lattal, 1991). (c) We broadened the inquiry to include previous experience with an extinction schedule; in an experiment with human subjects, Weiner (1969) reported that the high rates engendered by ratio histories were reduced when the history also included schedules that controlled low response rates.

METHOD

Subjects

Eighteen male albino Sprague-Dawley-derived rats were 3 to 5 months old at the start of the experiment. Fourteen had served previously in a student laboratory, where they had been given approximately 10 hr of operant training (shaping, progressive-ratio schedule, extinction). The remaining animals had not participated in research before. Animals were housed individually with free access to water. Food deprivation was accomplished by scheduling 1-hr feeding periods shortly after the experimental sessions (Hurwitz & Davis, 1983). Illumination within the vivarium followed a 16:8 hr light/dark cycle.

Apparatus

Single-lever rodent chambers (Grason-Stadler, E3125; 29 cm by 24 cm by 19 cm) were enclosed in sound-attenuating ventilated 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 shielded 3-W lamp on the right wall. Extraneous sounds were masked by white noise and the ventilating fan. Programming and data recording were controlled by microcomputers located in an adjacent room.

Procedure

Lever pressing was reinforced with liquid food consisting of reconstituted skimmed milk sweetened with 18 g of granulated sugar per 950 ml water. During preliminary training, all animals were trained to drink the milk when the dipper was raised, and the lever-press response was then shaped (retraining was necessary for the experienced animals; the student project had used food pellets, and the lever-press response was extinguished during the last phase). The 14 experienced animals were assigned to one of four conditions, three of which involved training with VR schedules: single VR ($n = 3$); or compound schedules with VR in one component and extinction in the other, either multiple VR extinction ($n = 3$) or mixed VR extinction ($n = 3$). The remaining 5 experienced animals and the 4 naive ones were assigned to the fourth control condition and were not given VR training ($n = 9$).

Table 1

Number of sessions and mean response rates (responses per minute; standard deviations in parentheses) for the final eight variable-ratio and extinction sessions of the training phase.

Condition	Rat	Sessions	Response rates VR	Response rates Ext
Single VR	R03	50	162 (41)	— —
	R10	54	204 (34)	— —
	R14	48	209 (25)	— —
Mult VR ext	R04	64	167 (37)	1.0 (0.4)
	R13	70	297 (63)	2.2 (2.8)
	R18	80[a]	79 (23)	0.8 (0.3)
Mix VR ext	R01	69	229 (40)	0.7 (0.9)
	R06	73[b]	85 (24)	1.5 (1.5)
	R17	71[b]	203 (40)	2.1 (1.7)

[a] Did not meet the 15% criterion.

[b] Met the 15% (but not the 10%) criterion.

Variable-ratio conditions. Animals assigned to the VR conditions were trained under a VR 20 schedule, that is, 20 responses were required on the average for delivery of the milk reinforcer. Training began with a low ratio that was increased in a series of steps from day to day. The VR 20 schedule was reached by the 15th session and was not changed for the remainder of training (a minimum of 48 sessions; see Table 1). During this and subsequent phases, each session continued until 100 reinforcers had been delivered or 20 min had elapsed. There were four versions of the final schedule, each with seven ratios ranging from 5 to 35 arranged in an irregular sequence.

Subsequent training during this phase depended on group assignment. For animals trained under the single schedule, sessions were scheduled on alternate days, and training continued until performances were stable (48 to 54 sessions). Animals assigned to the compound conditions also were exposed to the VR schedule every other session, but 20-min periods of extinction (lever pressing was ineffective) were scheduled during the intervening sessions. For the multiple-schedule condition, the left cuelight in the chamber blinked during extinction sessions; this stimulus was absent under the mixed condition. For both multiple and mixed conditions, a strict alternation of VR and extinction sessions was imposed for the first 30 sessions. Thereafter, the sequence was less regular; the schedule changed to the alternative component after one or two exposures ($p = .5$). Depending on the stability criterion (see below), multiple and mixed training continued for at least 64 and for as many as 80 sessions. The number of training sessions for each animal is shown in Table 1.

Variable-ratio stability. Stability was assessed using mean VR rates for two consecutive four-session blocks. The original plan was to require that the difference not exceed 10% of the mean for all eight sessions, and this criterion was met within 54 sessions by the 3 single VR subjects. When it became apparent that a 10% criterion was too severe for some of the compound-schedule animals, the criterion was relaxed to 15%. Five of the animals attained stability by the 73rd session; the 6th (R18) did not and was moved on after 80 sessions. Regardless of stability level, response rates on extinction days were quite low, and were never more than 2% of VR rates (see Table 1).

Fixed-interval schedule. All 18 subjects were then observed for an extended series of sessions under the same FI 30-s schedule studied by Wanchisen et al. (1989): The first response occurring 30 s after the previous reinforcer delivered the milk reinforcer. Sessions were conducted on alternate days and lasted 20 min (32 to 36 reinforcers). During this phase, the stimulus conditions were unchanged from previous VR training (i.e., the chamber was illuminated, and the left cuelight was off). For 3 of the experienced control animals (those from the student laboratory), FI training commenced immediately after initial shaping; for the other 2, the onset was postponed until the VR subjects had completed their training (approximately 5 months later). Because there were no apparent differences between these two procedures, the 4 inexperienced control animals were switched to the FI schedule immediately following the shaping phase. Training under the FI schedule continued for 90 sessions (an exception was R12, whose data after the 75th session could not be used because of illness).

RESULTS

Variable-Ratio Training

Table 1 shows mean response rates (responses per minute) at the end of this phase: the last eight VR sessions for all animals, plus the last eight extinction sessions for subjects in the compound conditions. Regardless of condition, the ratio schedules generated high rates, exceeding 60 responses per minute and considerably faster in some cases. By comparison, extinction rates within the compound schedules (multiple and mixed conditions) were much lower, averaging fewer than three responses per minute. Differences between the multiple-schedule and mixed-schedule groups were unsystematic. Table 1 shows, however, that subject-to-subject variation in ratio rates was greater under the compound-schedule conditions than under the single-VR condition.

Fixed-Interval Schedule

Figures 1 and 2 summarize each animal's response rates across the 90 sessions. The six functions within the panels depict rates for the six 5-s segments of the 30-s long interval; each point represents the median of a 5-day block. Figure 1 shows performances of the 9 control rats, those without a VR history (note that the panels are ordered in terms of the animals' overall response rates). It will be recalled that some of the animals were experimentally naive, whereas others had served in a student laboratory. Despite this difference, there is no indication that performances (i.e., overall rates, relative responding within the intervals, trends over sessions) were systematically related to the source of the subjects (compare the experimentally naive animals, R02N, R05N, R08N, and R20N, with the remainder from the student laboratory).

Several features characterized control performances. Initially, response rates were low in all segments of the interval. With exposure to the FI schedule, responding increased in the latter part of the interval and either decreased or continued at low levels in the early part. By the 30th session, all 9 control animals showed accelerated average rates as the interval elapsed, beginning with the second or third 5-s segment. Rates during the latter segments continued to increase beyond the 30th session for most animals; the modal pattern was a peak

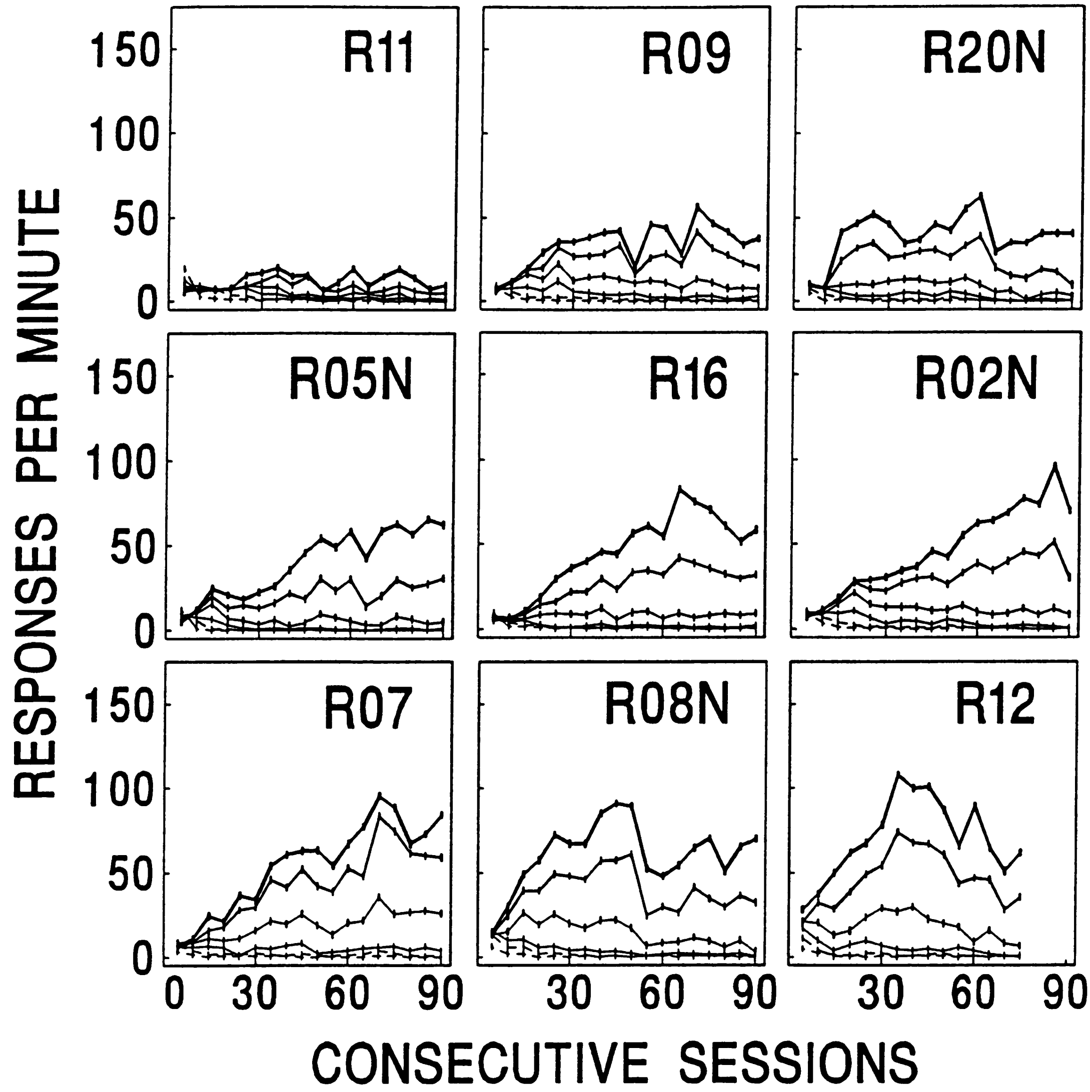

Fig. 1. Median FI response rates (responses per minute) for 9 rats trained exclusively with the FI schedule. The six functions for each animal depict rates in the six 5-s segments of the 30-s FI (1–5, 6–10, 11–15, 16–20, 21–25, and 26–30); the lines vary in darkness, with the lightest line signifying the first segment and the darkest line the last. Results for 90 sessions are grouped in five-session blocks.

midway in the experiment followed by a decline.

Figure 2 shows performances of the 9 VR-trained animals (single, top row; multiple, middle row; mixed, bottom row). The different histories were not accompanied by systematic differences in FI performances; therefore, these animals are considered together in this and subsequent analyses. Performances of history subjects were different from those of control subjects. Initial rates were much higher, particularly in the later part of the interval, and responding declined with continued exposure to the schedule. These reductions were usually concentrated in the early part of the interval, with the consequence that differentiated responding rapidly developed. By the 30th session, an accelerated response pattern was well established; when viewed in terms of relative responding, it was similar to that for the con-

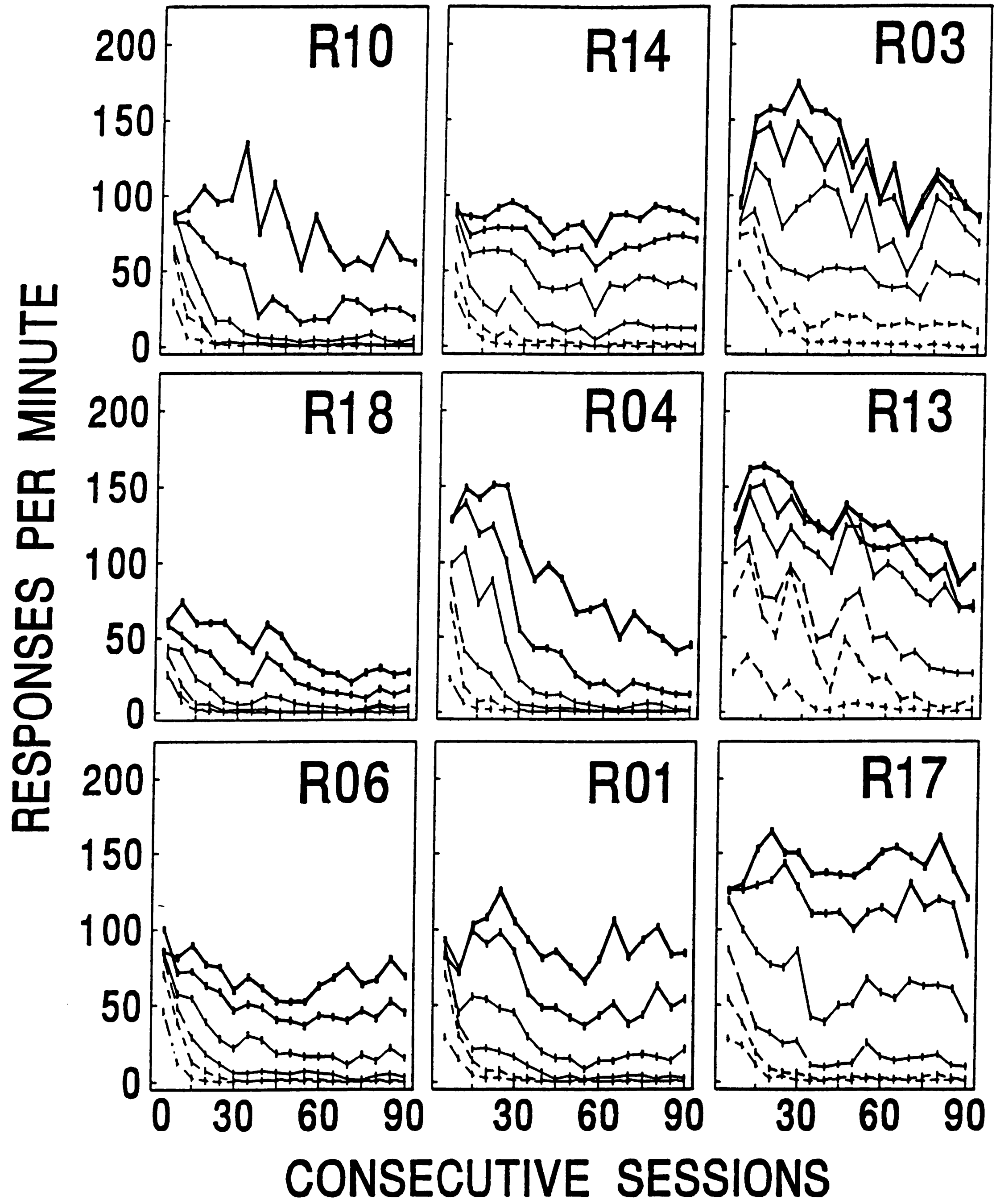

Fig. 2. Median FI response rates (responses per minute) for 9 rats trained previously with VR schedules. The six functions for each animal depict rates in the six 5-s segments of the 30-s FI (1–5, 6–10, 11–15, 16–20, 21–25, and 26–30); the lines vary in darkness, with the lightest line signifying the first segment and the darkest line the last. Results for 90 sessions are grouped in five-session blocks.

trol subjects. Absolute rates, however, still were considerably higher, particularly during the later segments of the fixed interval. Responding continued to decline during subsequent sessions (least for R06, R14, and R17), but rates were still substantial when the experiment ended.

Figure 3 was designed to clarify group differences as well as to facilitate comparisons with Wanchisen et al.'s (1989) results. They analyzed response rates in terms of the average for each entire interval rather than local rates within segments of the intervals; for the present analysis, therefore, overall rates were calculated for each animal from the values displayed in Figures 1 and 2. Figure 3 also presents quarter-life values (Lattal, 1991). The quarter life is an index of FI patterning used by Freeman and Lattal (1992) that designates the point in the interval at which 25% of the responses have been completed. These values were also derived from the 5-day rates in Figures 1 and 2.

Figure 3 is arranged to show quarter-life values as a function of overall rates. Data are grouped for different parts of the experiment, and each animal is represented by a single point within each panel. The intersections of the horizontal and vertical lines designate average (median) response rate and quarter-life values for each of the groups. The response-rate data for Sessions 1 through 15 (Panel 1) illustrate the previously mentioned higher response rates by the history animals. The remaining panels show that performances converged as their rates declined and control rates increased. At the end, 4 of the history animals were still outside the control range (Panel 4).

The other feature of Figure 3 pertains to the quarter-life measures. These values increased as responses became increasingly concentrated in the last half of the interval; changes correspond to those described previously for local response rates within the six segments of the fixed intervals (Figure 1 and 2). There is little indication, however, that the VR histories substantially impaired performances relative to the controls. During the early sessions (Panel 1), the group averages for control and history subjects slightly favored the history animals (12.3 s and 14.4 s, respectively). When the experiment ended (Panel 4), average values had increased to more or less the same level (22.4 s and 21.6 s). Figure 3 also suggests a negative relation between the quarter-life and response-rate measures. With exposure to the FI schedule (Panels 3 and 4), animals with the highest rates (all in the history group) had the lowest quarter-life values; the slope of the function, however, was not very pronounced.

Evidence that the VR histories interfered with temporal patterning was not forthcoming in the analyses of either relative rates (Figures 1 and 2) or quarter lives (Figure 3). Additional information about patterning comes from the postreinforcement pause (the latency of the first response within each interval). These results,

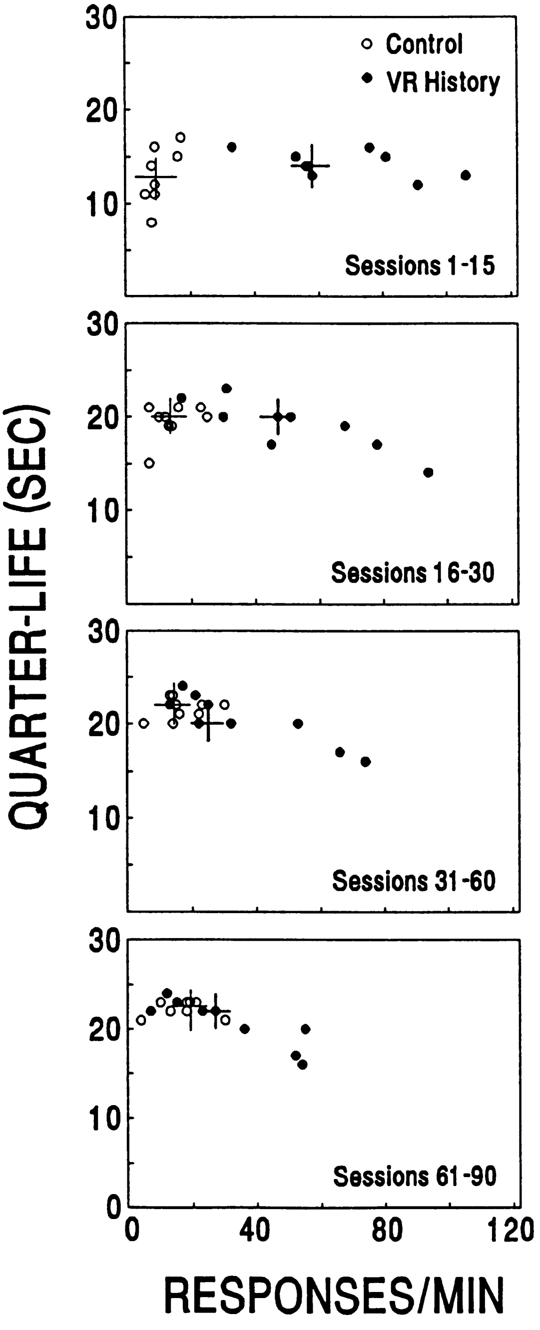

Fig. 3. Quarter life as a function of response rate. Each point represents either a control animal (open symbols) or a history animal (closed symbols). The crosses mark the medians of the distributions of scores.

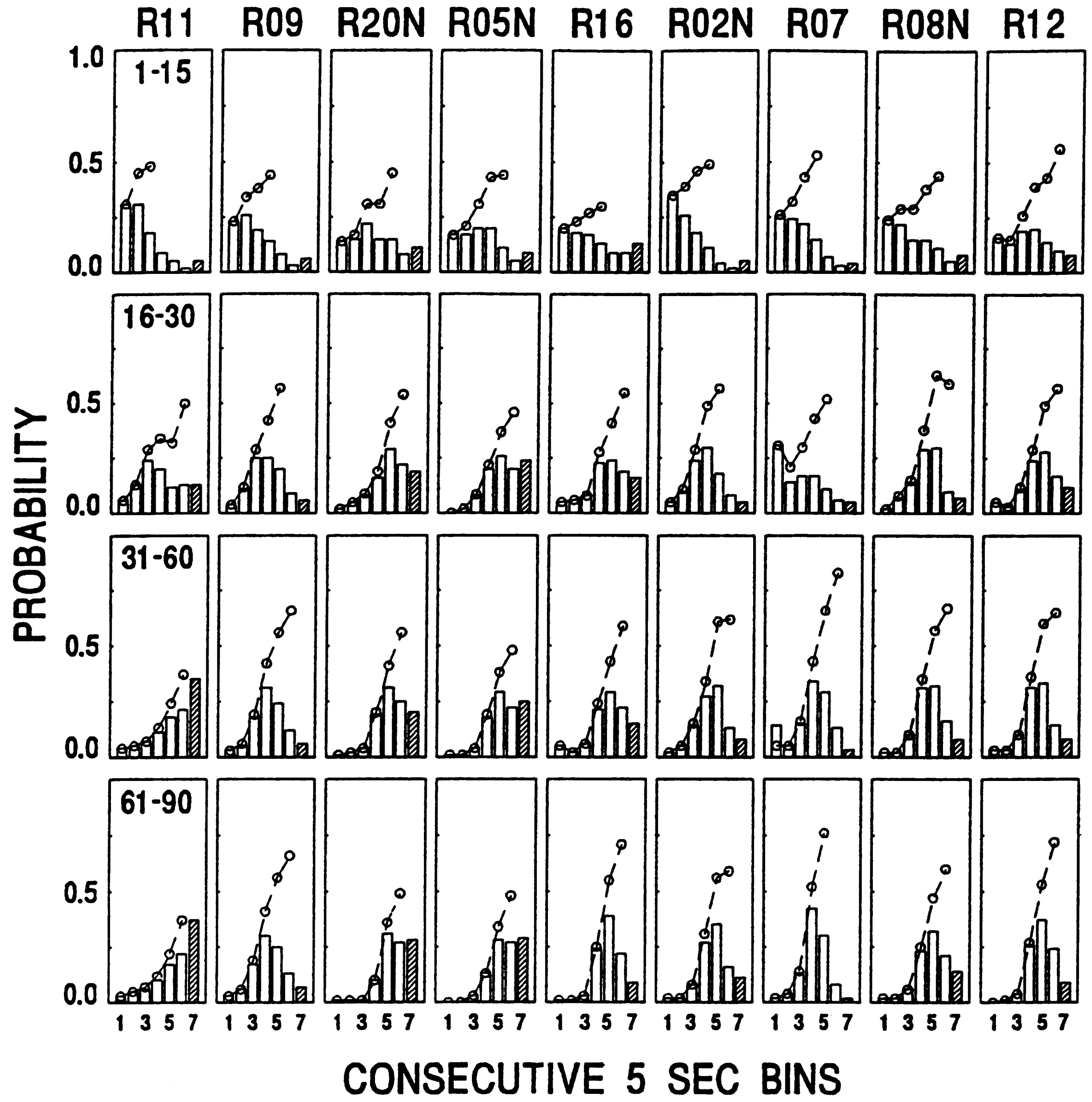

Fig. 4. Postreinforcement pauses of 9 rats trained exclusively with the FI schedule. The four bar graphs for each subject show relative frequency distributions for Sessions 1 through 15, 16 through 30, 31 through 60, and 61 through 90. Pauses are grouped in six 5-s bins; the seventh bin (shaded bars) designates intervals in which the latency exceeded 30 s. The line graphs express pauses as conditional probabilities (i.e., pause terminations per opportunity). Conditional probabilities are not plotted for bins with zero or very low entries or for Bin 7, where the probability was always 1.00.

in the form of pause distributions, are summarized in Figure 4 (control) and Figure 5 (history). Also displayed in Figures 4 and 5 are conditional probabilities of pause terminations (connected points); the probability of a termination within a particular bin was calculated as the number of terminations in that bin divided by the number in that and all longer bins (terminations per opportunity).

Figures 4 and 5 show features common to all animals. Temporal patterning, as indexed by postreinforcement pausing, became more pronounced as the experiment progressed. During initial sessions, pauses most often were terminated early in the interval, and the pause distributions were positively skewed. With training, however, longer pauses became more frequent, and the distributions became more

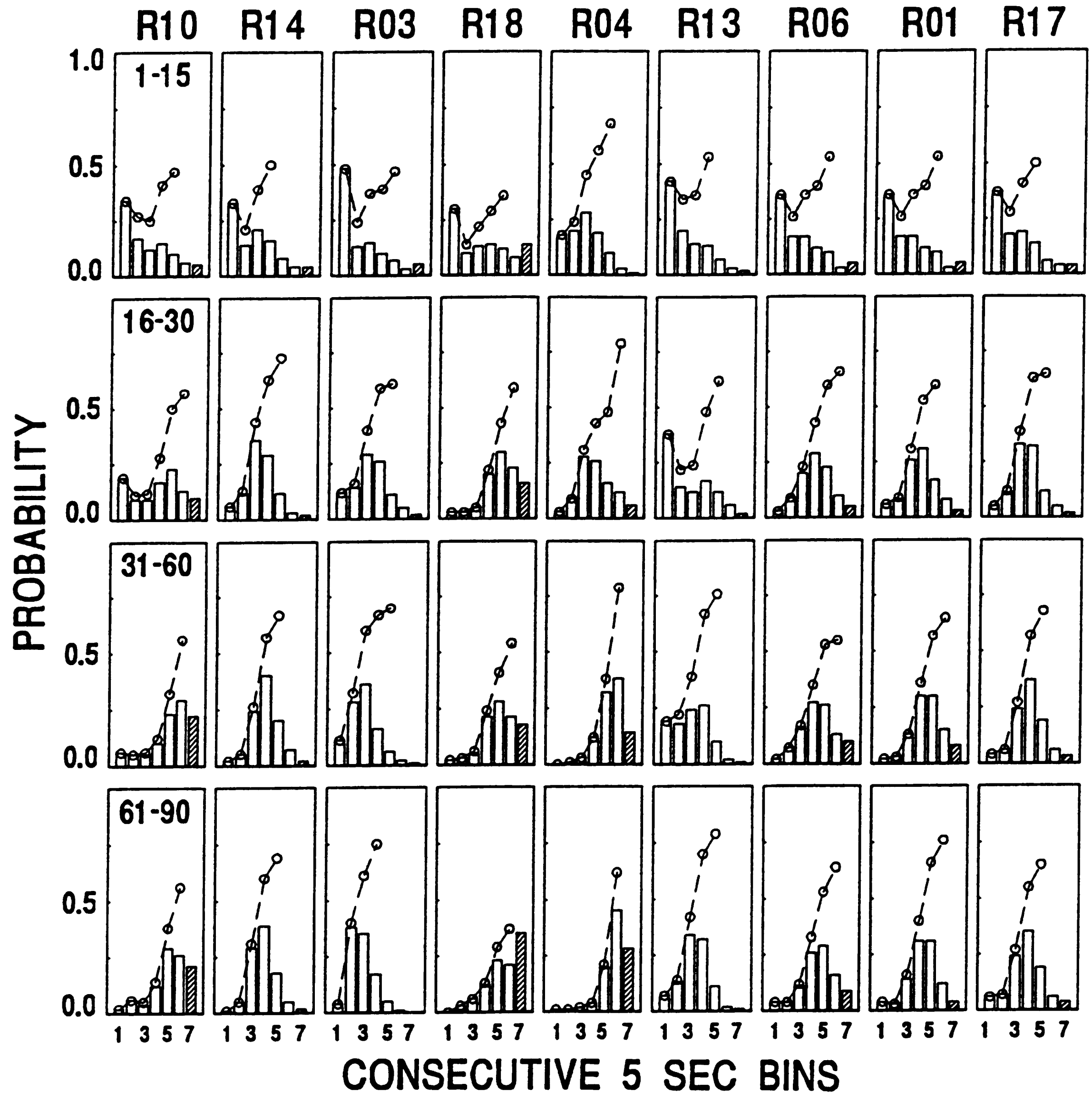

Fig. 5. Postreinforcement pauses of 9 rats trained previously with VR schedules. The four bar graphs for each subject show relative frequency distributions for Sessions 1 through 15, 16 through 30, 31 through 60, and 61 through 90. Pauses are grouped in six 5-s bins; the seventh bin (shaded bars) designates intervals in which the latency exceeded 30 s. The line graphs express pauses as conditional probabilities (i.e., pause terminations per opportunity). Conditional probabilities are not plotted for bins with zero or very low entries or for Bin 7, where the probability was always 1.00.

symmetrical and, in many cases, assumed a negative skew. The conditional-probability functions reveal a similar picture, with steeper and more regular slopes as the experiment progressed. Terminal functions were characterized by low values at the start of the interval (less than .10) and much higher values toward the end (more than .50).

The pause data do not provide strong evidence for differences as a function of history, certainly not to the extent as for overall response rates. But close inspection of the initial distributions (Sessions 1 through 15) suggests that the history subjects, taken as a group, may have manifested greater positive skews and briefer pauses. Group differences were small, however, and there were exceptions. To try to settle the issue, we evaluated the significance

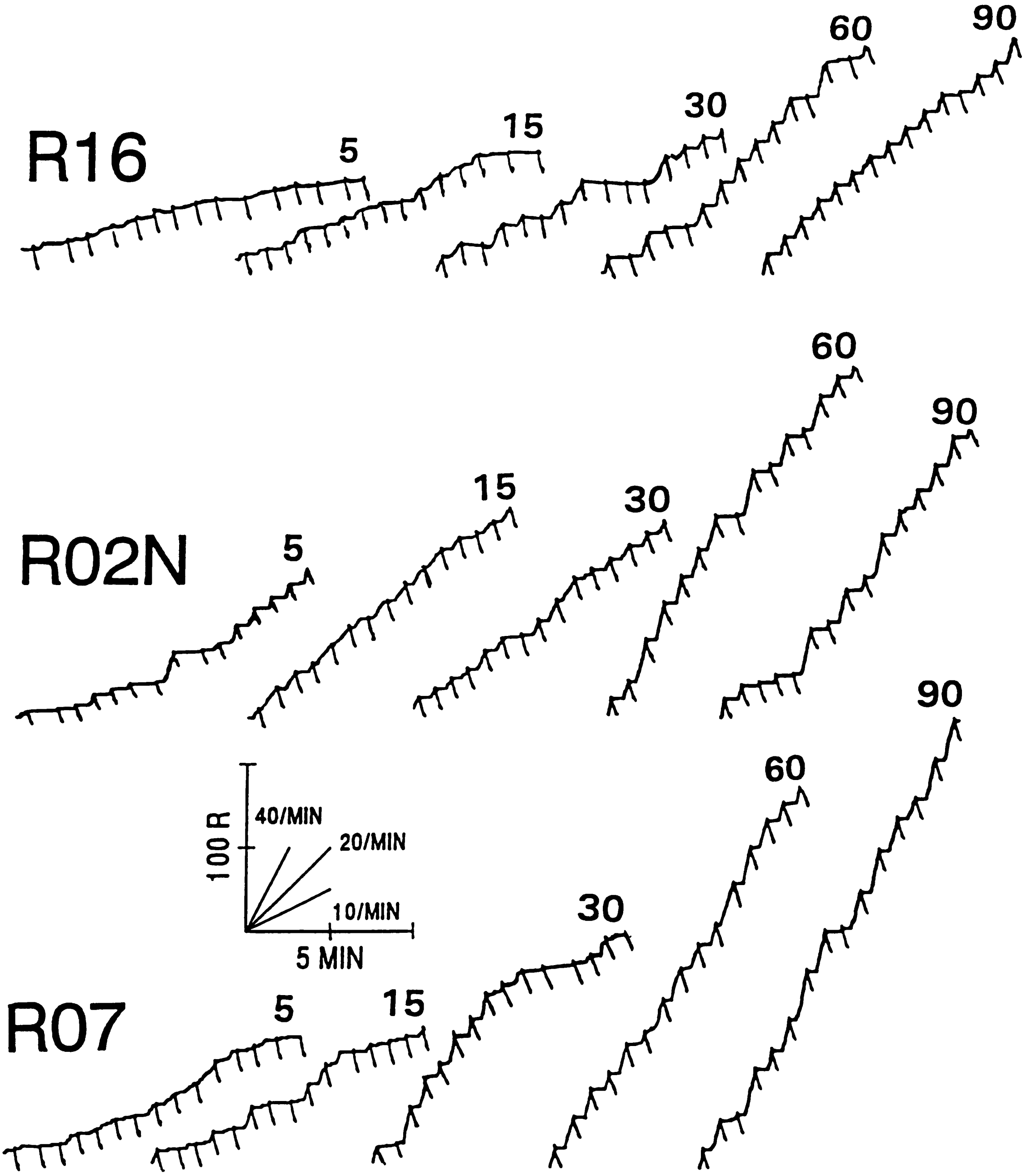

Fig. 6. Cumulative records from 3 control subjects under the FI 30-s schedule. Records are from the middle 14 intervals of Sessions 5, 15, 30, 60, and 90.

of differences with statistical procedures (analysis of variance). Each distribution was represented by its median value, and these values were entered into group-statistical comparisons for each block of sessions. The results for the first block (Sessions 1 through 15) established that pauses by history animals were indeed briefer, on the average: $F(1, 16) = 4.64$, $p = .047$; M (history) = 8.9 s, M (control) = 11.7 s. As suggested by the figures, differences for the remaining blocks were not statistically significant.

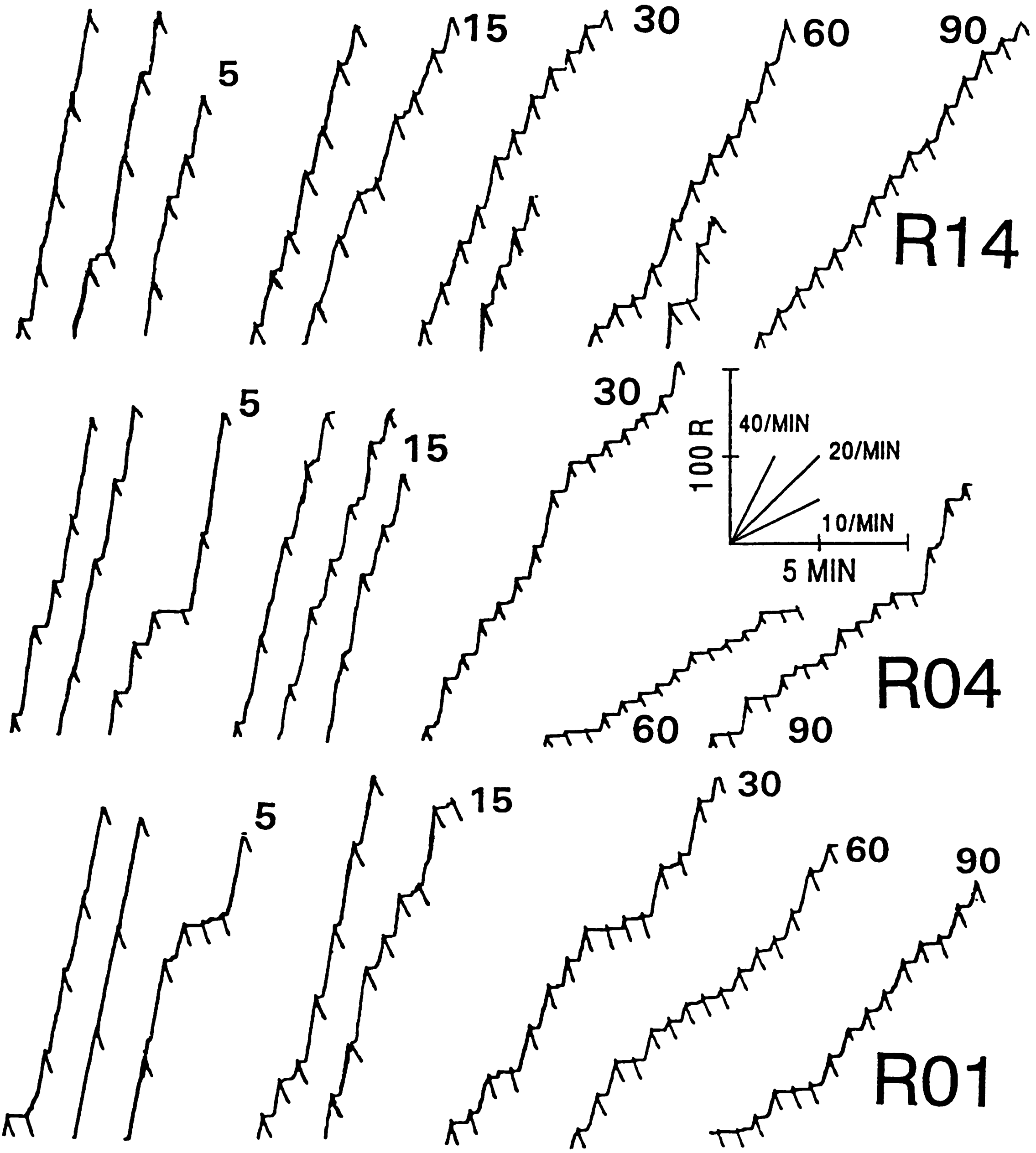

Fig. 7. Cumulative records from 3 VR history subjects under the FI 30-s schedule. Records are from the middle 14 intervals of Sessions 5, 15, 30, 60, and 90.

Finally, we turned to the cumulative records that were routinely collected during the course of the experiment. Our analyses paralleled those of Wanchisen et al. (1989) and were based on the middle 14 intervals of selected sessions (Sessions 5, 15, 30, 60, and 90). Figure 6 presents records from 3 control animals, selected from the middle of the range of average response rates (R16, R02N, R07; see rates in Figure 1). Figure 7 presents records from 3 history animals, the middle ones within each subcondition (R14, R01, R04; see rates in Figure 2).

The records illustrate on a response-by-response basis many of the more molar effects already described. Response rates of control subjects increased during the experiment, and undifferentiated performances at the start were replaced by patterned responding within the intervals (cf. Figure 1). Characterizing FI patterns is not easy, but the records appear to fall in three categories: scallops (rates accelerated within the intervals), break-and-run (an initial pause was followed by sustained responding), and a single response (the first response occurred after the interval expired). Although instances of all three patterns may be seen in the control records, the break-and-run pattern came to predominate as the experiment progressed.

The history animals' records also show previously described effects. Initial high rates were followed by a progressive decline and a convergence toward control group levels (cf. Figure 2). Also apparent is that patterned responding appeared early, and the patterns became more differentiated as the animals gained experience. Moreover, the modal pattern was break-and-run, the same as for the control records. When absolute rates of responding are taken into account, there do not appear to be striking differences between history and control subjects across sessions. (In comparing Figures 6 and 7, the reader should take into account the fact that larger variations in rate are needed to change the slope of a cumulative record when rates are high.)

DISCUSSION

Wanchisen et al. (1989) sought an improved animal model of human FI performance, one that might reproduce the persistent, undifferentiated responding frequently observed in experiments with humans (e.g., Weiner, 1970). Their essential conclusion was that the VR history had interfered with the development of standard FI behavioral patterns. In particular, accelerated patterns of responding (scallops) were infrequent; according to their report, they appeared in fewer than 5% of the intervals for 3 rats and fewer than 20% for the 4th. But other aspects of the history animals' performances suggested sensitivity to the FI contingency of a sort that usually does not appear in human subjects. With exposure to the new schedule, the initially elevated rates of the history subjects declined and postreinforcement pauses increased; when the experiment ended, these measures did not differ appreciably from those of rats not given a VR history.

Taken as a whole, the quantitative results of our replication (the data in Figures 1 through 5) are, perhaps, more at odds with Wanchisen et al.'s (1989) interpretations than with their actual findings. Although we added new analyses, we followed their lead and considered overall response rates (responding without regard to when in the interval the response occurred). As in their experiment, we found that the high rates initially engendered by the VR histories declined with exposure to the FI schedule. Noteworthy is that reductions in the history–control differences also depended on rate increases by the control subjects. This finding is by no means new (Millenson & Leslie, 1979), but it deserves greater recognition in light of a common assumption that FI schedules necessarily control low rates.

Our new analyses of local rates make it apparent that the markedly different overall rates were accompanied by similar average patterns of acceleration within the intervals. We found that the local rates of both history and control subjects varied in equivalent ways (Figures 1 and 2); in both cases, relative rates formed an "average scallop" (Baron & Leinenweber, 1994). The derived quarter-life index also indicated similar relative performances. Freeman and Lattal's (1992) experiment with pigeons found, at best, transient history effects with this measure; by comparison, our results did not indicate differences at all (Figure 3). The only hint that the VR histories may have interfered with temporal control came from the postreinforcement pause distributions (Figures 4 and 5). But these results are problematic. Control–history differences in average pauses were small and transient, and they could only be established on statistical grounds. Taken as a whole, then, these findings do not provide a good basis for the conclusion that sensitivity to the temporal requirements of the FI schedule was appreciably altered by the subjects' histories.

A surprising feature of the results was the dissociation of absolute and relative rates, performance dimensions that we supposed would be closely related. To judge from absolute rates, the history subjects' performances were impaired for many sessions. The persistent high rates had been optimal under the VR schedule (which provided reinforcers in direct proportion to response output) but were inappropriate for an FI schedule (which required no more than a single response per interval). Nevertheless, the local rates of the history animals varied as a function of time within the intervals.

Disparities between absolute and relative measures of performance have been observed with other procedures (e.g., in experiments on choice; Neuringer, 1967). In the present context, the seemingly disparate outcomes may have resulted from the development of new response units during VR training. Although we did not collect systematic data on the way that lever-press responses were grouped, we were struck by the animals' uncanny ability to operate the lever-controlled microswitch rapidly, a pattern that persisted well into the FI phase of the experiment. An analysis that treated bursts of individual responses as single functional units probably would have made the absolute rates of history and control animals more equivalent (cf. Mowrer & Jones, 1945). This consideration, plus the finding of similar relative rates within the intervals, suggest that these larger units are as subject to the temporal contingencies of FI schedules as are the individual lever presses.

To return to the issues raised by Wanchisen et al. (1989), the present findings do not provide encouragement for the view that historical variables are at the root of discrepancies between human performances and the animal model of FI responding. The hallmark of experiments with humans responding on FI schedules has been the subject's propensity to respond in an undifferentiated manner within the intervals, most often at high rates without appreciable postreinforcement pausing. These patterns persist despite continued exposure to the FI schedule, and, for most subjects, there is no real indication that performances would change with additional training (see Weiner, 1969, 1970). A reasonable supposition is that these performances are under the control of variables other than the temporal contingencies of the schedule.

Now consider the FI performances of rats with a VR history. Although we found that absolute response rates were quite high initially, the analyses of local rates indicated the orderly development of accelerated patterns within the intervals (parallel changes occurred in quarter-life and postreinforcement-pause measures). Furthermore, the conditioning history did not interfere with these effects; differentiated responding developed at more or less the same rate as for the naive control subjects. If nothing else, then, the present results illustrate a familiar and certainly essential principle of operant conditioning—that performances controlled by a particular set of contingencies change appropriately when the contingencies are changed.

Wanchisen et al. (1989) reached different conclusions from their results. Although they saw differences as well as similarities to "classic human-like FI responding," they concluded, nevertheless, that "our results are more like the human patterns overall" (p. 178). In our view, this conclusion is problematic, given the cumulative records that they presented. No doubt, interpretations of cumulative records are subject to bias (cf. Hyten & Madden, 1993); furthermore, published reproductions do not provide much detail, particularly with intervals as short as 30 s. Within our own records, at least (Figures 6 and 7), we could not find evidence of the characteristic human response pattern. A convenient standard for human performance is provided by the records reproduced from Weiner (1969) by Wanchisen et al. in the introduction to their report (their Figure 1); Weiner described these records as showing that "most subjects responded at high constant rates without pausing after reinforcement (that is, gave high rate performances) under FI 10-sec and FI 600-sec schedules" (p. 368). By comparison, the most characteristic outcome in our experiment with FI 30 s—for the history animals as well as for the control animals—was the break-and-run pattern (a pause followed by sustained responding), a pattern suggesting sensitivity to the temporal contingency.

Regardless of the interpretations one wishes to place on the cumulative records, it is well to remember that even under the best of circumstances such records do not provide a very good basis for assessing temporal control. Temporal control implies that temporal cues (the passage of time) differentially control the probability of a response. As we have discussed elsewhere (Baron & Leinenweber, 1994), such information is not revealed by the extent of response variation within any particular interval of the cumulative record. Instead, a probabilistic analysis requires a molar depiction of performance—data based on pooled responses from a number of intervals. These are the considerations that led us to adopt the present approach of reporting the findings in terms of average local rates (Figures 1 and 2) and conditional probabilities (Figures 4 and 5).

In summary, the above discussion has pointed to both similarities and differences between our results and those of Wanchisen et al.'s (1989) experiment. Important outcomes were replicated; in particular, the effects of history on overall response rates and postreinforcement pausing. Both experiments showed that with continued exposure to a new schedule, effects of the previous one were progressively reduced. Also noteworthy was that these effects appeared independently of whether extinction was included in the history; Weiner (1969) had suggested that this procedure might facilitate adjustment to the new schedule. The differences emerged from our more detailed analyses of local rates and conditional probabilities: The high overall rates of the history animals accompanied well-differentiated response patterns within the intervals. This outcome, plus the absence of clear history–control differences in performance in our cumulative records, lead us to conclude that our results do not provide evidence of the "human-like" FI performances alluded to by Wanchisen et al. (1989) and Mazur (1994). But we also recognize that our experiment may not have been a sufficiently faithful replication of the earlier work. Indeed, it was a *systematic* replication that contained an assortment of procedural differences (most notably, we used liquid food as a reinforcer and employed a different deprivation procedure).

We are left, therefore, with the puzzle of why humans are so unresponsive to FI contingencies programmed in the laboratory. We can only agree with Wanchisen et al. (1989) about the hazards of attempting comparisons of human performances with those from experiments with rats. Despite the somewhat confusing picture painted by the results thus far, the hypothesis that conditioning histories play a vital role is compelling and surely warrants further investigation.

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