

*MOLAR AND MOLECULAR CONTROL IN
VARIABLE-INTERVAL AND VARIABLE-RATIO
SCHEDULES*

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Response rates are typically higher under variable-ratio than under variable-interval schedules of reinforcement, perhaps because of differences in the dependence of reinforcement rate on response rate or because of differences in the reinforcement of long interresponse times. A variable-interval-with-added-linear-feedback schedule is a variable-interval schedule that provides a response rate/reinforcement rate correlation by permitting the minimum interfood interval to decrease with rapid responding. Four rats were exposed to variable-ratio 15, 30, and 60 food reinforcement schedules, variable-interval 15-, 30-, and 60-s food reinforcement schedules, and two versions of variable-interval-with-added-linear-feedback 15-, 30-, and 60-s food reinforcement schedules. Response rates on the variable-interval-with-added-linear-feedback schedule were similar to those on the variable-interval schedule; all three schedules led to lower response rates than those on the variable-ratio schedules, especially when the schedule values were 30. Also, reinforced interresponse times on the variable-interval-with-added-linear-feedback schedule were similar to those on variable interval and much longer than those produced by variable ratio. The results were interpreted as supporting the hypothesis that response rates on variable-interval schedules in rats are lower than those on comparable variable-ratio schedules, primarily because the former schedules reinforce long interresponse times.

Key words: variable-interval schedules, variable-ratio schedules, variable-interval-with-added-linear-feedback schedules, molecular feedback, molar feedback, lever press, rats

Variable-ratio (VR) schedules deliver a reinforcer after every n th response, on average, with the mean of the response-reinforcer ratios defining the schedule. Variable-interval (VI) schedules deliver a reinforcer for the first response that follows the passage of n seconds, on average, with the mean required interval defining the schedule. Although these schedules are similar in that on both schedules reinforcers are delivered on a relatively unpredictable basis, VR schedules generally lead to higher rates of responding even when the rates and patterns of reinforcer delivery are similar (Baum, 1993; Catania, Matthews, Silverman, & Yohalem, 1977; Cole, 1994; Ferster & Skinner, 1957; Reed, Schachtman, & Hall, 1988; Skinner, 1938; Zuriff, 1970).

One explanation that has been advanced to account for the response-rate differences between VR and VI is that VI schedules tend

to reinforce long interresponse times (IRTs) because the mere passage of time leads to an increase in the probability of reinforcement. To the extent that responses with long IRTs occur on a VI schedule, they will then be reinforced (Anger, 1956; Ferster & Skinner, 1957; Hearst, 1958; Morse, 1966; Platt, 1979; Shimp, 1969) and come to predominate, thus reducing the rate of response. On the other hand, VR schedules do not have a tendency to reinforce differentially any particular class of IRT and hence do not favor the emergence of long IRTs with a consequent reduction in response rate (Ferster & Skinner, 1957; Morse, 1966). Baum (1989) has termed this type of explanation *molecular* because an event that can occur at a particular point in time, in this case the reinforcement of an IRT, is sufficient to effect a change.

A second explanation of the frequently observed higher response rates on VR relative to VI schedules takes note of the fact that on VR schedules there is a direct correlation between rate of response and rate of reinforcement (Baum, 1973, 1981, 1989; Rachlin, 1978; Rachlin & Burkhard, 1978; Staddon, 1979). According to such explanations, to the extent that an organism's behavior is governed by this cor-

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relation, response rate should tend to increase toward maximizing the rate of reinforcement. On VI schedules, however, according to such explanations, there is virtually no relation between rate of response and rate of reinforcement, except at very low rates of response. Thus, on VI schedules, assuming at least a moderate rate of response, there is little effect on reinforcement rate from an increased response rate (Baum, 1973, 1989; Rachlin, 1978). This type of explanation has been called *molar* by Baum (1973, 1989), because the effective variables—reinforcement rate and its dependence on response rate—are temporally extended phenomena. The response rate/reinforcement rate correlations themselves have been termed *molar feedback functions* (Baum, 1973, 1989; Nevin & Baum, 1980; Rachlin, 1978; Rachlin & Burkhard, 1978; Staddon, 1979).

There is some evidence that the reinforced IRT plays a major role in determining response rate in schedules that resemble VI schedules (e.g., Galbicka & Platt, 1986; Shimp, 1973). There is also a good deal of evidence that an animal's behavior is not sensitive to molar feedback in complex linear VI schedules that have a negative correlation between rate of response and rate of reinforcement (e.g., Ettinger, Reid, & Staddon, 1987; Vaughan & Miller, 1984) or in interlocking FR schedules that have a negative correlation between the size of the FR and response rate (Ettinger et al., 1987). Heyman and Tanz (1995), however, have recently shown that deviations from *matching* (i.e., *maximizing*) can be shaped in pigeons working on concurrent VI schedules. This was done by making delivery of a scheduled VI reinforcer contingent on birds showing deviations from the response allocations to the two keys that would constitute matching and by providing stimuli that signaled the degree of such deviations. In the absence of such performance feedback, however, it seems that the mere opportunity to engage in maximizing does not reliably lead to reinforcement-rate maximizing.

Peele, Casey, and Silberberg (1984) using pigeons on VR 200 and Cole (1994) using rats on VR 10 compared response rates on VR with those on yoked VIs in which either the minimum interfood intervals only, or both the minimum interfood intervals *and* the duration of the reinforced IRTs, were yoked to perfor-

mance on the VR. Peele et al. found that the yoking of both reinforced IRTs and interfood intervals to VR eliminated the differences in response rate seen when VR 200 was compared to the VI in which only interfood intervals were yoked to VR. They interpreted this finding as support for the hypothesis that VI-VR response-rate differences are due to the molecular action of the duration of the reinforced IRT. However, it should be noted that in the Peele et al. study, the equalization of VR and VI response rates that occurred when the reinforced IRT was yoked to VR performance was due more to decreases in VR response rate than to increases in VI response rate. Cole found that yoking reinforced IRTs as well as interfood times in VI to VR 10 performance led to response rates midway between the higher rates produced by VR and the lower rates generated by a VI schedule with interfood-interval yoking only. Cole concluded that these results suggested a role for both the response rate/reinforcement rate correlation and the duration of the reinforced IRT in determining response rates on VR and VI. A limitation of the research by both Cole and Peele et al. is that in each case only one parametric value for the VR was examined, thus limiting the generality of the findings.

McDowell and Wixted (1986) reported behavior on a synthetic schedule that they termed a *variable-interval-with-added-linear-feedback* (VI+LF) schedule. The schedule was a VI schedule to which was added a component designed to produce a correlation between response rate and reinforcement rate. The initial minimum interreinforcement intervals (IRIs) were generated by an algorithm originally reported by Fleshler and Hoffman (1962):

$$IRI_i = \bar{n}[1 + \ln N + (N - i)\ln(N - i) - (N - i + 1)\ln(N - i + 1)], \quad (1)$$

where IRI_i is the i th minimum IRI, \bar{n} is the scheduled mean IRI, N is the number of IRIs in the schedule, and i is any integer from 1 to N . Note that, when $i = N$, $IRI_i = \bar{n}(1 + \ln N)$. Thus, for example, when $N = 12$, $\bar{n} = 30$ s, and i is varied from 1 to 12, the algorithm yields 12 minimum interreinforcement intervals ranging from 1.29 s to 104.55 s, with a mean of 30 s.

McDowell and Wixted (1986) modified the

basic VI schedule produced by this algorithm by substituting an adjustable mean IRI (\overline{IRI}) in place of \bar{n} :

$$\overline{IRI} = \bar{n}(\overline{IRT}). \quad (2)$$

Equation 2 was used to compute a new value for \overline{IRI} after the second response in a session by multiplying \bar{n} by the mean interresponse time (\overline{IRT}) in seconds since the last reinforcer. After each and every response, this recalculated IRI was then substituted for \bar{n} in Equation 1 as follows:

$$\overline{IRI}_i = \overline{IRI}[1 + \ln N + (N - i)\ln(N - i) - (N - i + 1)\ln(N - i + 1)]. \quad (3)$$

Any response that occurred after the passage of this repeatedly readjusted \overline{IRI}_i was reinforced, and the recalculation of \overline{IRT} began with the second response following any reinforcer delivery. Thus, if the response rate was exactly 1 response per second, \overline{IRT} remained at 1.0, and as a result, $\bar{n}(\overline{IRT}) = \bar{n}$. But if, for example, the response rate were to increase to 2 responses per second, the value of \overline{IRT} would be halved, thus doubling the reinforcement rate. Conversely, if the response rate were to fall to, say, 0.5 response per second, the value of \overline{IRT} would double and the reinforcement rate would be halved.

McDowell and Wixted (1986) argued that these manipulations provide a VI schedule with a response rate/reinforcement rate correlation similar to that engendered by a VR schedule. At the same time, the linear feedback schedule functions like a VI schedule in favoring the reinforcement of long IRTs, because reinforcement is delivered for the first response following the passage of a time interval. Thus, McDowell and Wixted pointed out, this schedule provides a means of assessing the relative contribution of the duration of the reinforced IRT and of the response rate/reinforcement rate correlation in the determination of response rate.

McDowell and Wixted (1986) tested human subjects and arranged for monetary reinforcers to be scheduled by the VI+LF schedule with \bar{n} systematically set at 15, 30, 60, 120, and 240 s within each session. In a second phase, subjects were shifted to VR schedules in which the Fleshler and Hoffman (1962) equation was used to generate re-

sponse-reinforcer ratios instead of time intervals. Subjects responded for 10 min on each schedule with a 5-min rest between schedules. McDowell and Wixted reported no differences between the response rates generated by the VI+LF schedule and the comparable VR for all values of \bar{n} . They further reported no difference in the reinforcement rates generated by the VI+LF schedule and the VR schedule for any \bar{n} . McDowell and Wixted concluded that, because the VI+LF schedule generated response rates as high as those on the corresponding VR schedule, the duration of the reinforced IRT was not important in governing response rates on VI and VR but rather that the response rate/reinforcement rate correlation must be responsible for the differences. However, McDowell and Wixted did not report the durations of reinforced IRTs, so it is unclear how different those reinforced IRTs were among the schedules.

The present study was designed to extend the interesting research conducted by McDowell and Wixted (1986). One change was the inclusion of VI schedules so that it would be possible to compare response rates between two schedules (VI vs. VI+LF) that should generate similar distributions of IRTs but different correlations between reinforcement rate and response rate. Moreover, distributions of reinforced IRTs were measured in the present experiment. The current research also extended the work of McDowell and Wixted by using rats as subjects and food as reinforcers instead of adult humans obtaining points and money. It is possible that verbally competent humans might behave differently than nonhuman animals do on these kinds of schedules (Catania, Matthews, & Shimmoff, 1982). Thus, the present experiment compared the response rates and reinforced IRT distributions generated by a series of comparable VI, VR, and VI+LF schedules using rats as the experimental subjects.

METHOD

Subjects

Four experimentally naive albino rats of the Sprague-Dawley strain were maintained at 85% of their 150-day-old free-feeding weights by means of a food-restricted diet. They had unlimited access to water. The rats were

housed in individual cages and were treated in accordance with the ethical guidelines of the Canadian Council on Animal Care.

Apparatus

A Gerbrands operant conditioning chamber with interior dimensions of 29 cm by 23 cm by 19 cm high was used. The chamber had two levers, mounted on either side of the feeder wall, their centers 8.5 cm above the floor and 11.5 cm from the left and right side walls. Only the left lever, which required a force of about 0.44 N to depress completely, was operable, the right lever having been immobilized. The feeder tray was centered on the feeder wall just above the floor and was accessed through an opening (2.5 cm wide by 3.0 cm). A Gerbrands feeder dispensed 45-mg Noyes Formula A/1 rodent pellets to the feeder tray. The center of the cuelight was located 14 cm above the floor and directly over the feeder opening. The cuelight remained on except during pellet deliveries, when it was off for approximately 0.25 s. An Epson Apex Plus[®] computer connected to the chamber was used to program events in the chamber and to record relevant data.

Procedure

Hand shaping was used to shape a lever-pressing response to the right lever. Rats were then placed on a series of different schedules with three parametric values explored for each schedule. The Fleshler and Hoffman (1962) algorithm (Equation 1) was used to program VI intervals and VR ratios with $N = 25$ and $\bar{n} = 15, 30, \text{ or } 60$. In the case of the VI schedules, this equation yielded a minimum interreinforcement interval in seconds (IRI_i) for each value of i . In the case of the VR schedules, the equation was used to produce a response-reinforcer ratio for each value of i . In the case of the VI+LF schedule, the modified equation reported by McDowell and Wixted (1986) and shown as Equation 3 in the present paper was utilized to provide minimum interreinforcement intervals (IRI_i), the durations of which were dependent on response rate. However, because the VI+LF schedule failed to support behavior during initial exposure to this schedule for Rats 19 and 21, the VI+LF schedule was modified and the rats were eventually exposed to both versions. Although a VI+LF schedule leads to

higher reinforcement rates when the response rate increases beyond 1 response per second, it also leads to decreased reinforcement rates whenever the response rate falls below 1 response per second. In this regard, the VI+LF schedule is not directly comparable to a VR schedule. On VR, gains attained by rapid responding are consolidated and are never lost through pausing. That is, on VR a burst of responding brings reinforcement closer but a pause following that burst, although it does not render reinforcement more imminent, also does not cause it to become less probable. On the VI+LF schedule described by McDowell and Wixted, gains made through rapid responding are rapidly lost when the animal pauses. In the first phase of the present experiment, Rats 19 and 21 often took lengthy pauses which extended the minimum required IRI to a point at which recovery was essentially impossible and extinction occurred. A revised version of the VI+LF schedule (VI+LF-R) prevented the loss through pausing of gains made previously by rapid responding. This was accomplished by permitting the minimum required IRI to shorten when the response rate rose above 1 response per second, but once shortened the required IRI did not then lengthen when the response rate fell below 1 response per second. Thus, on VI+LF-R, within any interreinforcement interval, the longest IRI was always the shortest IRI that had been created to that point, based on response rate.

Sampling of the 25 possible intervals (ratios) used in each daily session was random, with replacement. Each rat was exposed to the schedules (VI, VR, VI+LF, and VI+LF-R) in a different order, but within each schedule the parametric values of \bar{n} (mean VI interval or mean VR ratio) were presented in the same order (15, 60, 30) for each rat and for each schedule. Each type of schedule was in effect for 60 sessions, with 20 sessions devoted to each parametric value. Sessions were 30 min long. Table 1 shows the order of presentation of schedules for each rat over the entire experiment.

RESULTS

Figure 1 shows the response-rate data that constitute the primary results of the experiment. In order to permit an examination of

Table 1
Order of schedule presentations.

Rat	Phase 1	Phase 2	Phase 3	Phase 4
18	VI + LF	VI	VI + LF-R	VR
19	VI	VI + LF	VI + LF-R	VR
20	VI + LF	VI	VR	VI + LF-R
21	VI	VI + LF	VR	VI + LF-R

the relationship between response rate and reinforcement rate, the data are plotted as a function of *obtained* reinforcement rate. In general, the results for individual rats are representative of the averaged data. Setting aside the results for the VI+LF schedule which did not support behavior very well for 2 of the 4 rats, the data from the VI, VR, and VI+LF-R schedules are instructive. The averaged data show that response rates on VI+LF-R were similar to those on VI and lower than those on VR at all values of \bar{n} . The difference in response rate between VR on the one hand and VI and VI+LF-R on the other hand is most clearly seen when $\bar{n} = 30$. With the ex-

ception of Rat 21, these trends are also reflected in the data plots for individual rats. Moreover, the effect does not appear to be a result of reinforcement rate. The averaged data reveal that the three-point schedule curves are more or less aligned above one another and are not systematically horizontally displaced, as would be the case if the schedules had very different reinforcement rates. Again, with the exception of that for Rat 20, the individual data plots are in agreement with the averaged data.

As Figure 2 shows, the VR schedules also led to substantially shorter reinforced IRTs than did the VI and VI+LF-R schedules. This

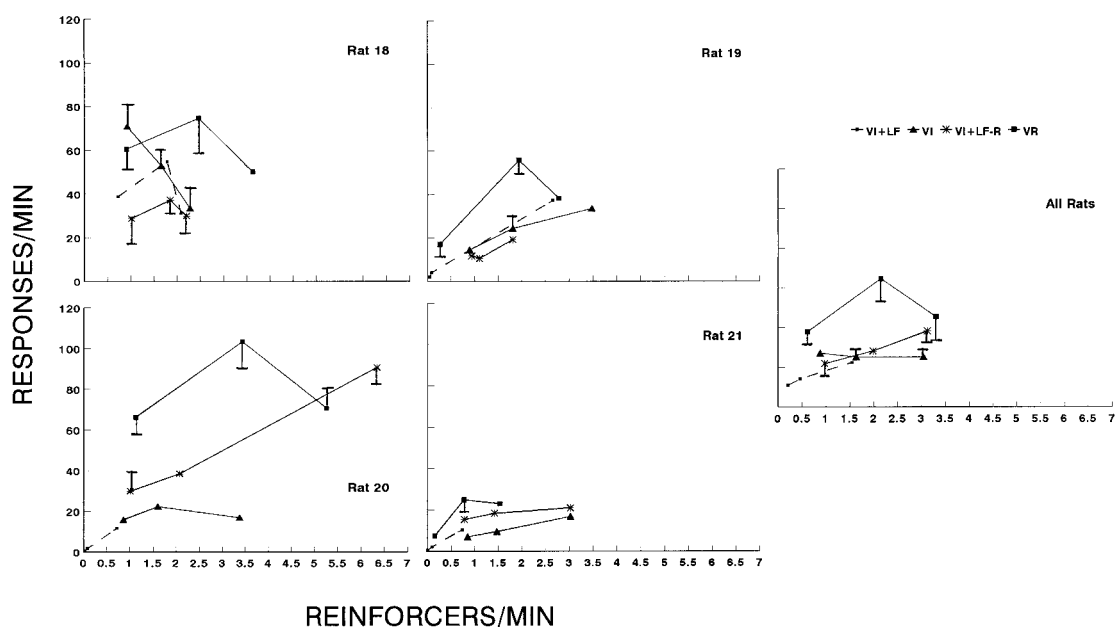


Fig. 1. Means of sessional response rates from the last five sessions on VR, VI, VI+LF, and VI+LF-R schedules as a function of obtained reinforcement rate with $\bar{n} = 15, 30$, and 60 for each schedule. Data for individual rats appear in the left panels, and data averaged over all 4 rats appear in the right panel. With one exception, for each set of connected points representing VI, VR, and VI+LF-R, the leftmost data point (the lowest reinforcement rate) corresponds to $\bar{n} = 60$, the middle data point to $\bar{n} = 30$, and the rightmost data point (the highest reinforcement rate) to $\bar{n} = 15$. For Rat 19, the middle data point for VI+LF-R represents VI+LF-R 15 s and the rightmost data point represents VI+LF-R 30 s. The vertical bars represent standard errors of the mean >2.0 responses per minute.

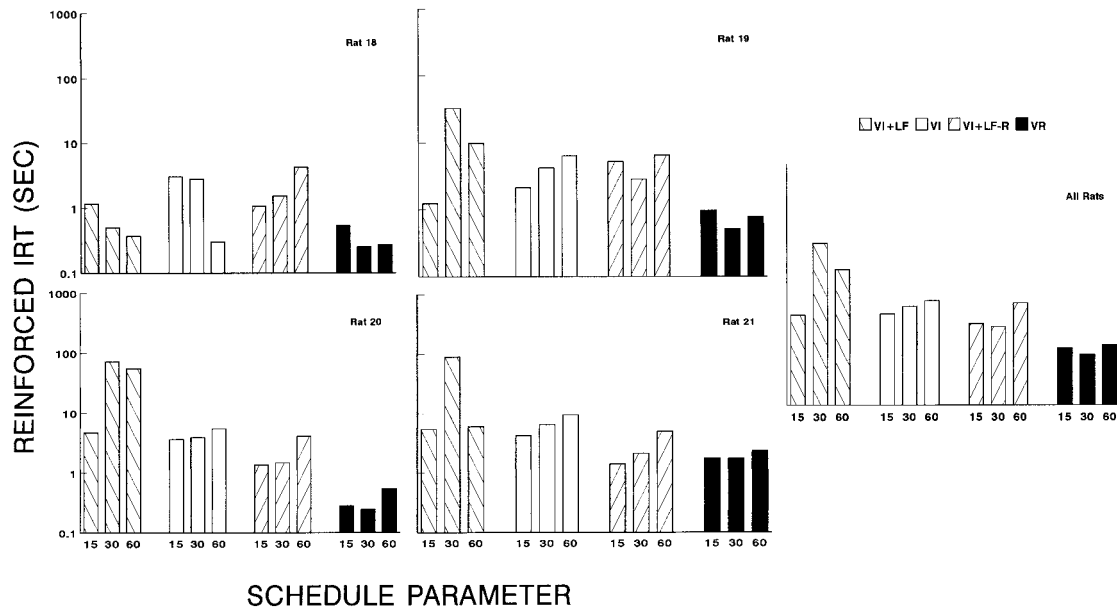


Fig. 2. Means of median sessional reinforced interresponse times from the last five sessions on VR, VI, VI+LF, and VI+LF-R schedules and for values of \bar{n} = 15, 30, and 60 for each schedule. The vertical axis is represented in logarithmic units. Data for individual rats appear in the left panels, and data averaged over all 4 rats appear in the right panel.

trend is apparent for all rats and for the averaged data. In addition, there do not seem to be any differences in the duration of the reinforced IRTs when the VI and VI+LF schedules are compared.

Figure 3 shows the dependency of reinforcement rate on response rate in the form of scatter plots. Those for VR show that the data tend to follow a straight line with positive slope for VR 15, VR 30, and VR 60, as would be expected when there is a direct response rate/reinforcement rate correlation (Baum, 1973). Conversely, the data points in the VI scatter plots tend to follow fairly flat negatively accelerated functions, most clearly seen in the case of VI 30 s and VI 60 s, and as might be expected when there is little correlation between response rate and reinforcement rate except at very low response rates (Baum, 1973; Nevin & Baum, 1980). Of particular interest, however, are the response rate/reinforcement rate scatter plots for the VI+LF-R schedules. These tend to resemble the VR scatter plots in tending towards being linear rather than curvilinear like the VI scatter plots, although this is most clearly seen in the case of VI+LF-R 15 s and VI+LF-R 30 s.

As shown in Figure 4, especially when \bar{n} = 30 or 60, the VI and VI+LF-R schedules yield-

ed relatively flatter IRT distributions than those produced by the VR schedules, which tend to be sharply peaked at 0.2 or 0.3 s. Exceptions to this general pattern are seen in Rat 18 on VI and Rats 18 and 20 on VI+LF-R.

As an index of peaking at short IRTs on VR and of flatness of the distributions on VI and VI+LF-R at all values of \bar{n} , the bin containing the median IRT was determined. This statistic is reminiscent of a statistic called *quarter-life*, which Herrnstein and Morse (1957) used to measure curvature in the cumulative records generated by fixed-interval schedules of reinforcement. The data appear in Table 2. In general, the data from individual rats, although quite variable, are representative of the means for each schedule at each value of \bar{n} . For the VI and VI+LF-R schedules, with the exception of Rat 18 on all the VI schedules and Rats 18 and 20 on all the VI+LF-R schedules, it was usually necessary to go to bins containing IRTs well over 1.0 s in length to reach the median IRT. Conversely, in the case of VR, the median IRT duration was usually found in bins containing IRTs well under 1.0 s, except for Rat 21 whose IRTs on VR were uncharacteristically long.

On balance, both the overall and reinforced IRT distributions suggest that re-

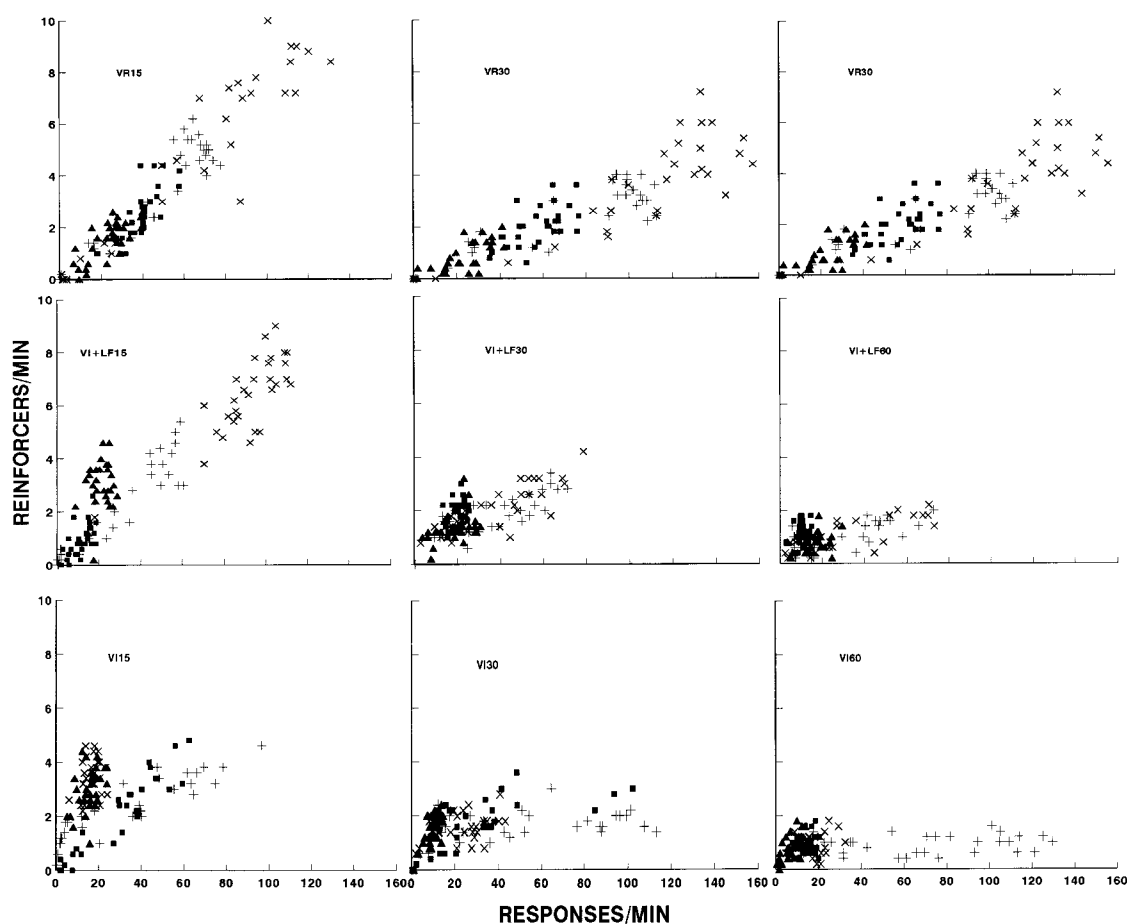


Fig. 3. Response rate plotted as a function of obtained reinforcement rate for successive 5-min segments of each 30-min session over the last five sessions for each of the 4 rats on VR, VI, and VI+LF-R schedules and for values of $\bar{n} = 15, 30,$ and 60 . The data points for Rats 18, 19, 20, and 21 appear as pluses, squares, Xs, and triangles, respectively.

sponding under the VI+LF-R schedule is more like that generated by VI than by VR schedules.

DISCUSSION

At the parametric values explored, the results of the present research reveal little support for the hypothesis that VR response rates are higher than VI response rates due to the molar feedback provided by the response rate/reinforcement rate correlation present on VR but largely absent on VI schedules. This is because, for the most part, response rates on VI+LF-R schedules were similar to those generated by VI and lower than those generated by VR schedules in spite of the presence of a response rate/reinforcement rate correlation on the VI+LF-

R schedule. This finding tends to support those from a number of other studies (e.g., Ettinger et al., 1987; Vaughan & Miller, 1984) that have failed to show that animals respond to response rate/reinforcement rate correlations by maximizing response rate. Studies that have found evidence for sensitivity to molar feedback have found only qualified support (Cole, 1994; McDowell & Wixted, 1986) or have involved situations in which performance feedback is provided and strong contingencies are arranged (Heyman & Tanz, 1995).

On the other hand, the data do show moderate support for the hypothesis that at the parametric values tested, VR schedules lead to higher response rates than VI or VI+LF-R schedules, due to reinforcement of long IRTs. With $\bar{n} = 15$ or 30 , except for Rat 18 at VI

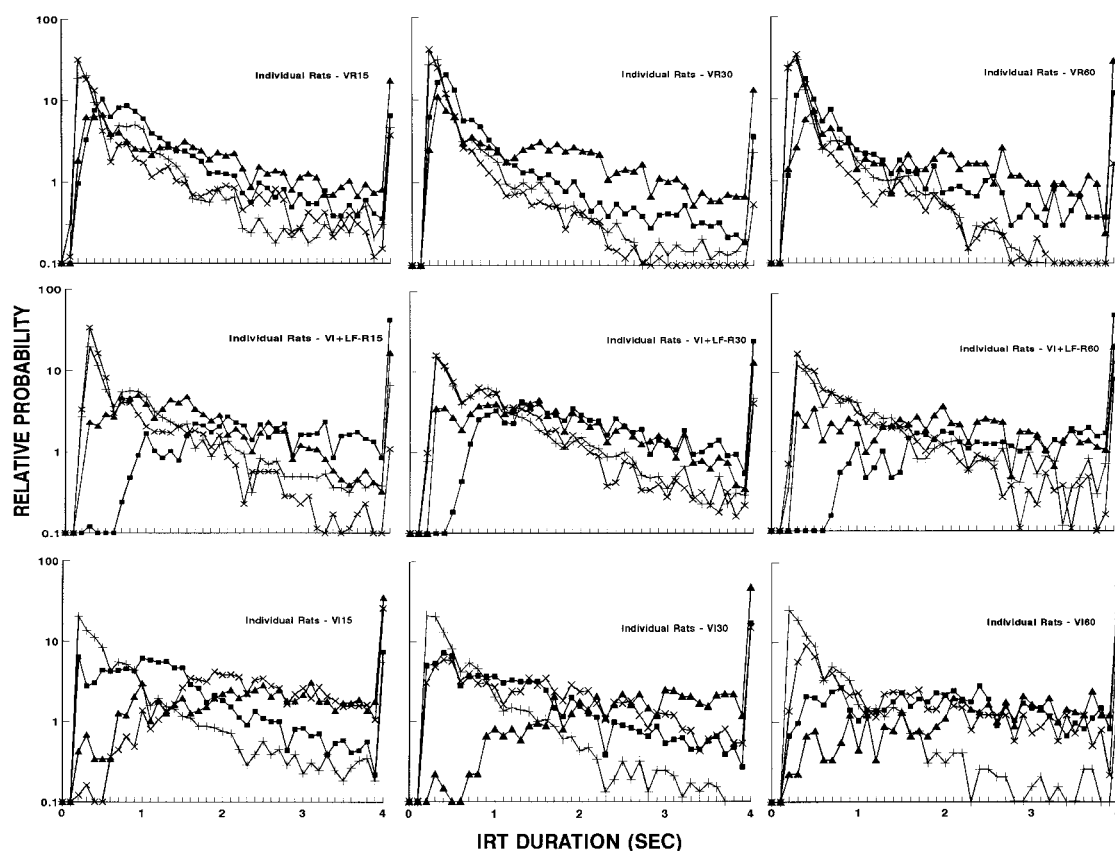


Fig. 4. Overall IRTs plotted in 0.1-s bins for all 4 rats on VR, VI, and VI+LF-R schedules for values of $\bar{n} = 15, 30$, and 60. The vertical axis is scaled in logarithmic units and shows the relative probabilities of IRT durations (bin counts as a percentage of total IRTs for each rat on each schedule). The data points for Rats 18, 19, 20, and 21 appear as pluses, squares, Xs, and triangles, respectively.

15, VR led to higher response rates than the VI schedules, including VI+LF-R, which possessed a response rate/reinforcement rate correlation comparable to that on VR. Only at $\bar{n} = 60$ was the general superiority of VR over VI in terms of response rate compromised. For Rat 18, VR 60 led to lower response rates than VI 60 s; for Rat 21, VR 60 led to a response rate nearly equal to that produced by VI 60 and lower than that generated by VI+LF-R 60 s. It should be noted that VR 60 in the present study was a demanding schedule, the largest ratio of which was 253:1, and these large ratios may have led to ratio strain (Baum, 1993; Ferster & Skinner, 1957), especially in Rat 21.

In further support of the conclusion that at least at the smaller parametric values, the superiority of VR over VI was due to reinforcement of long IRTs, are the IRT data

themselves. Both the VI and the VI+LF-R schedules led to reinforced IRTs nearly four times longer than those produced by the VR schedule. To the extent that longer IRTs, once having been produced, were then reinforced and thus came to replace shorter IRTs throughout the session, such an extension of IRT duration would be sufficient to explain the response-rate data. The VR 30 response rate was more than double that on the comparable VI schedules, whereas the VR 15 response rate was almost double that seen on the comparable VIs. The exception to the general findings with respect to reinforced IRTs were the results from Rat 18, whose reinforced IRTs were short on all the schedules, even on the original VI+LF, which failed to support behavior for the other rats (except at VI+LF 15 s).

Adding support to this general interpreta-

Table 2

The 0.1-s IRT bin containing the median IRT for individual rats and for all rats for each of VI + LF-R, VI, and VR with $\bar{n} = 15, 30, \text{ and } 60$.

Schedule	50th percentile				
	Rat 18	Rat 19	Rat 20	Rat 21	All rats
VI + LF-R 15	0.8	3.9	0.4	1.6	1.3
VI + LF-R 30	0.9	2.4	0.8	1.7	1.3
VI + LF-R 60	1.0	4.0	0.7	2.4	1.9
VI 15	0.5	1.2	2.7	3.1	1.8
VI 30	0.4	1.3	1.6	4.0	1.5
VI 60	0.4	3.0	1.7	4.0	2.1
VR 15	0.5	0.9	0.3	1.5	0.7
VR 30	0.3	0.5	0.2	1.4	0.4
VR 60	0.3	0.7	0.3	2.1	0.5

tion are the overall IRT distributions themselves. For the most part, they supported the conclusion that on VI schedules, shorter IRTs do not predominate. Rather, the IRT distributions on both VI and VI+LF-R were generally fairly flat. This may be due to reinforcement of long IRTs, although the distributions in and of themselves do not prove this. The VI and VI+LF-R IRT distributions may be contrasted with the IRT distributions for the VR schedules in which short IRTs were more prevalent.

The response rate/reinforcement rate data shown in Figure 3 suggest, however, that although the VI+LF-R schedule is like a VI schedule in some respects, its feedback function (Baum, 1973) is that of a VR schedule. This supports the argument that the VI+LF schedules are indeed VI schedules with an added response rate/reinforcement rate correlation, even though the evidence suggests that this correlation did not lead to faster response rates in the present experiment.

In short, the reinforced IRT data in Figure 2 suggest that the VI+LF-R schedule functions like a VI schedule in differentially reinforcing long IRTs, and the response rate/reinforcement rate data in Figure 3 suggest that there is a response rate/reinforcement rate correlation in the VI+LF-R schedules. These observations, coupled with the fact that the VI+LF-R schedules did not lead to response rates comparable to those supported by VR schedules, suggests a greater role for the reinforced IRT than for molar feed-

back in accounting for response-rate discrepancies on VR and VI.

The lack of correspondence between these results and those of McDowell and Wixted (1986) deserves some additional comment. In the absence of IRT data in the McDowell and Wixted study, it is difficult to comment on the role of the reinforced IRT in that research. Perhaps, as with Rat 18 in the present study, the humans in the McDowell and Wixted study simply responded rapidly on all the VR and VI+LF schedules. Long IRTs can be reinforced only if pausing occurs. Also, the absence of data from a normal VI in that study makes interpretation with respect to the role of IRTs more difficult. Finally, there may be significant differences in the way reinforcement schedules control behavior in humans and in rats (Catania et al., 1982).

The relationship between \bar{n} (15, 30, and 60) and rate of responding is also not in conflict with previous research. Felton and Lyon (1966) found that local response rates on fixed-ratio schedules tended to decrease as the ratio requirement was increased from 25 to 150. Baum (1993), using a multiple VR VI schedule with VI reinforcement rates yoked to the VR component, found that response rates in the VR component first increased as reinforcement rates increased from 0.33 reinforcers per minute to about 20 reinforcers per minute and then declined as reinforcement rate further increased from 20 reinforcers per minute to 60 reinforcers per minute. In the present data, response rate increased from VR 15 to VR 30 and then declined from VR 30 to VR 60 for all 4 rats. This occurred over a range of about 0.5 reinforcers per minute to about 4.0 reinforcers per minute. Catania and Reynolds (1968) found a general tendency for response rates in pigeons to decrease as the minimum required mean interfood interval on a VI schedule was increased from 15 s to 480 s. But within the range of interfood intervals that was explored in the present study, they found evidence of only a slight decline and then only in 2 of 6 pigeons. The other 4 birds in the Catania and Reynolds study showed virtually no change in response rate between VI 12 s and VI 45 s. Baum (1993) found a similar tendency in the yoked VI component of a multiple VR VI schedule over a comparable range of reinforcement rates. As was shown in Figure 3 in

the present data, there was little evidence of other than a relatively flat relationship between reinforcement rate and response rate on VI schedules over a range of reinforcement rates from about 1.0 per minute to about 3.0 per minute.

In conclusion, the present research is consistent with a body of literature that has not found widespread support for the influence of such molar variables as the response rate/reinforcement rate correlation underlying molar feedback functions, but has shown considerable support for the action of such molecular variables as the duration of the reinforced IRT in determining performance on schedules of reinforcement.

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