

BOUTS OF RESPONDING ON VARIABLE-INTERVAL SCHEDULES: EFFECTS OF DEPRIVATION LEVEL

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Rats obtained food pellets on a variable-interval schedule of reinforcement by nose poking a lighted key. After training to establish baseline performance (with the mean variable interval set at either 60, 120, or 240 s), the rats were given free access to food during the hour just before their daily session. This satiation operation reduced the rate of key poking. Analysis of the interresponse time distributions (log survivor plots) indicated that key poking occurred in bouts. Prefeeding lengthened the pauses between bouts, shortened the length of bouts (less reliably), and had a relatively small decremental effect on the response rate within bouts. That deprivation level affects mainly between-bout pauses has been reported previously with fixed-ratio schedules. Thus, when the focus is on bouts, the performances maintained by variable-interval schedules and fixed-ratio schedules are similarly affected by deprivation.

Key words: bouts, deprivation, satiation, log survivor plot, variable-interval schedule, key poke, rats

Responses that are maintained by variable-interval (VI) schedules of reinforcement sometimes occur in bouts (Baum, 2002; Baum & Rachlin, 1969; Blough, 1963; Conover, Fulton, & Shizgal, 2001; Davison, in press; Kirkpatrick, 2002; Kirkpatrick & Church, 2003; Mellgren & Elsmore, 1991; Nevin & Baum, 1980; Pear & Rector, 1979; Shull, Gaynor, & Grimes, 2001). In such cases, variables that affect response rate do so by acting selectively on particular aspects of bouts, and those variables can be classified based on which aspects of bouts they affect (Shull et al., 2001; Shull & Grimes, 2003; Shull, Grimes, & Bennett, 2004). For example, increasing the rate or the amount of the reinforcer increases response rate mainly by shortening the pauses between bouts and, less reliably, by lengthening the bouts. In contrast, imposing a small additional response requirement at the end of a VI (e.g., adding a small variable-ratio (VR) requirement) increases response rate mainly by lengthening bouts, not by decreasing the pauses between bouts. None of these variables has much effect on the rate of responding within bouts.

The purpose of the present experiment was to determine if deprivation level affects

response rate similarly to the way that reinforcer rate and amount do—that is, by altering the pauses between bouts and the length of bouts but not the within-bout response rate. One reason for thinking it might be that deprivation is widely viewed as an operation that alters the effectiveness of reinforcers (e.g., Heyman & Monaghan, 1987; Killeen, 1994; Michael, 1982; Smith, 1984). If deprivation functions that way, then the behavioral effects of deprivation should be similar to those of other operations that alter the effectiveness of reinforcers, such as changing the amount of the reinforcer. The results of the present experiment should help clarify the extent to which this, indeed, is the case.

The results of the experiment might also highlight some similarities between the performance generated by VI schedules and the performance generated by fixed-ratio (FR) schedules. Performance on FR schedules typically consists of a pause at the start of each ratio (the so-called postreinforcer pause) followed by a bout of high-rate responding that continues until the next reinforcer (Ferster & Skinner, 1957; Skinner, 1938). On FR schedules, variations in the amount of the reinforcer (Morse, 1966, pp. 80–81; Perone & Courtney, 1992; Powell, 1969) and variations in deprivation relevant to the reinforcer (Ferster & Skinner, 1957, Figures 52 & 53; Sidman & Stebbins, 1954) affect pause duration but have little effect on response rate within bouts (i.e., on the so-called running rate). As mentioned above, varying the

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amount of the reinforcer has a similar selective effect on responding maintained by VI schedules (Shull et al., 2001). Thus, regardless of whether responding is maintained by a FR or a VI schedule, varying the amount of the reinforcer appears to change response rate more by altering the pauses between bouts than by altering responding within bouts. The results of the present experiment should indicate whether or not this consistency between FR and VI performance holds as well when deprivation is varied. If it does, then the results would encourage the view that relations between reinforcer-effectiveness operations and performance are broadly consistent (e.g., across schedule type) when the focus is on the bout as the behavioral unit (Baum, 2002; Gilbert, 1958; Mechner, 1992; Premack, 1965; Shull et al., 2001, 2004).

METHOD

Subjects

The subjects were 7 male, Long Evans hooded rats, 3 comprising Squad G and 4 comprising Squad H. They were obtained from a commercial breeder as juveniles (about 150 g) and used initially as subjects in an undergraduate laboratory class for demonstrating basic behavioral processes such as shaping of lever pressing and acquisition of discrimination. During that time they were gradually (over several months) brought to a weight of about 335 g (± 15 g) and maintained at that level throughout the present project by free access to food blocks in their home cages for 1 to 1.5 hr after each daily session. Ator (1991) describes reasons favoring this method of food deprivation for rats over other methods. In particular, Ator notes, percentage free-feeding body weight usually is not a satisfactory method for controlling deprivation level because rats given unrestricted access to food will grow continuously throughout their lifetimes.

The rats' home cages were plastic boxes (460 mm long by 250 mm wide by 210 mm deep) with metal grate lids and with wood shavings covering the floor. They were kept in a room maintained at a temperature of about 22 °C and illuminated from about 6:00 a.m. until 6:00 p.m. each day; the experimental sessions were conducted during the lights-

on periods. The rats had continuous access to water in their home cages.

Apparatus

Each rat was assigned to one of four similar experimental chambers for the duration of the experiment. These chambers (Shull et al., 2004), located in a separate room from the home cages, were 300 mm wide by 320 mm deep by 300 mm high. They were constructed of sheet metal (top and three sides), clear plastic (rear door), and stainless steel rods (7 mm diameter) spaced 10 mm apart (floor). The reinforcers were food pellets (45 mg Noyes, Formula A, obtained from Research Diets, Inc.) delivered into a small metal food tray located behind a square opening (44 by 44 mm) in the middle of the front panel, 43 mm above the floor. The operation of the pellet dispenser produced a click, that was followed a fraction of a second later by a clinking sound from the pellet dropping into the metal tray.

The operandum was a translucent plastic key (a Lehigh Valley Electronics pigeon key), mounted behind a 19 mm diameter round hole through the left wall. The center of the key was 51 mm toward the rear of the chamber from the front wall and 62 mm above the floor. For a response to be recorded, the key had to be pushed a distance of about 1.5 mm (measured at the center) with a force of at least 0.18 N (three of the four chambers) or 0.3 N (the fourth chamber; Rat H3). A recordable response produced a brief click from a small snap-action switch connected to the key. When observed, each rat usually poked its key with its nose but occasionally with its paw. At the start of each session, the key was illuminated white from behind, and it remained illuminated until the end of the session.

A metal drinking spout extended into the chamber through a small hole in the left wall near the back left corner (approximately 240 mm from the front wall and 25 mm above the floor). The spout, attached to a water bottle suspended outside the chamber, provided continuous access to water.

The four chambers were placed on a cart, two to a shelf. No attempt was made to shield any of the chambers from sounds made in the others; it was apparent that each rat quickly learned to go to its food tray only

when its own feeder operated. The four chambers operated concurrently, although out of phase.

The experimental sessions were conducted with the room darkened except for low-level light that entered from the corridor through a translucent window. The keylight provided the only other source of illumination in the chamber (i.e., there was no houselight or feeder light).

Four special-purpose computers (Walter & Palya, 1984), one for each chamber, controlled the experimental events and recorded the data. These computers were connected to a desktop computer for uploading programs and downloading data.

Procedure

Key poking was established by shaping—that is, by reinforcing successively closer approximations with food pellets. Following shaping, the rats in Squad H were exposed for several months to various VR schedules—training that was carried out for a project different from the present one. Then for the present project, the Squad-H rats were shifted to a VI 60-s schedule. After shaping, the rats in Squad G were given a few days' training on progressively longer VI schedules until the value reached was a VI 120-s schedule.

The design of the experiment was to generate baseline performance with the rats about 21 hours food deprived at the start of their daily sessions. Then after 20 such daily baseline sessions, the rats were given free access to food blocks in their home cages for the hour immediately before their next (21st) daily session. This *prefeeding* operation was intended to reduce the level of deprivation. A sequence of 20 baseline sessions followed by a prefeeding session was carried out with the VI set at 120 s (Squad G) and with the VI set at 60 s and then at 240 s (Squad H). Some details regarding the VI schedules and the daily sessions follow.

For the VI schedules, the first response (key poke) to occur after an interval of time elapsed was immediately followed by a food pellet. The first interval in each session was timed from the start of the session, indicated by the illumination of the keylight; all subsequent intervals were timed from the previous reinforcer. Each interval was selected randomly (with replacement) from a list of 16

that was constructed to provide the appropriate mean duration and to generate a roughly constant probability of reinforcement in time since the last reinforcer (Fleshler & Hoffman, 1962; Hantula, 1991), except that the shortest interval in the list was never longer than 4 s regardless of the mean VI.

Sessions were conducted 7 days per week, at about the same time each day. Each session (during which the key was illuminated) lasted for 2 hr or until 101 food pellets (at one food pellet per reinforcer) had been delivered, whichever occurred first. Based on visual inspection, total response rate typically appeared to stabilize before the 15th session.

During the last five baseline sessions of each condition and during the prefeeding session, the computer recorded the time of occurrence of every response and reinforcer. Interresponse time (IRT) distributions were derived from these times. The times were recorded in units of 0.01 s, but the actual resolving power of the system appeared to be about 0.1 s.

RESULTS

Baum (1993) showed that the postreinforcer pauses on VI schedules are functionally different from the other IRTs and suggested that it made sense, therefore, to exclude them when calculating response rate. Accordingly, in the following analyses of responding, all postreinforcer pauses, and the responses that ended them, have been excluded. (In fact, however, this exclusion had no practical effect in the present data set. When the VI is longer than about 60 s, the reinforcers are sufficiently infrequent that differences due to including or excluding the postreinforcer pauses are too small to be consequential—at least with rats and 45 mg food-pellet reinforcers [Shull et al., 2004].)

Table 1 lists the mean rates of key poking over the last five baseline sessions along with standard deviations to give some indication of day-to-day variability. For Squad H, the familiar (e.g., Baum, 1993; Catania & Reynolds, 1968; Dallery, McDowell, & Lancaster, 2000) positive relation between response rate and reinforcer rate is apparent.

Figure 1 shows that prefeeding was effective in reducing the rate of key poking for all the rats and under all three VI schedules.

Table 1

Mean responses per minute over the last five sessions before the prefeeding session, with the standard deviation in parentheses, for each rat and VI schedule.

Rat	VI Schedule		
	VI 60 s	VI 120 s	VI 240 s
G1		8.09 (1.80)	
G2		2.67 (0.57)	
G3		12.88 (2.04)	
H1	12.92 (1.74)		4.37 (1.54)
H2	9.21 (1.58)		2.83 (0.71)
H3	11.84 (0.63)		6.19 (0.95)
H4	53.76 (5.54)		10.97 (1.84)

Across rats and VI schedules, prefeeding reduced the rate of key poking to about a third ($M = 0.33$; range = 0.08 to 0.53) of the baseline rate. Because the y axis is logarithmically scaled, the slope of a line indicates the proportional reduction in key poke rate from baseline to the prefeeding session. There was no apparent effect of VI duration on the proportional reduction of response rate due to prefeeding, consistent with data from rats reported by Clark (1958). (Mean percentage decrease in responding at each VI was 36.8% [Squad H], 24.5% [Squad G], and 36.7% [Squad H], for the VI 60-, 120-, and 240-s schedules, respectively.)

The primary question prompting this research was whether prefeeding decreased response rate mainly by increasing the duration of between-bout pauses rather than by decreasing the within-bout response rate. To answer this question, it is necessary to have some method for determining whether responses occur in bouts and for estimating characteristics of bouts such as the average between-bout pause. One method that is sometimes helpful for this purpose is to display the frequency distribution of IRTs as a log survivor plot (Berdoy, 1993; Conover et al., 2001; Fagen & Young, 1978; Machlis, 1977; Shull et al., 2001; Sibley, Nott, & Fletcher, 1990; for some limitations on the use of this method, see Davison, in press; Langston, Collett, & Silby, 1995; Slater, 1974; Tolcamp & Kyriazakis, 1999). A log survivor plot is a kind of cumulative frequency distribution showing the proportion of IRTs (logarithmic scale) that are longer than any duration, t .

The bout-like conception of responding implies that the frequency distribution of

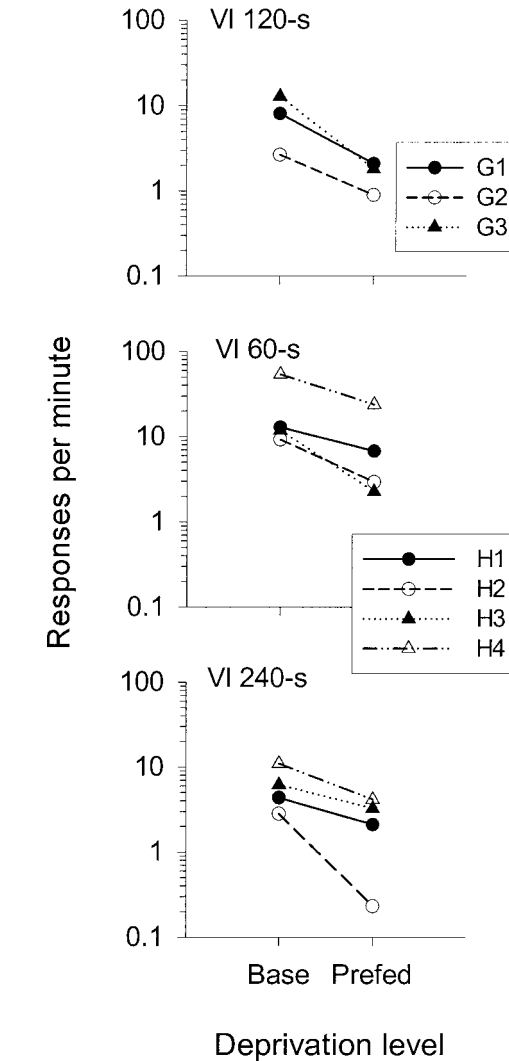


Fig. 1. The total rate of key poking (without the post-reinforcer pauses and the responses that ended them) for baseline (mean over the last five sessions) and the subsequent prefeeding session. Each pair of connected points indicates the data from 1 of the rats (Squad G, top panel; Squad H, lower two panels). The y axis is scaled logarithmically.

IRTs is actually composed of two distributions, one representing within-bout IRTs (which are short) and the other representing between-bout pauses (which may also be short but which are, on average, relatively long). Characteristics of these component distributions—and thus characteristics of bouts—can sometimes be inferred from the shape of the log survivor plot.

For example, a bout-like organization of re-

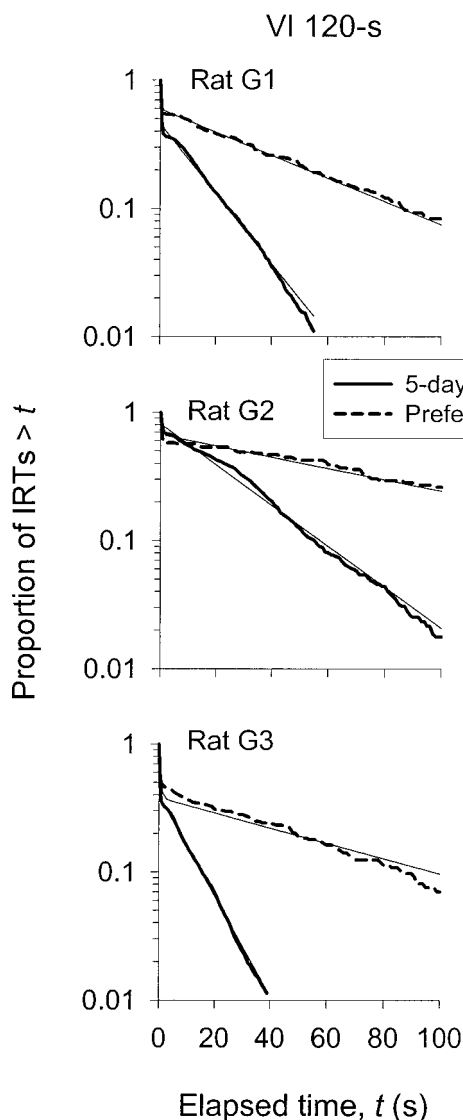


Fig. 2. Log survivor plots of IRTs from the rats in Squad G. The baseline plot ("5-day") is derived from combining all the IRTs (except for the postreinforcer pauses) from the last five baseline sessions into a single distribution. In each panel, the plot labeled "Prefed" is derived from the IRTs during the single session that immediately followed 1-hr access to food. The fitted smooth lines show the best-fitting sum of two exponentials (Equation 1), as described in the text.

sponses is strongly suggested by the log survivor plots for the rats in Squad G (Figure 2). (Ignore for the moment the thin lines; these are fitted functions that will be described shortly.) For both baseline and prefeeding, the plots appear to be composed of two

limbs, a steeply declining limb at the left and a more gradually declining limb at the right. The steep left limb is interpretable as representing a distribution composed mainly of within-bout IRTs but also of short between-bout pauses. The less steep right limb is interpretable as composed mainly of between-bout pauses.

For all 3 rats in Squad G, the effect of prefeeding was to make the right limb of the log survivor plot less steep. That is, prefeeding appeared to rotate the right limb upward. If the right limb is interpreted as representing the distribution of between-bout pauses, the upward rotation of the right limb indicates an increase in the relative frequency of long between-bout pauses and, hence, an increase in the mean between-bout pause.

In contrast to the large effect on the slope of the right limb, prefeeding had at most only a small decremental effect on the slope of the left limb. This result indicates that prefeeding had only a small effect on within-bout IRTs (and thus only a small decremental effect on the within-bout response rate, which is the reciprocal of the mean within-bout IRT).

One additional effect is apparent in the plots for Rats G1 and G3 (but not G2). Consider an imaginary line drawn to characterize the right limb and extrapolated left to intersect the y axis. This y -axis intercept is an estimate of the proportion of IRTs in the distribution that are between-bout pauses. The lower the intercept is along the y axis, the lower the proportion of between-bout pauses and, correspondingly, the higher the proportion of within-bout IRTs. Thus the lower the y -axis intercept, the larger the average number of responses per bout. For Rats G1 and G3, prefeeding appeared to shift the y -axis intercept of the right limb upward by a small amount; hence prefeeding reduced the average number of responses per bout (i.e., *bout length*) somewhat.

Thus simply from inspecting the log survivor plots it is apparent that prefeeding reliably lengthened the mean between-bout pause (indicated by the slope of the right limb), sometimes decreased bout length, and had little effect on within-bout response rate (suggested by the slope of the left limb). It is possible, in addition, to generate quantitative estimates of these features of bouts based on

inferring or assuming the forms of the component distributions.

Probably the simplest assumption is that bout initiations during pauses and within-bout responses during bouts occur randomly in time but at different rates. That is, during a between-bout pause the probability of initiating a bout is low and constant, and during a within-bout IRT the probability of a response is high and constant (cf. Killeen, Hall, Reilly, & Kettle, 2002; Shull et al., 2001). If so, the assumed component survivor distributions—one for between-bout pauses and the other for within-bout IRTs—would be approximated by negative exponential functions. With a logarithmic y axis, a negative exponential plots as a decreasing straight line. Thus each full log survivor plot (such as any of the plots in Figure 2) would, in effect, be constructed from two decreasing straight lines—a steep one at the left for the within-bout IRTs and a less steep one at the right for the between-bout pauses. More precisely, each full survivor plot would be approximated by the sum of two negative exponential functions (cf. Killeen et al., 2002), which may be written:

$$F_{(IRT>t)} = (1 - p)e^{-Wt} + pe^{-Bt}, \quad (1)$$

where $F_{(IRT>t)}$ is the proportion of IRTs longer than any given duration, t . The term to the left of the plus sign, $(1 - p)e^{-Wt}$, represents the component of the plot contributed by within-bout responding, and the term to the right of the plus sign, pe^{-Bt} , represents the component due to between-bout pauses. For both terms, e is the base of the natural logarithms, and t is elapsed time in units of the x axis. For the within-bout term, $1 - p$ represents the proportion of all IRTs that occur within bouts, and W is the rate of responding within bouts. For the between-bout term, p is the proportion of all IRTs that are bout initiations, and B is the rate of initiating bouts. The reciprocal of B , then, is the mean between-bout pause.

Equation 1 was fitted to the survivor plots, and the results of these fits are shown by the thin lines in Figure 2. For these fits, each baseline sample included all the IRTs during the last five sessions prior to prefeeding (excluding the postreinforcer pauses) that were 30 s or less plus any longer IRTs needed to ensure that the sample contained all but the

longest 1% of the distribution. Each sample from a prefeeding session was constructed the same way except that the IRTs were from a single session instead of five. The fits were carried out with a routine (“Exponential decay, double exponential, 4 parameters, reciprocal-y weighting”) provided by SigmaPlot® 8, a graphing program that uses an iterative process (100 iterations) to find values of the parameters that minimize the squared deviations from the function. For these fits, the coefficients, $1 - p$ and p , were constrained to sum to 1.0 because those terms represent the proportions of the two kinds of response that are assumed to comprise the distribution. The “reciprocal-y weighting” gives greater weight to deviations at low survivorship values than would be given without such weighting, which, in effect, is what the logarithmic scaling of the y axis does visually.

The best-fitting sum of two exponentials appears to match well the large-scale features of most of the log survivor plots in Figure 2. Importantly, with one exception, the right tails of the fitted functions correspond well to the right tails of the obtained log survivor plots. This correspondence is important because the right-tail slope is the basis for estimating the mean between-bout pause. The most evident discrepancy between fitted and obtained plots occurred with Rat G3’s prefeeding data. The reason for this discrepancy is that beyond 100 s, the prefeeding plot became negatively accelerated (i.e., more horizontal), which, in essence, rotated the right limb of the fitted function upward.

Figure 3 shows the results of these fits that are most relevant to assessing the effect of prefeeding on within-bout response rate (W) and mean between-bout pausing ($1/B$). To facilitate comparison of these two measures, bout-initiation rate (B) is plotted rather than its reciprocal ($1/B$); that way both measures are expressed as a response rate. For comparison, total key-poking rate is replotted from Figure 1. All three types of response rate were reduced by prefeeding but to different proportions of their baseline levels. Because the y axis is scaled logarithmically, the slopes of the lines indicate the proportional change from baseline. For all 3 rats, the proportional decrease due to prefeeding was larger for bout-initiation rate (open circles) than for within-bout response rate (triangles). Indeed,

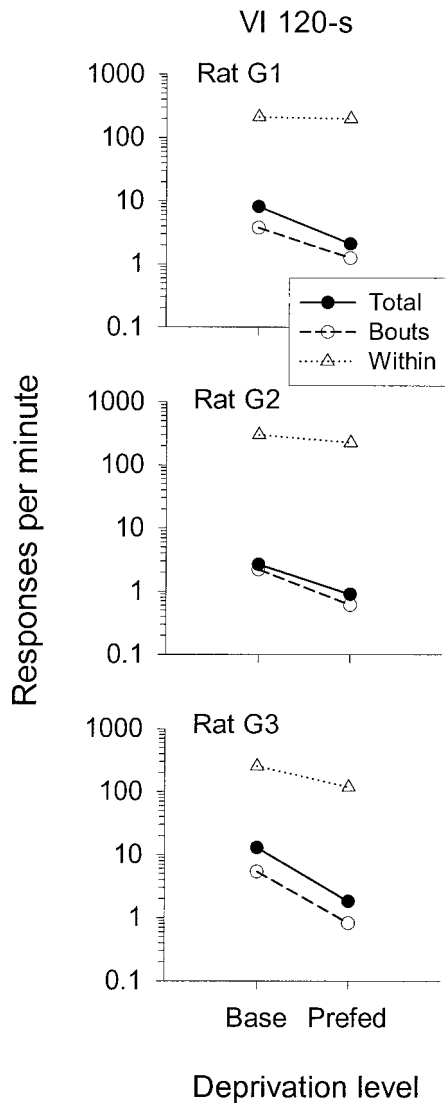


Fig. 3. Three different kinds of response rate (total key-poke rate, bout-initiation rate, and within-bout response rate) are shown for the baseline (last five sessions) and prefeeding conditions. The data are from the rats in Squad G. Bout-initiation rate and within-bout response rate were derived from the fits of Equation 1, as described in the text.

the proportional decrease in bout-initiation rate was similar to that for total key-poking rate (closed circles), indicating that changes in the former were largely responsible for changes in the latter. The results of the quantitative estimates thus confirm the main conclusions derived from inspecting the log survivor plots.

Figures 4 and 5 show the same analyses ap-

plied to the data from the rats in Squad H, obtained with VI durations of 60 s and 240 s. Again, from inspecting the log survivor plots (Figure 4) it is evident that prefeeding lengthened the mean between-bout pause (upward rotation of the right limb), occasionally reduced bout length (e.g., Rat H4), and had at most only a small decremental effect on the within-bout response rate (little effect on the slope of the left limb).

For the most part, the quantitative estimates from the fits of Equation 1 (Figure 5) supported these conclusions. There are, however, some exceptions and complications in the data from Squad H (Figures 4 and 5) that deserve comment.

First, two of the fits of Equation 1 failed to detect a distinct bout (Rat H1, prefeeding for VI 240 s, and Rat H2, prefeeding for VI 60 s). These failures appear in Figure 4 as an absence of a steep left limb in the fitted function despite a steep left limb (albeit a short one) in the corresponding obtained log survivor plot. Probably the short left limb provided too few data points for the fitting program to detect a distinct high-rate segment; and the downward bend of the right limb probably exacerbated the problem. In any case, because of the failures to detect a bout, no estimate of within-bout response rate could be obtained for these two log survivor plots. Hence two points for within-bout response rate (prefeeding) are missing in Figure 5 (Rat H1, VI 240 s and Rat H2, VI 60 s).

Second, some of the log survivor plots in Figure 4 had right limbs that deviated systematically from linear, and thus from a simple negative exponential. One kind of deviation is especially evident in the VI 60-s baseline plots for Rats H3 and H2 but is also evident in some other plots: Immediately to the right of the steep left limb, the plot is fairly flat for several seconds before declining. (Such patterns have been observed previously [Shull et al., 2004], most often when the mean VI was brief—i.e., 15 s or 30 s.) This pattern implies that the probability of reinitiating a bout is reduced for several seconds after the end of the last bout, resulting in fewer brief between-bout pauses than would occur with a true exponential distribution. Consequently, for these plots the estimates of bout-initiation rate from fits based on assuming an exponential distribution (i.e., the values of B from fits

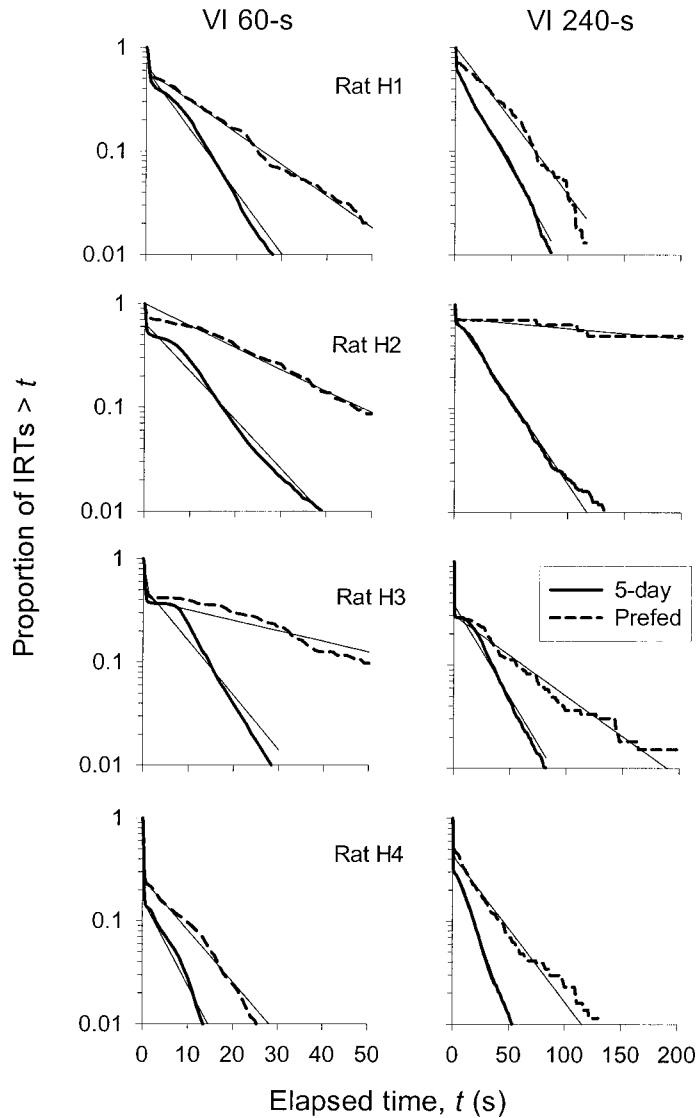


Fig. 4. Log survivor plots of IRTs from the rats in Squad H for the VI 60-s series (left column) and the VI 240-s series (right column). The baseline plot (“5-day”) is derived from combining all the IRTs (except for the postreinforcer pauses) from the last five baseline sessions into a single distribution. In each panel, the plot labeled “Prefed” is derived from the IRTs during the single session that immediately followed 1-hr access to food. The fitted smooth lines show the best-fitting sum of two exponentials (Equation 1), as described in the text. Note the different x -axis scaling for the left and right columns.

of Equation 1) are likely higher than they should be. These deviations do not, however, compromise the conclusion that prefeeding increases the mean between-bout pause, only the precision of the quantitative estimates.

Third, for Rat H4 prefeeding reduced the estimated values of within-bout response rate and bout-initiation rate by about the same proportion from baseline: with the logarithmic

y axis in Figure 5, the lines for these two kinds of response rate are nearly parallel. These data from Rat H4 are, then, exceptions to the claim that prefeeding affects response rate primarily by increasing the between-bout pauses.

The fits of Equation 1 provide imperfect estimates of within-bout response rate. For one thing, they are based on assuming a sim-

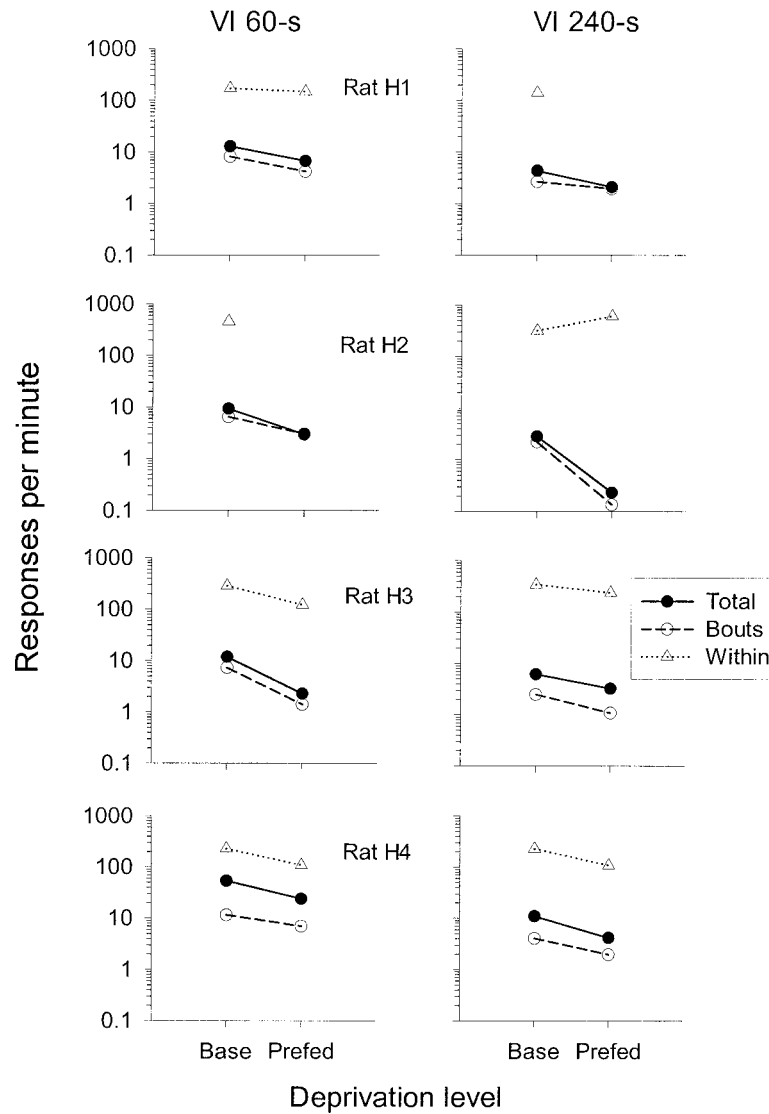


Fig. 5. Three different kinds of response rate (total key-poke rate, bout-initiation rate, and within-bout response rate) are shown for the baseline (last five sessions) and prefeeding conditions. The data are from the rats in Squad H for the VI 60-s series (left column) and the VI 240-s series (right column). Bout-initiation rate and within-bout response rate were derived from the fits of Equation 1, as described in the text.

ple negative exponential for the distribution of within-bout IRTs. That assumption might be reasonable as a first approximation, but it is implausible as an exact description. A negative exponential function declines continuously from 0, yet the physical requirement that the rat move its head to poke the key virtually precludes IRTs briefer than some above-zero minimum duration (Killeen et al., 2002; Palya, 1992). Consequently, the actual distribution likely contains fewer very short

IRTs than is implied by a true exponential. And that, in turn, means that W , from the fits of Equation 1, probably overestimates within-bout response rate.

It seemed desirable, then, to consider a different method of assessing the effect of prefeeding on within-bout IRTs and between-bout pauses—simply to insure that the main conclusions are not restricted to a particular method of estimating these characteristics of bouts. To this end, Figure 6 (for Squad G)

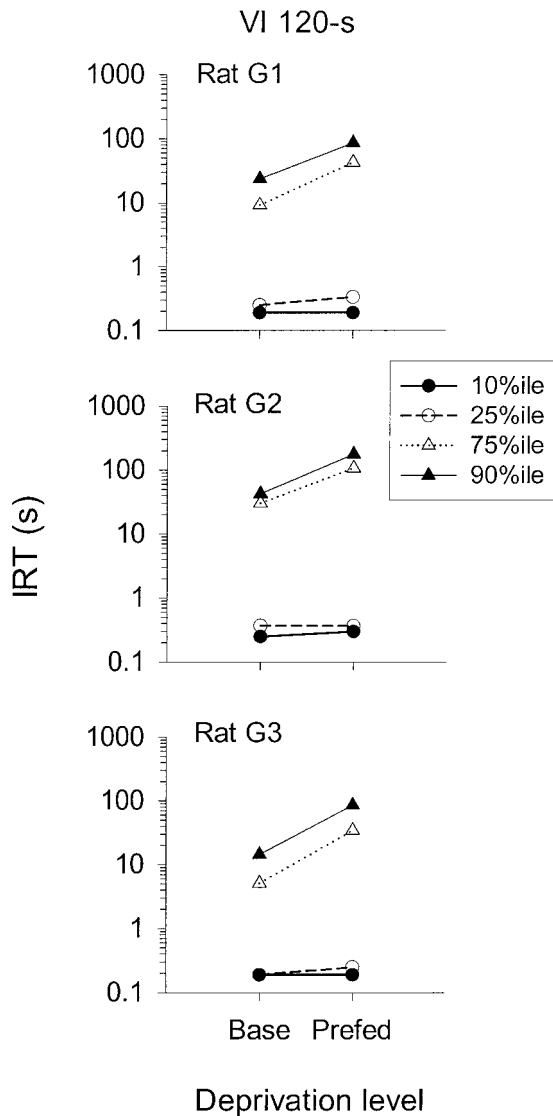


Fig. 6. The durations of IRTs at selected percentiles are shown for baseline and prefeeding conditions from the rats in Squad G (VI 120 s).

and Figure 7 (for Squad H) show the effect of prefeeding on selected percentiles of the cumulative frequency distribution of IRTs (the 10th, 25th, 75th, and 90th percentiles). The 10th percentile, for all rats, and the 25th percentile, for all rats except for H2, were in the steep left limbs of the log survivor plots (Figures 2 and 4). Thus those percentile values are heavily weighted toward the distribution of within-bout IRTs (except for Rat H2's 25th percentile). The 75th and 90th percen-

tiles all fall in the right limbs, and so come from the component of the distribution representing between-bout pauses.

For all rats (except for Rat H2), prefeeding increased IRT duration more relative to baseline for the 75th and 90th percentiles than for the 10th and 25th percentiles. (Again, because of the logarithmic y-axis scaling, slope indicates change relative to baseline.) For Rat H2, the 25th percentiles are in the right tails of the prefeeding log survivor plots (Figure 4). The 25th percentile IRT for Rat H2, then, should change similarly to the way that rat's 75th and 90th percentile values changed, as it did. The pattern of Rat H2's 10th percentile values was consistent with those for the other rats in showing relatively little change from baseline due to prefeeding. In short, the analysis of IRT percentiles supports the conclusion that prefeeding has a larger effect on between-bout pausing than on within-bout response rate.

DISCUSSION

As noted in the introduction, when responding occurs in bouts, variables that affect response rate on VI schedules can be grouped based on which components of bouts they affect. Some variables (e.g., reinforcer amount and rate) increase response rate mainly by reducing the pauses between bouts whereas other variables (e.g., adding a VR requirement) do so mainly by increasing the length of bouts (Shull et al., 2001, 2004; Shull & Grimes, 2003). From the present study, it appears that deprivation (at least as altered by single-session prefeeding) operates essentially the way reinforcer amount and rate do—that is, mainly by altering the between-bout pauses. Such consistency supports the view that reinforcer amount, reinforcer rate, and deprivation (but not adding a VR requirement) are functionally equivalent in their effect on response rate (e.g., Heyman & Monaghan, 1987; Killeen, 1994; Michael, 1982; Smith, 1984).

That responding on VI schedules occurs in bouts, at least sometimes, suggests one way that performance on VI schedules and performance on FR schedules might be similar. The differences between VI and FR performances are, of course, striking: FR performance is obviously bout-like (i.e., pause-and-

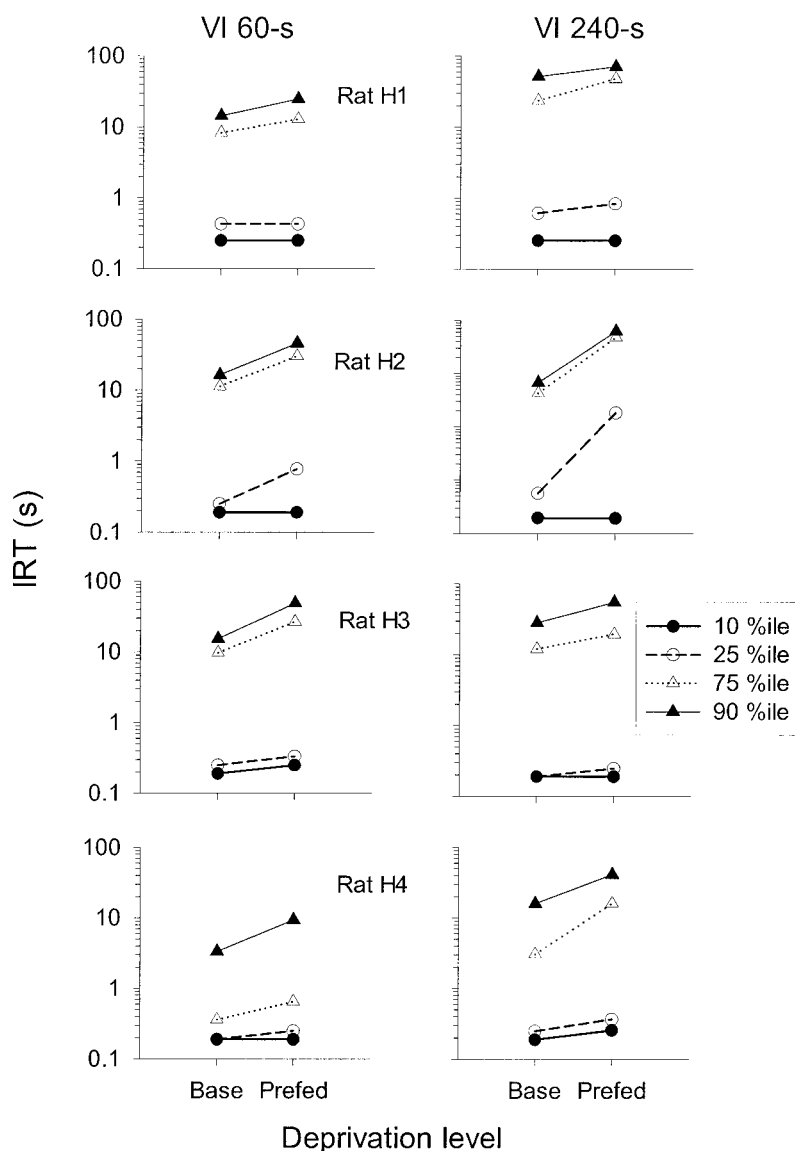


Fig. 7. The durations of IRTs at selected percentiles are shown for baseline and prefeeding conditions from the rats in Squad H for the VI 60-s series (left column) and the VI 240-s series (right column).

run) whereas VI performance is not (Ferster & Skinner, 1957; Lattal, 1991). Yet, if techniques are used to reveal the bout-like organization in VI performance, functional similarities between VI and FR performances can be striking as well. To appreciate these similarities, it is necessary to regard the “runs” of responses on FR schedules (which are evident in cumulative response records) as analogous to the bouts of responses on VI schedules that are revealed in the log survivor

plots, such as those in Figures 2 and 4. So regarded, the typical bout on FR schedules is the run of responses following the postreinforcer pause; thus the bout length is approximately equivalent to the FR size.

Altering the reinforcer amount or the deprivation level changes response rate on FR schedules mainly by altering the pauses between bouts—that is, by altering the postreinforcer pauses—and hardly at all by altering the within-bout (i.e., the running) response

rate (Ferster & Skinner, 1957; Morse, 1966; Perone & Courtney, 1992; Powell, 1969; Sidman & Stebbins, 1954). (Bout length is constrained by the size of the FR, so it is not free to vary with these variables.) By focusing on bouts, an analogous pattern of change is evident for performance on VI schedules due to altering reinforcer amount (Shull et al., 2001) and deprivation (the present study). Thus this kind of differential effect on between-bout pausing and within-bout responding holds across reinforcement schedules that otherwise appear to generate different patterns of responding (see also Mechner, 1992; Mechner & Guevrekian, 1962). Indeed, this kind of differential effect of reinforcer amount and deprivation holds for a variety of response types including consummatory licking by rats (Allison & Castellán, 1970; Davis, 1973; Davis & Smith, 1992; Steller & Hill, 1952) and both consummatory (Premack, 1965) and operant (Cotton, 1953) running by rats.

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