EFFECTS OF HUNGER AND VI VALUE ON VI PACING¹

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In two experiments, each involving four rats, responses preceded by an inter-response time between 8 and 10 sec in duration were intermittently reinforced. In Experiment I, final performance was compared under two hunger levels, while the frequency of reinforcement was held constant by a VI 5 schedule. In Experiment II, hunger was held constant and VI 3 was compared with VI 8. Both hunger and frequency of reinforcement increased the over-all rate of response, but the exact effects of these operations on temporal discrimination were different for different rats. Usually, a peak "response probability" (IRTs/Op ratio) was obtained 8 to 10 sec after the preceding response, indicating adaptation to the reinforcement contingency, but in some cases this peak was about 2 sec earlier. One rat exhibited unusually pronounced bursting which seemed to alternate with adaptive temporally spaced responding. Prolonged pauses, observable in the cumulative records, particularly following reinforcement, were attributed to the fact that inter-response times greater than 10 sec were not reinforced, so that as the interval of time since the preceding response became discriminably greater than 10 sec, the probability of a response became small.

The two present experiments involve VI schedules to which the contingency has been added that reinforced IRTs must be between 8 and 10 sec in duration (DRL 8 sec, limited hold 2 sec). Ferster and Skinner (1957) have called this procedure VI pacing. Pacing prevents hunger and frequency of reinforcement operations from indirectly affecting the durations of reinforced IRTs by means of their direct effects on performance. Anger (1955) discussed the possible effect of the lack of control of the durations of reinforced IRTs during conventional VI. In Exp. I, the final performance of each rat was compared under two hunger levels, while the frequency of reinforcement was controlled by means of a VI 5 schedule. In Exp. II, a high hunger level was used throughout and the final performance of each rat was compared for VI 3 and VI 8.

METHOD

Subjects

Eight male hooded rats, over 200 days old at the beginning of the experiments were

used. Their *ad lib* weights ranged between 431 and 510 gm.

Apparatus

Two rats were trained simultaneously in individual lever-pressing boxes. The boxes were 5.6 in. wide, 9.8 in. long and 6.8 in. high, inside dimensions, and had Plexiglas ceilings, aluminum walls, and steel tubing floors of the type described by Dinsmoor (1958). On the front panel, 3.9 in. above the floor, was a lever of the type described by Verhave (1958). The crossbar was a rod of steel, .25 in. in diameter and 2.5 in. long. From 18 to 22 gm of force on the lever opened a switch; the switch closed when the force was approximately 2 gm below the force required to open it. The lever operated a Potter and Bromfield KRP14DG relay mounted on a Plexiglas plate on the outside of the box near the front panel. Presumably the rat could hear this relay operate. An opening 1.1 in. below the lever, 2.8 in. wide and 1.3 in. high led into a food trough. A General Electric NE-58 neon light bulb ($\frac{1}{2}$ watt) was approximately 4 in. above the ceiling of the box, over a point approximately 4 in. from the front panel. Each box was enclosed in a lightproof and sound resistant chamber.

Depression of the lever reset a stepping switch; its release caused the stepping switch

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to move one step forward at fixed intervals. For the rats designated "A", these intervals were 2.05 sec in duration. For the rats designated "B", these intervals were 2.00 sec in duration except for the first interval after the preceding response, which ranged between 1.95 and 2.25 sec, with a mean between 2.05 and 2.1 sec. For convenience, the durations of all these intervals are referred to as 2 sec throughout this report. These stepping switch systems were used to record IRTs on counters and to control a DRL, limited hold contingency whenever reinforcement had been assigned by a VI tape programming system with a memory of two reinforcements. (Since the apparatus did not begin to measure time until the lever was released, these IRTs are release-press intervals, not the more usual press-press intervals.) After day 76 or 77 (depending on the rat), the timing system for the rats designated "B" became inaccurate; the first post-response interval was sometimes too short.

Procedure for Exp. I

High hunger is defined as approximately 21 hr of food deprivation at the start of a lever-pressing session and maintenance at 70% *ad lib* weight. Low hunger is defined as 2.5 hr of food deprivation and maintenance at 85% *ad lib* weight. Rats A_{HI-LO} and B_{HI-LO} received prolonged high hunger training followed by prolonged low hunger training. For A_{LO-HI} and B_{LO-HI}, the counterbalanced procedure was used. Pre-training and training sessions were 2 hr in duration throughout the experiment and administered daily.

Rats A_{HI-LO} and B_{HI-LO} received four pre-training sessions under high hunger; the lever was absent and the food magazine delivered 97 mg. Noyes pellets (which were used as reinforcers in both experiments) on a VI 5 schedule. On day 1 (of lever press training) after approximately eight continuous reinforcements of DRL 8 sec, DRL reinforcement was programmed by a VI 5 schedule. On day 5, limited hold 4 sec was added to the reinforcement contingency. On day 11, the limited hold was reduced to 2 sec and there were no subsequent changes in the reinforcement schedule. On day 51, transition was made to low hunger by giving the rats *ad lib* access to powdered chow from 4 hr after one experimental session until 2.5 hr before the next experimental session for as long as was neces-

sary to establish 85% *ad lib* weight. Then, each ration was first given to the rat 3.5 hr before the experimental session and removed after 1 hr; any food not consumed within that hour was returned 4 hr after the session. Training was discontinued after day 85.

The A_{LO-HI} and B_{LO-HI} procedure differed from the above procedure only in the following respects. The first magazine pretraining session was under 2.5 hr deprivation but 70% body weight; then, transition was made to the 85% *ad lib* weight component of low hunger in the previously described manner. After day 50 of lever press training, transition was made to high hunger by not feeding the rats except in the lever pressing apparatus until their weights were slightly below 70% *ad lib*.

Procedure for Exp. II

High hunger, as defined previously, was used throughout. At least one, 2-hr session was administered per day; during early training under low frequency of reinforcement, an additional 3-hr session beginning at 15.5 hr of deprivation was added. Magazine training and introduction of the DRL, limited hold contingency were as in Exp. I. For A₃₋₈ and B₃₋₈, days 1-50 involved VI 3 and days 51-85 involved VI 8; during days 51-54, a 3-hr session was administered in addition to the 2-hr session. For A₈₋₃, days 1-50 involved VI 8, and days 51-85 involved VI 3; days 1-25 included an additional 3-hr session. B₈₋₃ was substituted for a rat that died on day 13. On that day, transition from *ad lib* weight to high hunger began, and lever press training was introduced without magazine pretraining. On day 13, after approximately eight continuous DRL 8 sec reinforcements, VI 8 was added to the contingency. On day 15, limited hold 10 sec was added. On day 23, the limited hold was reduced to 4 sec, and further reduced to 2 sec on day 24. Until day 31, two sessions were administered per day; then the A₈₋₃ procedure was used.

Data Analysis

The subject matter of each experiment is final performance. For both experiments, this was defined, *a priori*, as performance on days 36-50 and 71-85; *ex post facto*, this definition seemed reasonable in view of the stability of the data. However, circumstances forced omis-

sion of data for some of these days for some animals. For A_{HI-LO} , the data from days 39, 40, 42, and 43 were omitted due to experimental errors which did not seem to affect subsequent performance (see Revusky, 1961). Due to failures in the data recording system which did not affect the rats, day 37 was omitted for A_{3-8} , day 36 for A_{8-3} , and day 41 for B_{3-8} . Days 48-50 were omitted for A_{8-3} because he escaped from his home cage following the day 47 session and was found to be at 82% *ad lib* weight when recaptured. On day 50, his usual performance was recovered. Due to the defect in the timing apparatus, days 78-85 were omitted for the rats designated "B"; for B_{HI-LO} , day 77 was also omitted.

IRTs/Op is a statistic which estimates the conditional probability of a response between x and y sec after the preceding response, given that S spends x sec without responding; it is obtained by dividing the number of IRTs between x and y sec in duration by the number of IRTs greater than x sec in duration (Anger, 1955). This report will use a notation trivially different from Anger's; the interval of time bounded by x and y will be called band(x - y) and IRTs/Op for that band will be called IRT/Op(x - y). In the present experiments, where IRTs/Op is used to analyze the probability of response in different bands, inhomogeneity, which is a type of variability in performance (Anger, 1955), may distort the results. To reduce such distortion, three computational precautions were taken as follows: (a) Since behavior seemed most variable during the first $\frac{1}{2}$ hr of each session, IRTs during this $\frac{1}{2}$ hr were omitted. (b) Since the greatest remaining variability seemed to be between sessions, the IRTs/Op were calculated separately for each session; then the means over sessions were obtained. (c) IRTs following reinforcement were omitted because consump-

tion of the food pellet presumably alters the probability of a subsequent response. Except for A_{8-3} , such IRTs were usually greater than 20 sec in duration. Omitting such long IRTs tends to increase the IRTs/Op in all bands for which the upper bound is less than 20 sec; the amount of this increase is an increasing function of the time since the preceding response (Anger, 1955).

RESULTS AND DISCUSSION

Table 1 shows the mean rate of response for each rat in Exp. I during final performance under high hunger and final performance under low hunger. Table 2 shows corresponding data for Exp. II. It is apparent that addition of the pacing contingency to VI and consideration only of final performance did not eliminate the usual effects of hunger and frequency of reinforcement (Clark, 1958) on VI rate of response.

Figure 1 shows the IRTs/Op for each rat under each final performance condition in both experiments. As may be expected from the over-all rates shown in Tables 1 and 2, both hunger and frequency of reinforcement tend to increase the IRTs/Op, but visual inspection of the differences between pairs of curves for each S discloses no evidence of an effect of hunger or VI value on the *shape* of the IRTs/Op curve which is consistent for different rats. (Revusky, 1961, supplements this observation with statistical evidence.) This indicates that unequivocal control over the timing process was not obtained by the schedule of reinforcement. Since the reinforcement contingency did not specify the exact nature of the cues correlated with the passage of time ("clock", in the sense used by Sidman, 1956) which the animals could use, perhaps different animals used different clocks and

Table 1

Response Per Minute During
Final Performance Under Each of Two Hunger Levels

Rat	High Hunger	Low Hunger
A_{HI-LO}	3.8	.8
B_{HI-LO}	7.1	3.8
A_{LO-HI}	6.2	5.4
B_{LO-HI}	8.6	7.2

Table 2

Responses Per Minute During Final Performance
Under Each of Two Reinforcement Frequencies

Rat	VI 3	VI 8
A_{8-3}	4.5	2.1
B_{8-3}	7.0	6.9
A_{3-8}	68.6	12.8
B_{3-8}	3.5	2.1

Fig. 1. The IRT/Op curves for each rat during final performance, where only IRTs between 8 and 10 sec in duration were reinforced on a VI schedule. On the left above each pair of curves is the "name" of the rat that produced them. The designation "high" refers to VI 5 performance under a high hunger level; the designation "low" refers to VI 5 performance under a low hunger level. The VI value designations all refer to performance under a high hunger level.

these different clocks were differently affected by hunger and VI value. Unfortunately, the apparatus did not permit observation of the rats while these data were being collected to obtain information about the nature of these clocks. However, Wilson and Keller (1953) found that rats trained on a DRL schedule developed chains of collateral behaviors between lever depressions, which were maintained by secondary reinforcement because the occurrence of these chains insured that the IRTs would be long enough for reinforcement to be obtained; each of three rats exhibited a different sequence of collateral behaviors. Collateral chains have been found to occur during DRL performance of monkeys (Hodos, Morse, and Brady, 1962) and of humans (Bruner and Revusky, 1961). Bower (1961) also obtained such chains in rats by reinforcing runway responses immediately when the running time was relatively

long and after a delay when it was short. Clocks apparently not involving collateral chains have been reported by Anger (1955) and Kelleher, Fry, and Cook (1959). (After the data reported here were obtained, the wattage of the houselight was increased to allow observation of the rats. Much overt activity during the IRTs was observed, but the nature of this activity did not seem to remain constant from IRT to IRT. My impression was that the amount of this activity was far greater than would normally be obtained in a nonreinforced situation; presumably, each rat developed a variety of chains because the reinforcement contingency did not specify any single chain).

The curves of Fig. 1 usually show a relative peak at band (8-10), which was the reinforced band. The one instance (A_{HI-LO} , low hunger) where a peak occurs at band (10-12) may well be a sampling error. Two cases in which this

peak clearly occurs at band (6-8) are the present concern. The high hunger curve of B_{LO-HI} is based on six days, during each of which IRT/Op (6-8) was greater than IRT/Op (8-10); computation of the IRTs/Op was based on 2105 occurrences of band (6-8) and 737 occurrences of band(8-10). The VI 3 curve of A_{3-8} is based on 14 days, during each of which IRT/Op(6-8) was greater than IRT/Op(8-10); 2469 occurrences of band(6-8) and 1221 occurrences of band(8-10) were used. It seems unlikely that these peaks prior to the reinforced band are sampling errors, although previous experimentation involving DRL and DRL, limited hold (Anger, 1955; Sidman, 1956; Conrad, Sidman, and Herrnstein, 1958; Kelleher *et al*, 1959) has disclosed no instance of this peak failing to occur in the reinforced band during stabilized performance. (The reader should remember that we refer to the IRTs/Op, not the proportion of all IRTs.) These early peaks cannot be readily explained by hunger or VI value, since their failure to occur during low hunger may be due to chance. Two possible types of explanation deserve some consideration as follows.

(a) Inhomogeneity may artifactually produce an early peak (Anger, 1955). Inspection of the cumulative records with the assumption that inhomogeneity is an increasing function of observable variability in local rate within sessions has convinced me that it was no greater than usual when IRT/Op(6-8) was at a relative peak. In addition, examples of the distortion produced by great inhomogeneity are shown by Anger; such distortion does not seem great enough to produce as pronounced an artifactual peak as those obtained in the present instances.

(b) If collateral chains were the clocks used by the rats showing peaks at band(6-8), perhaps some type of least action principle may have made the chain usually emitted shorter than the reinforced chain by causing frequent omission of some segments of the reinforced chain. It may be objected that any least action principle should be most potent when motivation is low, but, as Wilson and Keller (1953) pointed out while describing one such least action principle applicable to the present experiments, a crucial matter is the strength of each segment of the collateral chain relative to lever pressing. How this relative strength is affected by hunger and VI value is not known.

The next concern is with the fact that all the curves of Fig. 1 show IRT/Op(0-2) to be greater than IRT/Op(2-4), so that there is a secondary peak in the IRTs/Op curves at band(0-2), although that band was never reinforced. Part of the reason for this is that band(0-2) begins with release of the lever; the rat is still on the lever and is in good physical position to respond. By the time band(2-4) begins, the rat is likely to have withdrawn from the lever. In the case of A_{8-3} , the difference between IRT/Op(0-2) and IRT/Op(2-4) is so large that it seems likely that additional factors are also in operation. Figure 2 contains cumulative records of lever depressions for typical 2 hr sessions for A_{8-3} and for B_{8-3} during VI 3 and VI 8; the pips indicate reinforcements. A_{8-3} 's records are very different from those obtained from any other animal in either experiment; B_{8-3} 's records are fairly typical. A_{8-3} characteristically alternated between a low rate of response showing good adaptation to the reinforcement contingency, and an extremely high rate or "burst" (Sidman, 1956). When the wattage of the houselight was increased after the experiment,

Fig. 2. Cumulative records for A_{8-3} and B_{8-3} , where the pips indicate reinforcements. All of these records show final performance under high hunger and the indicated VI value when only IRTs between 8 and 10 sec are reinforced. The records produced by A_{8-3} are different in appearance from those produced by the other rats.

$A_{8.3}$ ceased bursting and when the wattage was reduced to its initial value, the bursting was not recovered. The IRTs/Op in bands other than band(0-2) were not greatly affected by these bursts because the latter rarely included pauses long enough to permit these bands to occur, except that it seems possible that IRT/Op(2-4) was greater than IRT/Op(4-6) during VI 3, because band(2-4) occasionally occurred during bursts. Since it is only because $A_{8.3}$'s bursts were extremely pronounced that they are readily distinguishable from responding at a low rate, it is possible that similar but far shorter bursts also helped increase IRT/Op(0-2) for some of the other rats. Bursting, in the sense of a large value of IRT/Op(0-2) during DRL performance, has been obtained by Anger (1955), Sidman (1956), Conrad *et al* (1958), Brady and Conrad (1960), and Ayers and Thompson (1961). In addition, Ferster and Skinner (1957, p. 499, p. 551), obtained bursts under VI pacing very similar to those produced by $A_{8.3}$; they considered these bursts to be breakthroughs of a VI performance which, under their experimental conditions, may have been in S's repertoire. Kelleher *et al* (1959), have suggested that bursts may be artifactually reinforced if S fails to cease responding after a first response has produced reinforcement; $A_{8.3}$'s bursts are not due to any such process because E's inspection of Esterline Angus operations records for the last 90 min of each rat's daily performance past day 30 disclosed no instance of a second response immediately following a reinforced response. A similar observation has been made by Ayers and Thompson (1961). Nor does Sidman's (1956) explanation that bursting occurs because a single response fails to reset S's clock seem likely in the case of $A_{8.3}$, since frequently over 100 responses were emitted in a single burst. A cognate explanation that bursting may be due to the breakdown of collateral chains (either observable or nonobservable) which presumably control the durations of IRTs seems more probable, although it is not easily testable.

A prolonged pause following reinforcement was characteristic of all the rats except $A_{8.3}$ and is prominent in the cumulative records of $B_{8.3}$ shown in Fig. 2. A similar pause was obtained by Ferster and Skinner (1957, p. 499) under VI pacing. As two successive reinforce-

ments frequently were available, it seems best to attribute this pause to the presumed fact that eating the 97 mg. pellet and behaviors elicited by eating required over 10 sec which, of course, precluded reinforcement of the following response due to the limited hold. ($A_{8.3}$ frequently was reinforced for two successive lever depressions; presumably, he ate faster than the other rats.) More generally, as the interval of time since the preceding response becomes long enough to generate cues correlated with nonreinforcement, the probability of a response becomes low. Therefore a failure to respond for much over 10 sec is likely to result in a prolonged pause, no matter what causes the initial failure to respond. Such pauses which were not initiated by reinforcement were occasionally exhibited by all the rats and are particularly prominent in the VI 8 cumulative record of $B_{8.3}$ shown in Fig. 2. It seems likely that addition of the limited hold to the DRL contingency reduced over-all rate of response by producing these prolonged pauses. This is paradoxical because the limited hold increased the rate of response preceding reinforcement by preventing reinforcement of IRTs greater than 10 sec in duration. An analogous effect has been suggested by Herrnstein and Morse (1958).

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