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BRAIN STIMULATION AS A REINFORCER: INTERMITTENT SCHEDULES[1]

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Rats with chronically implanted, bipolar electrodes in the septal and medial forebrain bundle areas, in addition to the region of the mammillary bodies of the posterior hypothalamus, were trained to press a permanently mounted lever in order to produce a second, retractable lever. Rewarding brain stimulation was programmed on the retractable lever; following completion of the programmed number of CRF response-stimulations, that lever was retracted from the box. Responding on the permanent lever could reintroduce the retractable lever. Fixed interval, fixed ratio, DRL, and variable interval schedules were programmed on the permanent lever in the range of schedule parameters often used with conventional reinforcers. Typical effects are described, and it is concluded that there are no striking differences between brain-stimulation reinforcement and the conventional reinforcers.

It is well-known that electrical stimulation of certain subcortical brain sites can serve as a reinforcer. Much of the research on brain-stimulation reinforcement (BSR) over the past 10 years or so has been concerned with (a) the mapping of various loci which produce reinforcing effects when stimulated, (b) the analysis of brain-stimulation phenomena, and (c) theoretical attempts to integrate many of the research findings. Olds (1962) has summarized a substantial portion of those efforts. See also Stein (1964) and Deutsch (1963) for representative theoretical attempts.

While operant conditioning techniques have been prominent in much BSR research, it is unfortunately true that behavioral considerations have been secondary, with anatomy and physiology the primary concerns. The animals' responses, most often maintained by continuous reinforcement, have served as an index of guessed-at events occurring in the brain. Exceptions to that rule can be found, however. Sidman, Brady, Boren, Conrad, and Schulman (1955) examined performances maintained by intermittent schedules of BSR. The limits of their analysis, however, were fixed ratios of less than 10 and variable intervals of 15 sec. Keesey (1962) employed a variable interval of 16 sec. Approaching more conventional schedule sizes were those used by Brady and Conrad (1960b), *viz.*, a 60-sec variable interval schedule and by Brady and Conrad (1960a), *viz.*, a DRL of 20 sec. Brodie, Moreno, Malis, and Boren (1960) obtained a fixed ratio performance of 150 responses in one of 11 monkeys. Also, Boren and Malis (1961) reported an adjusting avoidance schedule employing an electrode placement at which stimulation was aversive.

Conspicuously absent from the BSR literature have been experimental reports describing behaviors maintained by intermittent schedules of BSR in the range of parameter values ordinarily used with food as a reinforcer. The lore of BSR research teaches that intermittent schedule performances are difficult to maintain. It is hard to estimate the degree to which that lore is the result of research on intermittent schedules, since "negative" results tend not to be published, and the degree to which its acceptance has discouraged such research. Following a lead from our laboratory (Pliskoff and Hawkins, 1964), it was decided to examine intermittent schedule performances employing a chaining procedure in which the first chain member is traditional self-stimulation (CRF, but with a fixed number of stimulation-reinforced responses) and the second chain member is an intermittent reinforcement schedule. There was reason to

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believe that substantial schedule performances could be maintained with that procedure, provided the first chain member consisted of not less than 20 stimulations per exposure.

METHOD

Subjects

Ten male, albino rats, nine of them with no experimental history, were obtained from the colony maintained by the Walter Reed Army Institute of Research. They weighed between 200 g and 300 g when implanted. Each subject was implanted under Nembutal anesthesia on a commercially available[2] stereotaxic instrument with bipolar, stainless steel electrodes insulated except at the tip. The exposed portion of each pole was 10 mils in diameter. The implanting procedure was similar to a standard technique reported by Valenstein, Hodos, and Stein (1961).

When all of the data were collected, the 10 rats were sacrificed and perfused with saline and a 10% formaline solution. Frozen sections 50μ thick were prepared, stained with chresyl violet, and mounted for microscopic examination.[3]

Figure 1 contains photomicrographs of frontal sections for each of the rats used in the present experiment. The locations of the electrode tips are indicated by the heavy markers. Labels have been omitted to conserve space, and the reader interested in anatomical details is referred to one of the standard atlases of the rat brain (*e.g.*, Massopust, 1961; DeGroot, 1959; Zeman and Innes' revision of Craigie, 1963).

The rats used in the experiment were selected from a population of implanted rats according to three arbitrary criteria based on qualitative estimates of their performances for BSR. First, any rat that could not be trained to lever press for BSR (continuous reinforcement) was discarded. Rats that were discarded most often showed no reward effect and sometimes displayed a tendency to avoid responses followed by brain stimulation. Second, each rat selected according to the first criterion was run on continuous reinforcement for BSR. During the CRF sessions, stimulation intensity was varied, and an intensity was selected for each rat which would maintain a relatively sustained performance. Any rat for which such a stimulation intensity could not be found was discarded. Third, the rats surviving the second selection criterion were run on the alternation procedure described below (Procedure, first paragraph). Sustained performance on that procedure was necessary for final inclusion as an experimental rat. While no records were kept with respect to the exact number of rats eliminated, subsequent experience with the three criteria indicates that about two-thirds of the rats tested are ultimately selected to serve as experimental subjects. During the course of the work to be described, one rat LS 101 was lost when its electrode was accidentally torn away. Food and water were freely available in the home cages at all times.

[2]David Kopf Instruments, Tujunga, California.

[3]Histological preparations were by Mrs. Joan Cohen.

Apparatus

The experimental rat box was made of clear plastic throughout with the front wall painted black. Two response levers were mounted on the front wall about 6 in. apart. The left-hand lever (Gerbrands) was modified with a flat, paddle-like sheet of metal bolted to the bar so that the lever protruded into the box about 1.5 in. (Additional counterweighting was added.) The right-hand lever was retractable (Lehigh Valley). The box was standard in other respects. Timers, relays, stepping switches, *etc.* were employed to provide automatic programming. Cumulative recorders and electromagnetic counters were used for data collection.

The stimulator employed provided biphasic, square-wave stimulation with positive and negative excursions of a pulse-pair each 0.2 msec in duration. An "off-time" of 0.2 msec intervened between the two excursions of a pulse pair. The stimulator delivered 100 pulse-pairs per second, and the duration of a single train of pulse-pairs in addition to current intensity were independently controlled by the experimenter. Both duration and intensity were set and monitored on an oscilliscope. The stimulation was delivered to the animal through a hearing aid cord which was connected to the stimulator cable through a commutator. The hearing aid cord was lightly spring loaded to keep it taut. The rat could move freely to all parts of the box and turn 360° without twisting the cord.

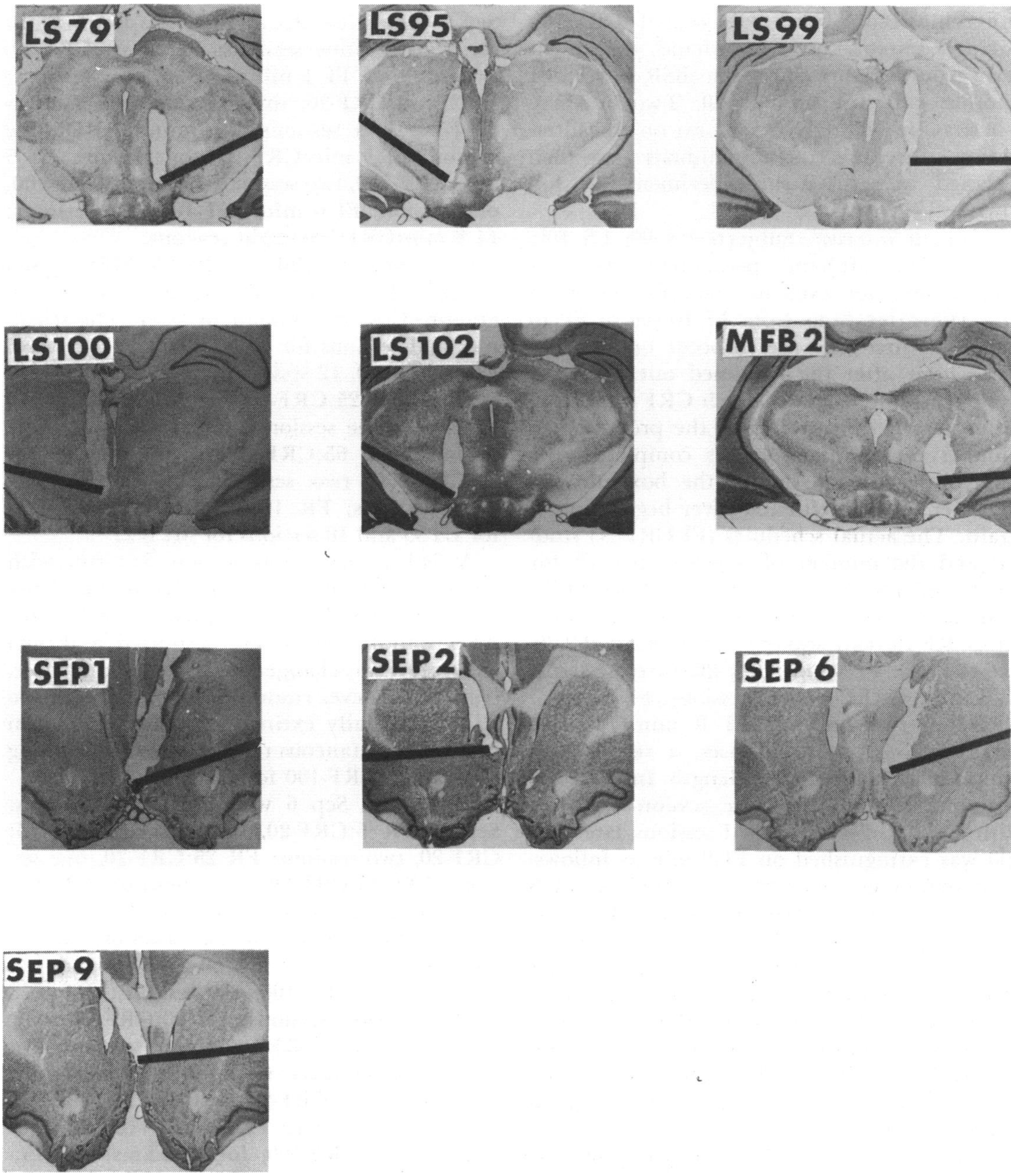

Fig. 1. Photomicrographs for each of the rats used in the present experiment. Each is a frontal section with the electrode tip indicated by the heavy marker. Anatomical details may be identified with the aid of a standard atlas of the rat brain (see text).

Procedure

After recovery from the surgical procedure, each rat was shaped to press the retractable lever on continuous reinforcement for BSR. Stimulation intensity was set at a value which would produce sustained performance. For nine of the rats, the intensity was between 340 and 600 μA, zero to peak. For one rat, Sep 1, 1400 μA were used. In all cases, train duration was set between 150 and 200 msec per stimulation. After about two 1-hr sessions on CRF, the circuit was altered so that the BSR lever would retract out of the box after 20 stimulation-reinforced presses (designated CRF-20). A single response on the left-hand, permanent lever could reintroduce the BSR lever for another exposure to CRF-20. Two or three 2-hr sessions were given each rat on this alternation procedure, and the animals were then assigned to several sub-experiments as follows:[4]

1. *Fixed interval.* Subjects LS 99, LS 100, Sep 9: The left-hand, permanent lever was programmed for fixed interval (FI) schedules of various durations from FI 10 sec to FI 10 min. The first response to occur on the left-hand lever after the FI timed out produced the retractable lever on which CRF self-stimulation was permitted. When the programmed number of stimulations was completed, the lever was retracted out of the box and the FI timer for the left-hand lever began timing again. The actual schedules (FI:CRF-N) studied and the number of sessions on each for LS 99 and LS 100 were: FI 10 sec:CRF-20, 14 sessions; FI 30 sec:CRF-20, five sessions; FI 1 min:CRF-20, two sessions; FI 2 min:CRF-20, five sessions; FI 3 min:CRF-20, three sessions; FI 5 min: CRF-20, three sessions; FI 7.5 min: CRF-100, two sessions; FI 8 min:CRF-100, three sessions. In most cases, a session was approximately 2 to 3 hr in length. In addition, a single, continuous 24-hr session was run with LS 100. Five standard sessions later, LS 100 was extinguished on FI 8 min as follows. Two reinforcements were permitted on FI 8 min, and then the circuit was changed so that the retractable, stimulation lever could not be produced. After the initial session on that procedure, two additional extinction sessions, one on each of the next two days, were run to assess spontaneous recovery. Reconditioning on FI 8 min:CRF-100 followed. Finally, LS 99 was run for seven sessions on FI 10 min:CRF-1000.

The procedure was basically the same for Sep 9. The schedules and sessions were: FI 10 sec:CRF-20, nine sessions; FI 30 sec:CRF-20, two sessions; FI 1 min:CRF-20, two sessions; FI 2 min:CRF-20, three sessions; FI 3 min:-CRF-20, three sessions; FI 5 min:CRF-20, one session; FI 5 min:CRF-100, one session; FI 5 min:CRF-250, two sessions; FI 5 min:CRF-100, one session; FI 6 min:CRF-100, two sessions; FI 8 min:CRF-100, eight sessions.

2. *Fixed ratio.* Subjects LS 95, MFB 2, Sep 1, Sep 6: Fixed ratio (FR) schedules were programmed on the permanent lever. The schedules and sessions for LS 95 and MFB 2 were: FR 5:CRF-20, 12 sessions; FR 15:CRF-20, two sessions; FR 25:CRF-20, two sessions; FR 35:-CRF-20, three sessions; FR 50:CRF-20, three sessions; FR 65:CRF-20, three sessions; FR 80:CRF-100, two sessions; FR 90:CRF-100, three sessions; FR 100:CRF-100, six sessions for LS 95 and 10 sessions for MFB 2.

A 24-hr, continuous session was run with LS 95 on FR 100:CRF-100. Five standard sessions later, LS 95 was extinguished on FR 100. Two reinforcements were permitted, and then the circuit was changed so that the retractable, stimulation lever could not be produced. Two additional daily extinction sessions were run to assess spontaneous recovery. Reconditioning on FR 100:CRF-100 followed.

Sep 1 and Sep 6 were treated as follows: Sep 6: FR 5:CRF-20, nine sessions; FR 15: CRF-20, two sessions; FR 25:CRF-20, one session; FR 35:CRF-20, one session; FR 50:-CRF-20, three sessions; FR 50:CRF-100, three sessions; FR 50:CRF-250, two sessions; FR 50:-CRF-100, one session; FR 60:CRF-100, one session; FR 70:CRF-100, six sessions; FR 80:-CRF-100, three sessions; FR 90:CRF-100, one session; FR 100:CRF-100, three sessions. For Sep 1, the sequence was: FR 5:CRF-20, nine sessions; FR 15:CRF-20, two sessions; FR 25:-CRF-20, one session; FR 25:CRF-100, one session; FR 25:CRF-500, four sessions; FR 15:-CRF-500, five sessions; FR 20: CRF-100, two sessions; FR 25:CRF-100, two sessions; FR 30:-CRF-100, five sessions; FR 40:CRF-100, six sessions; FR 15:CRF-100, five sessions.

3. *DRL and transitions to fixed interval and fixed ratio.* Subjects LS 102 and Sep 2: The permanent lever was programmed for DRL schedules from 10 sec to 3 min. After final performance on DRL 3 min, both rats were switched to FI 3 min and then to FR schedules of several sizes. The sequence of

[4]The specification of the sequence of schedule values, in addition to the number of sessions on each, may seem overly detailed. We feel that too much detail is preferable in a relatively novel research area where techniques are not standard. During the sequence of experimental conditions, CRF-20 was often changed to CRF-100 and even to CRF-1000. There were no important effects beyond CRF-20, a finding consistent with our previous work. Note also: at the start of each session, regardless of the schedule on the permanent lever, the first reinforcement, *i.e.*, exposure to CRF on the retractable lever, was produced by a single response on the schedule lever.

experimental conditions for Sep 2 was: DRL 10 sec:CRF-20, nine sessions; DRL 20 sec:CRF-20, two sessions; DRL 1 min:CRF-20, two sessions; DRL 2 min:CRF-20, three sessions; DRL 2 min:CRF-100, three sessions; DRL 3 min:CRF-100, three sessions; FI 3 min:CRF-100, five sessions; FR 15:CRF-100, four sessions; FR 2:CRF-100, four sessions; FR 10:CRF-100, two sessions. The sequence of conditions for LS 102 was: DRL 10 sec:-CRF-20, seven sessions; DRL 15 sec:CRF-20, seven sessions; DRL 20 sec:CRF-20, five sessions; DRL 1 min:CRF-20, two sessions; DRL 2 min:CRF-20, five sessions; DRL 2 min:CRF-100, three sessions; DRL 3 min:CRF-100, three sessions; FI 3 min:CRF-100, five sessions; FR 15:CRF-100, four sessions; FR 25:CRF-100, two sessions; FR 50:CRF-100, two sessions; FR 75:CRF-100, one session; FR 100:CRF-100, one session; FR 125:CRF-100, three sessions; FR 150:CRF-100, two sessions; FR 200:CRF-1000, seven sessions.

4. *Supplementary observations on DRL and variable interval.* Subject LS 79: This rat had been used in another experiment employing the same two-lever technique but with VI 30 sec on the permanent lever. Data on this rat were not recorded systematically; it was run on DRL schedules of 20 sec, 30 sec, 90 sec and 3 min, each with CRF-20 as the first chain member. After those sessions, it was run on VI 2:CRF-20, VI 2:CRF-100, and VI 4:CRF-100.

RESULTS

The results are not presented in point-to-point correspondence with the preceding description of the sequence of experimental manipulations. To do so would result in redundancies and much non-informative description. Instead, the main points are organized in a manner designed to facilitate presentation.

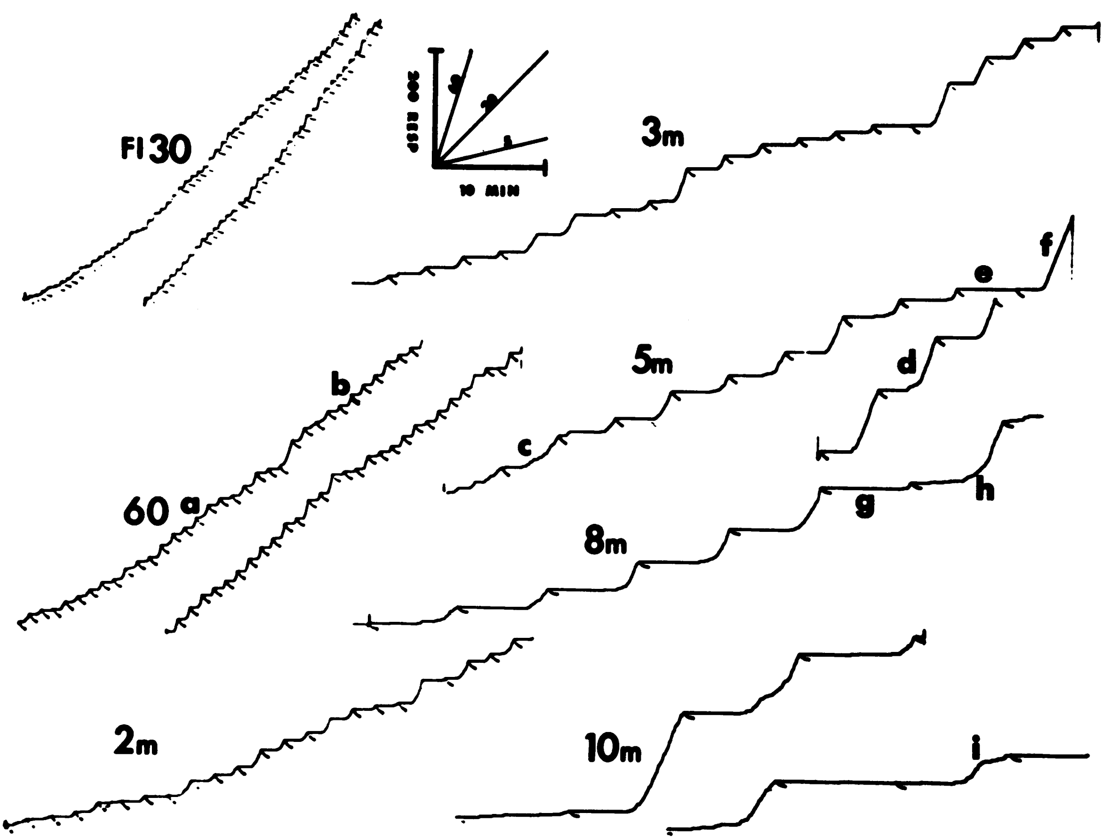

Fig. 2. Cumulative records showing FI performances of LS 99. Pips mark reinforcements; the double pip at b on the FI 30 record resulted from a failure of the recorder motor during that interval. The records are for FIs of 30 and 60 sec, and FIs of 2, 3, 5, 8, and 10 min.

Figures 2 through 8 present cumulative records of performances on the permanent lever. In all cases, the pips on the records represent reinforcements, *i.e.*, access to the retractable lever for BSR. During exposure to BSR, the recorder paper drive for the permanent lever was stopped.

A. *Posterior Hypothalamic Placements*

1. *Fixed interval.* Figure 2 shows characteristic FI performances maintained by BSR. All of the records in Fig. 2 are for LS 99. Performance on FI 30 sec (FI 30) is rather stepwise in appearance—it represents an alternation of pausing after reinforcement (CRF-20) and responding at an essentially steady rate. Some instances of the pause-run FI performance are still in evidence in the FI 60 sec record (60), although the development of intermediate rates can also be seen (a). The double pip at b resulted from a failure of the recorder paper drive. Performances on the FI 2 min (Record 2m) and FI 3 min (3m) schedules display a continued development of intermediate rates and the emergence of scalloping. A number of well-formed scallops are in evidence (c and d) in the FI 5 min (5m) record. Note, also, the final three intervals (at d) shown immediately below the main FI 5 record—each is characterized by high response output. The last two intervals of the main FI 5 record (e and f) show a kind of second-order effect (Ferster and Skinner, 1957) often seen in FI performances maintained by food reward. The FI 8 min (8m) record shows characteristic FI scalloping. The behavior is under good schedule control; again, a second-order effect can be seen at the end of that record (g and h). Some ragged performances (i) can be seen on FI 10 min (10m). However, the overall performance is maintained.

2. *Extinction, spontaneous recovery, and reconditioning after fixed interval.* The data shown in Fig. 3 are for LS 100. The record labeled FI 8 min shows characteristic performance on that schedule for the rat and is very much like the FI 8 min performance for LS 99 in Fig. 2. The second record (Ext after $2S^R$) is from the first extinction session. Note the two reinforced intervals (a and b) at the start of the session. Responding begins about 6 to 7 min after the second reinforcement, and

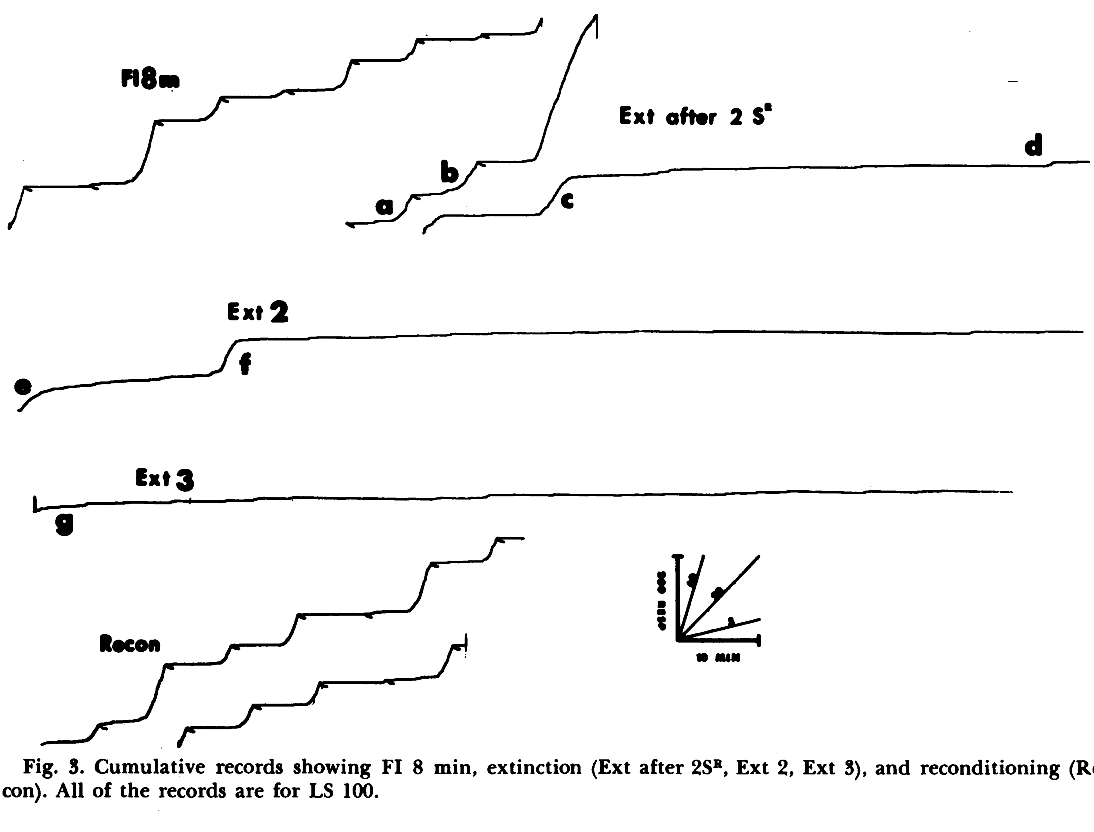

Fig. 3. Cumulative records showing FI 8 min, extinction (Ext after $2S^R$, Ext 2, Ext 3), and reconditioning (Recon). All of the records are for LS 100.

about 350 to 400 responses are emitted before a break occurs. Another burst of responding (c) occurs about 15 min later. The record immediately below (Ext 2) is from the second extinction session run the next day. Since extinction was virtually complete by the end of the first extinction session (d), the responding at the start of the next extinction session (e and f) represents spontaneous recovery. The third extinction record (Ext 3), run on the third extinction day, may also show some spontaneous recovery at g. Particularly interesting are the several instances of rate deceleration (e, for example) evident in the three extinction records—a performance characteristic of extinction after interval reinforcement with food. The last record (Recon) is taken from the first reconditioning session. Performance has quickly returned to the pre-extinction level.

3. *DRL and transitions to fixed interval and fixed ratio.* Figure 4 is composed of records for LS 102. The top record (DRL3m) shows performance on DRL 3 min. Note that a single reinforcement was obtained early in the session (at a) but that performance was well maintained throughout. A low, steady rate of responding characteristic of DRL performance is in evidence. The record labeled "FI3m 1st Sess" is from the final part of the first session after the transition from DRL 3 min to FI 3 min. Overall response rate has increased (compare slopes), but no evidence of scalloping has appeared. The three records immediately below (2nd, 3rd, and 4th Sess) are the final portions of the immediately succeeding daily sessions on FI 3 min. The development of characteristic FI scalloping is perhaps the most striking characteristic of those records. Compare, for example, the intervals labeled b, c, d, e. The last record on the left (FR15 1st Sess) shows the final portion of the first session after the transition from FI 3 min to FR 15. Note the pauses after reinforcement and the emergence of a fixed-ratio response rate in two of the last three ratios (at f and g). The top record on the right side of the figure (labeled 15 and 2nd Sess) is the last part of the succeeding session. Ragged performance characterizes the earlier part of that record, followed by the emergence of well-formed ratio behavior at h. A short pause after reinforcement is followed by a steady, smooth run to the next. The three records below (labeled

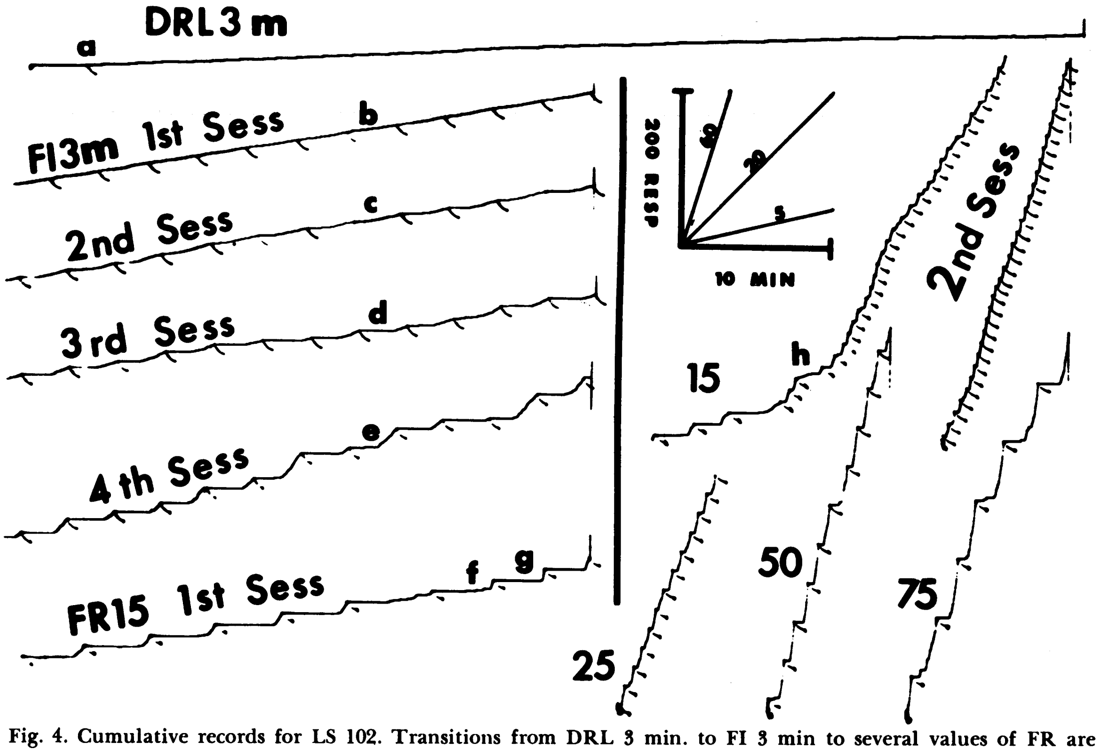

Fig. 4. Cumulative records for LS 102. Transitions from DRL 3 min. to FI 3 min to several values of FR are shown.

25, 50, 75) show ratio performances on FR 25, FR 50, and FR 75. Again, ratio performance is like that obtained with food reinforcement. Observe the lengthening pause after reinforcement as the FR size increases.

Figure 5 contains additional data for LS 102 and shows performances on FR 100, FR 150, and FR 200 (FR 125 is omitted from the figure). Pauses after each reinforcement are considerably lengthened on FR 150 and even more so on FR 200. While some notable tendency to run and break during a ratio appears on FR 150 (at a) and FR 200 (at b), overall performance is maintained. The first ratios shown on the FR 100 and FR 200 records (c and d, respectively) are the first of the respective sessions. Such uneven performance was characteristic of our "ratio rats", and the same phenomenon has been noted in pigeons working for grain reinforcement on the first ratio of the session. The bottom record of Fig. 5 (labeled 100) is from MFB 2 and is included for comparison with the top, left record of LS 102 on the same schedule. MFB 2 showed characteristically good ratio performance, but with pauses after reinforcement of from 10 to 20 min.

4. *Extinction, spontaneous recovery, and reconditioning after fixed ratio.* The data in Fig. 6 are for LS 95. The figure is comparable with Fig. 3 in format. The top left record shows typical performance on FR 100 and is similar to the FR 100 performance of LS 102 in the preceding figure. The record labeled "Ext after 2S^R" is from the first extinction session which began with two reinforced ratio runs (a and b). Characteristic extinction performance after ratio reinforcement is easy to detect. Although there are some tendencies toward intermediate rates such as at c, the overall record is characterized by run-and-break sequences. That record should be compared with the corresponding record of Fig. 3, which was extinction after interval reinforcement. Since responding (at d) occurred at the end of the first extinction record, suggesting that extinction was not yet complete, it cannot be claimed that the responding (e) at the

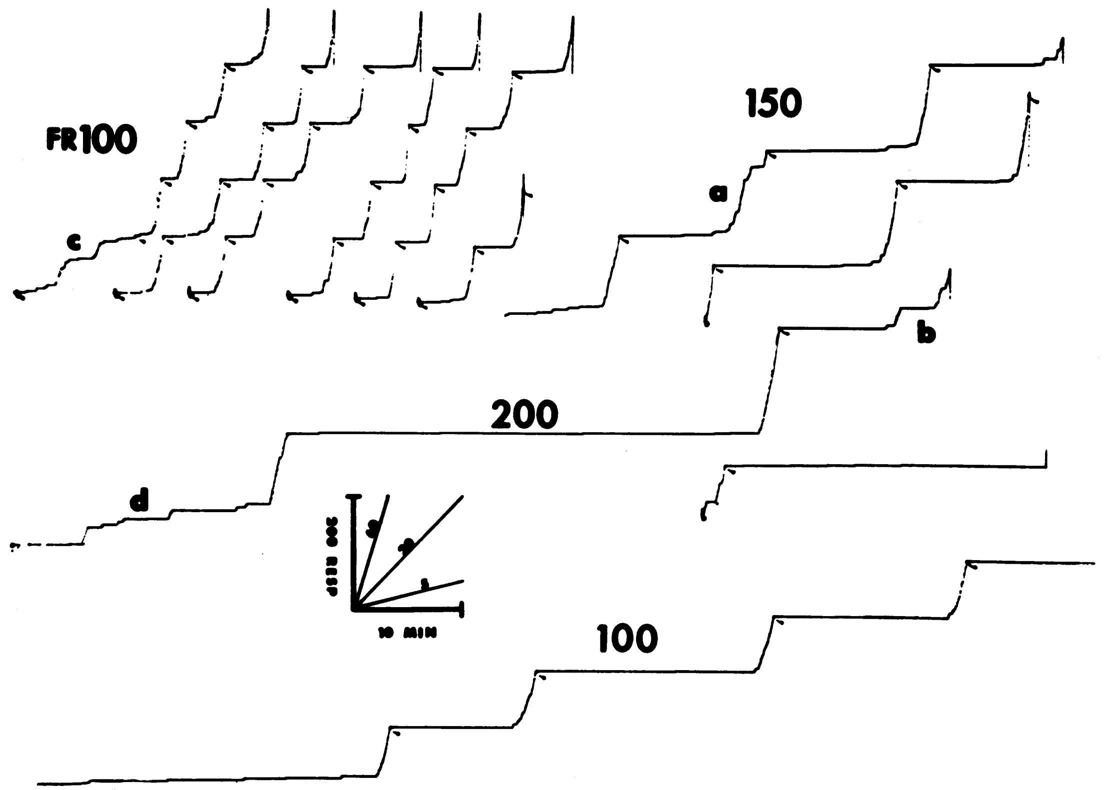

Fig. 5. A continuation of the data for LS 102. Performances on FR 100, FR 150 and FR 200 are shown. The bottom record is for MFB 2 on FR 100. The pauses after reinforcement are considerably longer than those of LS 102.

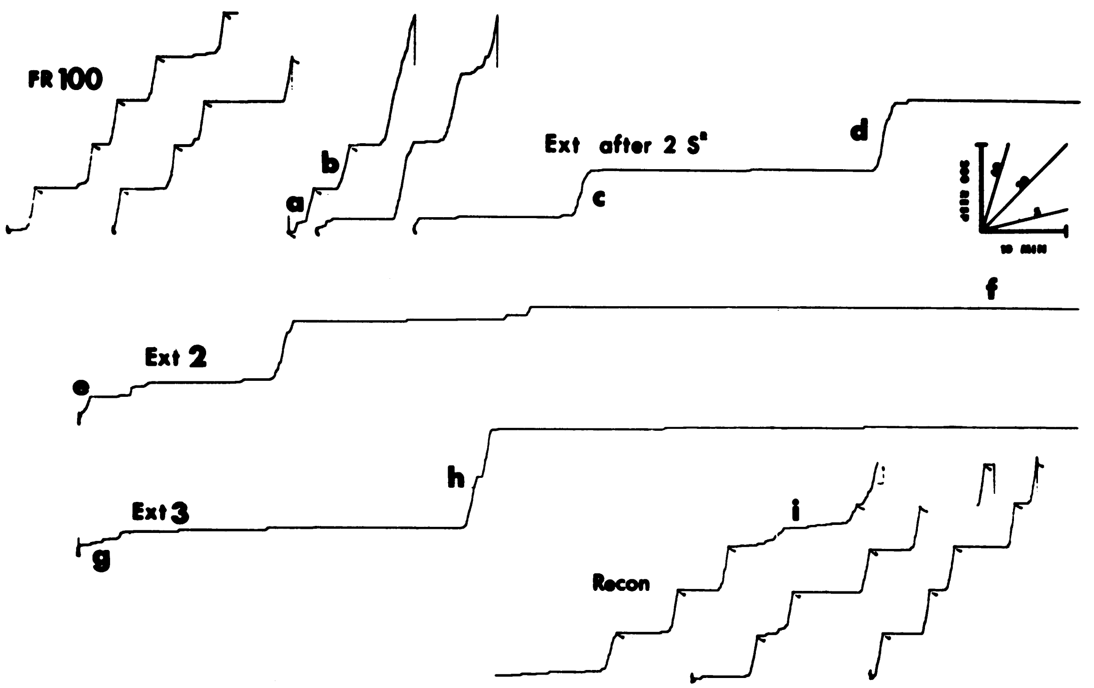

Fig. 6. Cumulative records for LS 95 showing FR 100, extinction (Ext after $2S^R$, Ext 2, Ext 3), and reconditioning (Recon).

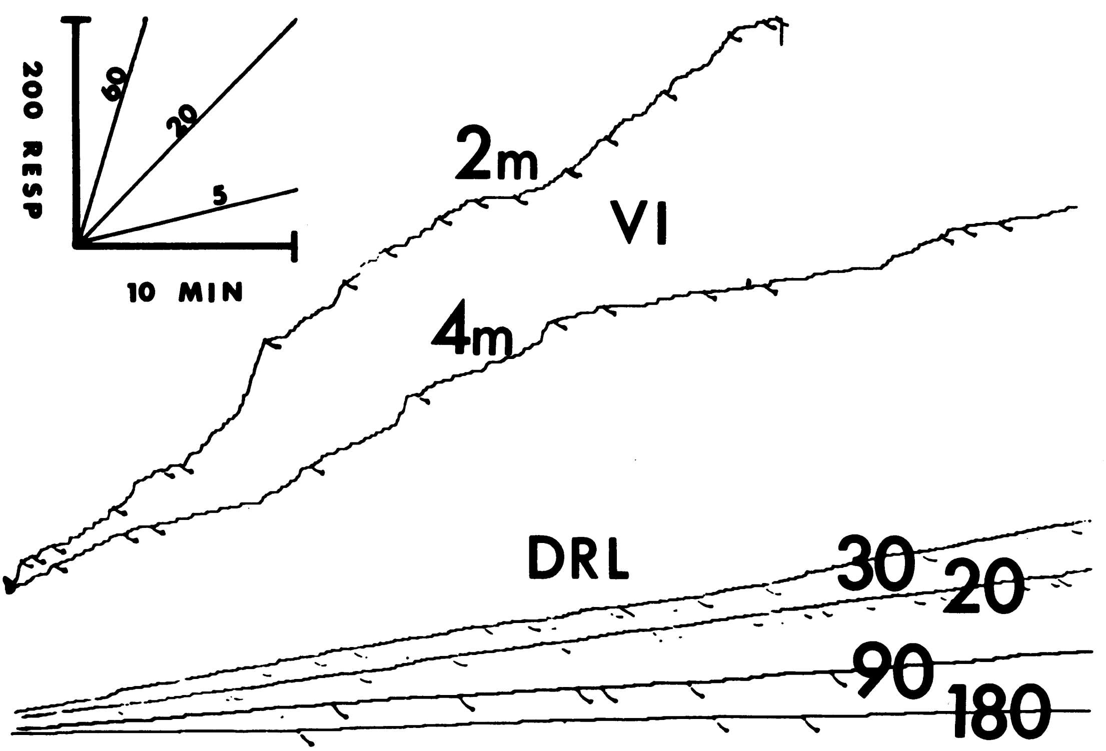

Fig. 7. Cumulative records for LS 79. These observations were not systematically made. They show performances on DRL schedules of 20, 30, 90 and 180 sec. The VI performances were obtained after the observations on DRL.

beginning of the second extinction record (Ext 2) taken 24 hr later represents spontaneous recovery. Note, however, the absence of responding at the end of the second record (f)—the responses occurring at g at the start of the third day's extinction session (Ext 3) may represent spontaneous recovery. Note the two long bursts of about 100 responses each later in the final extinction session (at h). The topography of each burst is ratio-like. The final record is labeled "Recon" and is from the first reconditioning session following extinction. The quick recovery of ratio performance is evident. The fourth ratio in that record at i is interesting in that there is a complete breakdown in schedule control—the 100 responses are emitted in short run-and-break sequences.

5. *Variable interval and DRL: supplementary observations.* Figure 7 shows DRL and VI performances for LS 79. The DRL performances for DRL 20 sec, 30 sec, 90 sec, and 180 sec are typical, except, perhaps, for the fact that LS 79's DRL 30 sec rate was higher than its DRL 20 sec rate. After the session shown for DRL 180 sec, LS 79 was switched to VI 2 min, and the record shown is for the last session on VI 2 min before the change to VI 4 min. The 2-min rate is higher than the 4-min rate, and both performances are uneven.

B. *Septal Placements*

Figure 8 summarizes schedule findings with the septal electrode placement. The DRL 3 min (DRL3m) and FI 3 min (FI3m) records are for Sep 2 and show its final performances on those schedules. The FI 3 min record may be compared with the FI 3 min record of Fig. 2, although the latter performance was maintained by CRF-20 while Sep 2's FI 3 min performance was maintained by CRF-100 (see footnote 4). While overall performance is maintained by the septal animal on FI 3 min, response output is relatively low. The FR 15 record is also for Sep 2 and represents its final performance on that schedule. Pauses after

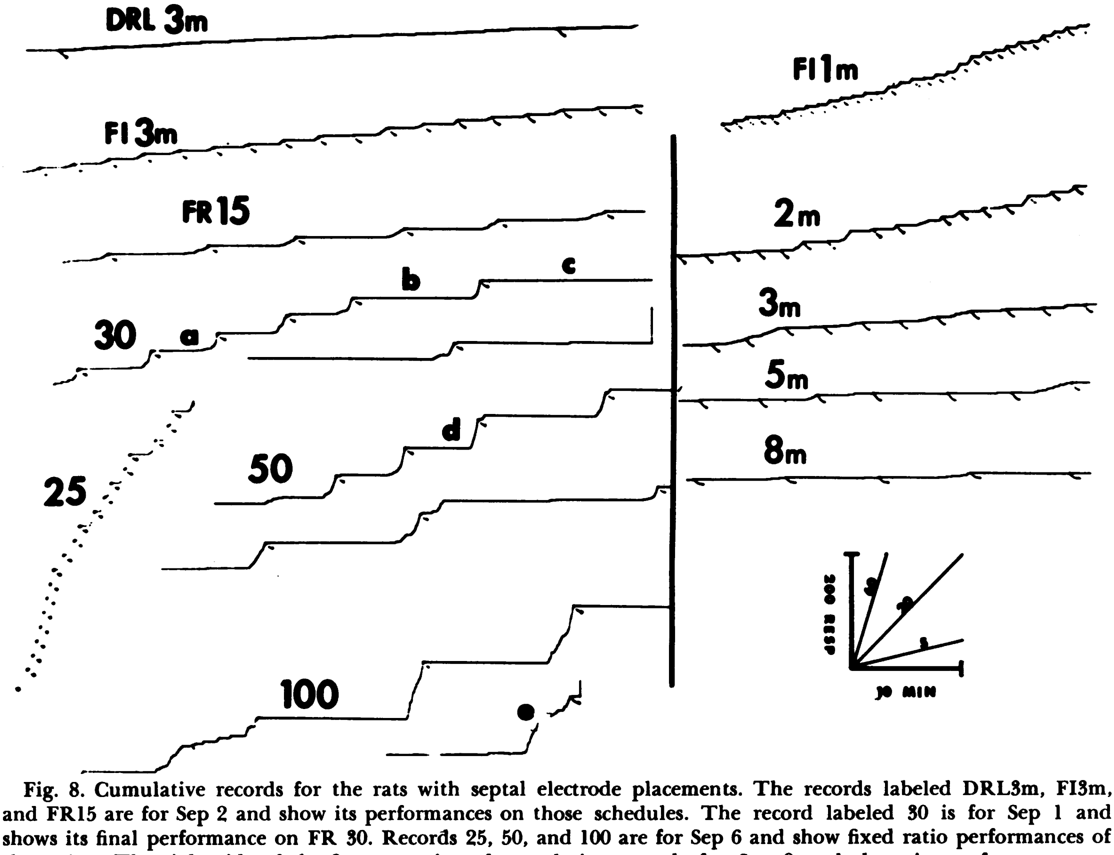

Fig. 8. Cumulative records for the rats with septal electrode placements. The records labeled DRL3m, FI3m, and FR15 are for Sep 2 and show its performances on those schedules. The record labeled 30 is for Sep 1 and shows its final performance on FR 30. Records 25, 50, and 100 are for Sep 6 and show fixed ratio performances of those sizes. The right side of the figure consists of cumulative records for Sep 9 and show its performances on fixed interval schedules of 1, 2, 3, 5, and 8 min.

reinforcement are quite lengthy, and as suggested by the record, tended to lengthen during the course of a session. Response rate was quite unlike that frequently observed in ratio performance for food. The ratio requirement could not be raised beyond 15 responses for Sep 2. The record labeled 30 is for Sep 1 on FR 30. Running rate is much higher than for Sep 2; pause length is long for the ratio size and clearly tends to lengthen during the session, as shown by a comparison among the performances at a, b, c. The "best" septal placement with respect to ratio performance was Sep 6. Its records are labeled 25, 50, 100 and show performances on ratios of those sizes. The FR 50 performance provides some examples of good ratio behavior as at d—again, pauses tend to lengthen during the session. The FR 100 record shows some tendency toward uneven performance (at e, for example). The five records on the right of Fig. 8 are for Sep 9 and show its FI performances at several of the values run. Overall performance is maintained, although there is little response output at FIs of 3 min, 5 min, 8 min. These FI records may be compared with the FI performances in Fig. 2. The differences are striking and may represent an effect of electrode placement.

C. *The 24-Hr Sessions*

Figures showing the 24-hr performances of LS 100 on FI 8 min and of LS 95 on FR 100 are not presented. They did not provide anything new with respect to schedule topography which is the main topic of this report. LS 100 displayed FI performance for the entire 24-hr session with the longest interreinforcement time equal to 15 min. There were many "one response" intervals, often several strung together, alternating with fixed interval performances of the usual scalloped type. The 24-hr session for LS 95 on FR 100 began with 40 reinforcements followed by several hours of one or two reinforcements per hour. Then, another series of 34 reinforcements were obtained. The rest of the session consisted of long periods of inactivity broken by one or two complete ratio runs.

D. *First Member Performance*

Figure 9 consists of cumulative records obtained from performances on the first chain member, retractable lever. Because of the selection procedure used in choosing the experimental rats, a broad range of performances in the first chain member (continuous reinforcement for BSR) was not obtained. The records in Fig. 9 are representative; the main difference among all subjects was reflected in absolute response rates.

Record A shows the initial portion of a continuous reinforcement session for MFB 2 with the retractable lever permanently in place. The record shows uneven performance during the first 10 min with a relatively sustained performance thereafter. Note the sudden breaks in responding, often followed by an acceleration to the high CRF rate. The acceleration is particularly evident at a. Record B is also for MFB 2 and shows its performance on CRF-20. The paper drive on the recorder was turned off during the second chain member, *i.e.*, while the retractable, stimulation lever was withdrawn from the box. The overall rate of response is high, and there are no breaks in responding. Record C is for MFB 2 on CRF-100. The markers alongside the first excursion of the pen divide the record into CRF-100 units. The overall performance is smooth; slight tendencies toward deceleration at the start of a CRF-100 block of responses are in evidence, as at b. The inset record at n is for LS 100 and shows its performance on CRF-100. The marked acceleration at the start of a CRF-100 block (note the markers) contrasts with the deceleration of MFB 2.

Record D shows the performance of Sep 2 on continuous reinforcement with the retractable lever permanently in the box. The grain is generally uneven, and the overall performance is characterized by breaks in responding. Record E, also for Sep 2, shows its performance on CRF-20. Long breaks in responding are absent, as in record F which shows Sep 2's performance on CRF-100. Record G is for Sep 6 on CRF-250. The record is included because it shows conspicuous acceleration at the start of each CRF-250 block. Once the acceleration phase was over, Sep 6 responded at an extremely high rate. Recall that Sep 6 showed the "best" ratio performance among the septal rats. While those observations suggest a correlation between first member response rate (which may reflect reward value; however, see Hodos and Valenstein, 1962; Hawkins and Pliskoff, 1964) and second member schedule performance, our analyses of the

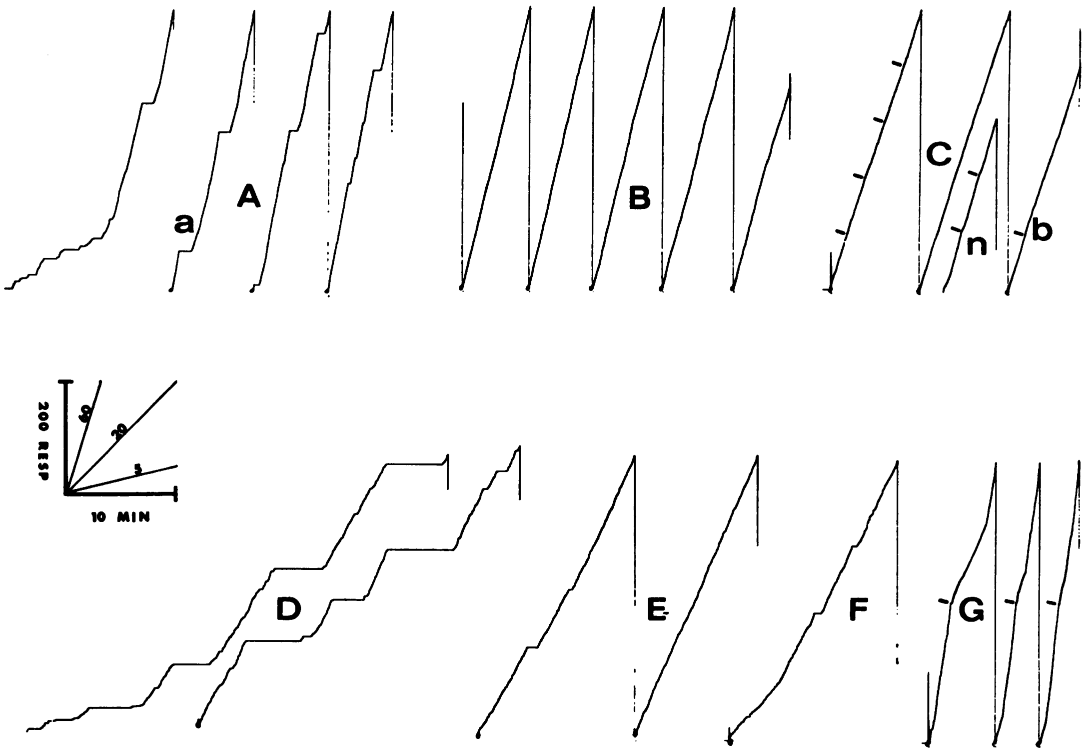

Fig. 9. First member performances for several rats. Each response is reinforced by brain stimulation. Record A shows continuous reinforcment performance for MFB 2. Record B, for the same rat, shows performance on CRF-20; record C, CRF-100. The inset at n is for LS 100 on CRF-100. The bottom records D, E, and F are for Sep 2 and show its performances on continuous reinforcement, CRF-20, and CRF-100, respectively. Record G is for Sep 6 on CRF-250.

records do not permit a conclusion on that point.

DISCUSSION

The results of the present research indicate clearly that BSR is not markedly less potent than the more traditional reinforcers such as food, water, *etc.* Contrary to the commonly held view, BSR can be used to maintain intermittent schedule performances in the range of parameter values often used with the conventional reinforcers. Response output can be considerable; schedule control is dramatic, and transitions in performance from one reinforcement schedule to another are easily obtained. How then can one account for the often-noted tendency of BSR to maintain intermittent schedule performances only with difficulty, if at all? Several possibilities come to mind.

The most frequent experimental procedure with rats using food reward delivers one pellet of food (often 47 mg) per reinforcement. Reward quantity where the rat is water-deprived is often in the neighborhood of 0.1 ml delivered in one cup operation. What could be more natural than to deliver one stimulation per reinforcement, particularly when continuous reinforcement response rates for BSR can be so high as to imply a very powerful reinforcer? Further, the parameter limits of that powerfully reinforcing stimulation have been suggested by research.[5] Train durations in the neighborhood of 0.5 sec and current intensities in the range from 75 to 500 μA have been most frequently used, although variations in wave form and methods of measurement make comparison difficult. If BSR so defined is inferior to traditional reinforcers in its ability to maintain intermittent schedule perform-

[5]Again, see Olds (1962) for a general review. Particularly, see Bower and Miller (1958), Stein (1962), Stein and Ray (1959), Reynolds (1958), Keesey (1962). See also Hodos and Valenstein (1962) and Hodos (1963).

ances, then either (a) BSR is a weaker reinforcer or (b) BSR has some special properties. There has been clear reluctance to conclude the former and very little interest in documenting the latter. Our feeling is that neither conclusion is justified by the data, particularly ours. By questioning the hasty assumption that one stimulation equals one food pellet, the use of several or many stimulations per BSR is suggested. Our work indicates that once that change in procedure is adopted, BSR may be as strong a reinforcer (in terms of behavior maintenance) as the conventional reinforcers.

The analogy between the food experiment and the brain-stimulation experiment can be drawn in finer detail by a closer examination of a rat's behavior at the food cup. The reinforcing event, eating a food pellet, is not over in a fraction of a second. Ordinarily the rat grasps the pellet, most frequently with his jaws, and there ensues a lengthy chain of consummatory activity: chewing, salivation, more chewing, *etc.* In a similar vein, water reinforcement involves several licks at the cup. By defining brain-stimulation reinforcement as several response-produced trains of stimulation, we attempted to simulate the consummatory chain. Note also that the rate at which a consummatory chain occurs is under the control of the rat; our procedure with brain stimulation similarly permits the rat to pace itself on the stimulation lever.[6]

It is clear that the foregoing analogy places a lever press in the same relation to stimulation as the complex consummatory response bears to the ingestion of food or water. That fact suggests a purely analogical status for our procedure, since a lever press is behaviorally and biologically arbitrary while consummatory activity may have special properties (Sheffield and Roby, 1950; Sheffield, Roby, and Campbell, 1954; Tinbergen, 1951).

Another possible reason for the difficulty in maintaining schedule performances with the standard BSR techniques may be found in a difference between the behavioral situations used to study BSR and those employing conventional reinforcers. The latter experiments provide for a conditioned reinforcer (feeder operate) immediately after the reinforced response followed by a short delay before receipt of the primary reinforcer. The delay results from the requirement that the rat leave the lever and go elsewhere, *i.e.*, to the pellet hopper, to obtain the food pellet. The typical BSR experiment, however, involves BSR coincidentally with the reinforced lever press and at the lever rather than elsewhere in the box.

The performances described in this report were obtained under conditions more closely approximating the conventional arrangement than ordinarily obtains in BSR research. The reinforced response in the second chain member was followed immediately by a stimulus (relay click in the housing of the retractable lever) which very likely developed conditioned reinforcing properties. Primary reinforcement, BSR, occurred after a short delay while the rat left the schedule lever and went to the stimulation lever.

In summary, performances were obtained on schedules of intermittent reinforcement in the range of parameter values often used with food reinforcement. The results support the notion that BSR and conventional reinforcers are similar and suggest that the "poor" performances often obtained with BSR may be attributed to the use of a single train of stimulation as the reinforcer and to differences in experimental techniques. The contribution to our results attributable to each of the procedural variations employed is open to experimental evaluation. That dramatic and important effects on behavior can be expected from seemingly very minor procedural variations has been clearly documented by Findley (1962). We believe that as more attention is given to the methodological aspects of BSR research, the need to postulate special properties for BSR will begin to diminish accordingly.

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[6]Meyers and Valenstein (1964) examined the question of the rat's preference for controlling the rate of stimulation as opposed to control by the experimenter. They concluded that, over a wide range of stimulation intensities, there was little difference between the two methods of control. At the highest intensities, however, both hypothalamic and septal rats preferred self control rather than experimenter control. Our work was completed before the Meyers and Valenstein article was published, and their results suggest that we would have obtained substantially the same results had the rate of stimulation in the first chain member been preset rather than left to the rat. Their procedure, however, does not allow the multiple response feature in the first chain member, since a single response initiates the preset series of stimulations.

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