JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1981, 36, 191-205 NUMBER 2 (SEPTEMBER)

EFFECTS OF RATIO CONTINGENCIES ON RESPONDING MAINTAINED BY SCHEDULES OF ELECTRIC-SHOCK PRESENTATION (RESPONSE-PRODUCED SHOCK)

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Squirrel monkeys' lever pressing was established under fixed-interval schedules of electric-shock presentation (response-produced shock). After appropriate temporal patterns of lever pressing were engendered, either fixed-ratio schedules of shock presentation were added to the fixed interval, or yoked variable-ratio schedules were substituted for the fixed-interval schedules. When fixed-ratio schedules were added, there was an initial rise in response rate and schedule-appropriate patterns of responding developed. After many sessions, however, responding ceased abruptly, in some cases with remarkable quickness. When variable-ratio schedules were substituted, responded declined gradually and eventually was poorly maintained. Ratio contingencies may not support responding as well as interval contingencies when electric shock is the maintaining event.

Key words: response-produced electric shock, fixed-interval schedules, fixed-ratio schedules, variable-ratio schedules, reinforcement, punishment, squirrel monkeys

More than 10 years have passed since the appearance of the first published report that lever pressing by squirrel monkeys can be maintained indefinitely under intermittent schedules of electric-shock presentation (Kelleher & Morse, 1968). During this period more than a score of reports on the phenomenon have been published that attest its reliability (see McKearney & Barrett, 1978 and Morse & Kelleher, 1970, 1977 for reviews). Nevertheless, this startling effect is still poorly understood and has received comparatively little study. This is especially surprising in light of the implications of such findings for concepts such as reinforcement and punishment.

Interestingly, in all except one of the published reports on responding maintained by intermittent response-produced shock, responding has been supported by interval schedules of shock presentation. Ratio schedules have been employed rarely and only with rather low ratio values (Kelleher & Morse, 1968; McKearney, 1970, 1972), with the usual result being that responding was suppressed, rather than maintained, under ratio contingencies (Kelleher & Morse, 1968; McKearney, 1972). In fact, there is a large literature showing that ratio schedules of shock presentation result in punishment (Azrin & Holz, 1966; Morse & Kelleher, 1977), even when responding is being simultaneously maintained, under different stimulus conditions, by an interval schedule of shock presentation (Barrett, 1977; Barrett & Glowa, 1977).

In only one study (McKearney, 1970) has responding apparently been maintained under a ratio schedule of electric-shock presentation. In this experiment responding under a multiple fixed-interval 10-min fixed-ratio 30 schedule of shock presentation was maintained for 20 daily sessions of 10 shocks per session and under multiple schedules with lower fixed-ratio values for at least five sessions. One subject was exposed to a simple fixed-ratio 30 schedule for eight consecutive sessions, and response rate declined steadily over this period.

Given the widely documented suppressive effect of electric shock under ratio schedules, and the equally reliable effect of response maintenance under interval schedules of shock presentation, the present experiments were undertaken to examine the effects of introducing a ratio schedule of shock presentation after responding was established under an interval schedule of shock presentation. We planned to introduce ratio schedules in a

Research supported by USPHS Grant No. DA-01417 from NIDA. The authors thank M. R. Pelick, M. E. Dearing, and G. Galbicka for technical assistance, J. Glowa and J. Katz for helpful suggestions, and K. O'Dea for aid in preparation of the manuscript. Reprints may be obtained from either author at the Psychology Department, University of Florida, Gainesville, Florida 32611.

manner that would not be likely to produce suppressive effects, i.e., beginning with large ratio values and then decreasing the ratio values systematically. However, the results of introducing the large ratios led in other directions as outlined below.

GENERAL METHODS

Subjects

Three adult male squirrel monkeys (*Saimiri sciureus*) were used; two were used in the first two experiments reported below, and the third monkey was used exclusively in the third experiment. All were experimentally naive at the beginning of the procedures reported here, and were maintained at 95% of their free-feeding body weights by restricting their food intake. Between sessions the monkeys were housed individually, with continuous access to vitamin-enriched water, in a room with a 12:12 light-dark cycle.

Apparatus

During sessions a monkey was restrained in a Plexiglas chair similar in construction to that described by Hake and Azrin (1963). A waistlock on the chair restrained a subject in a sitting position facing a transparent Plexiglas wall through which protruded a response lever (Coulbourn Instruments Model E21-03), and behind which, at eye level, were mounted a pair of 1.2-W (GE 1829) lamps. The lamps were illuminated during experimental sessions. A static force of about .25 N operated a microswitch attached to the lever, operated a relay mounted on the plywood base of the chair for 40 msec, and was counted as a response. A shaved portion near the end of the monkey's tail was held motionless by a stock, and two brass electrodes rested on this portion of the tail. Electrode cream (EKG Sol) ensured good contact between the electrodes and the tail. Electric shocks were delivered from a 60-Hz, 650-V-ac source through series resistors. Shocks usually were 6 mA in intensity, and each lasted 100 msec.

During sessions the restraining chair was placed in a ventilated, sound-attenuating enclosure that was located in a room where white masking noise was continuously present. In an adjacent room a PDP-8/f minicomputer, operating initially under the SKED and later the SuperSKED process-control systems (Snapper & Inglis, 1978; Snapper, Stephens, Cobez, & Van Haaren, 1976), monitored sessions and controlled experimental events.

Sessions were usually conducted daily, seven days per week, between 3 and 5 hours into the light cycle, and usually lasted for 12 5-min cycles or 1 hr. Occasionally they were extended when responding was poorly maintained.

EXPERIMENT 1

This experiment studied the effects of adding a large-ratio contingency on responding maintained under a fixed-interval schedule of shock presentation.

Subjects

Monkeys 523 and 525 served.

Procedure

A summary of procedures for each subject, along with the number of sessions each was in effect can be found in Table 1.

Monkeys 523 and 525 initially were trained to press the lever under a shock-postponement procedure (Sidman, 1953). In the absence of responding, shocks occurred every 5 sec (shock-shock, or S-S, interval = 5 sec), and each response postponed shock for 20 sec (response-shock, or R-S, interval = 20 sec). The next condition was one in which a fixed-interval five-min (FI 5-min) schedule of electric shock presentation was added to the shock-postponement schedule. This schedule can be referred to as a conjoint (conjt, Catania, 1968) shock-postponement FI 5-min schedule.

Following 16 (Monkey 523) or 22 (Monkey 525) sessions under the conjoint schedule, the shock-postponement schedule was discontinued and a simple FI 5-min schedule of shock presentation was in effect. Monkey 525's behavior did not stabilize (i.e., appropriate temporal patterning did not develop, and response rate was variable) during 50 sessions of exposure to the FI 5-min schedule, so the conjt FI 5-min shock-postponement schedule was reinstituted for 14 sessions, after which the FI 5-min schedule alone was reimposed.

During this phase the number of lever presses in each interval was recorded, and the median number of responses per shock in each session was determined. The median of these medians over the last 10 sessions of exposure to the FI 5-min schedule was then calculated

Table 1

Procedures and Numbers of Sessions in Experiment I

Monkey 523		*Monkey 525*	
Condition Procedure	*Sessions*	*Condition Procedure*	*Sessions*
1. Shock postponement*	6	1. Shock postponement	8
2. Conjt shock postponement + FI 5-min**	16	2. Conjt shock postponement + FI 5-min	22
3. FI 5-min	137	3. FI 5-min	50
		3a. Conjt shock postponement + FI 5-min	14
		3b. FI 5-min	
4. Conjt FI 5-min + FR 116***	70	4. Conjt FI 5-min + FR 95	70
		4a. FI 5-min	3
5. Conjt shock postponement + FI 5-min	25	5. Conjt shock postponement + FI 5-min	19
6. FI 5-min	86	6. FI 5-min	158
7. Conjt FI 5-min + FR 123	67	7. Conjt FI 5-min + FR 111	46

* Shock-postponement contingencies consisted of R-S = 20 sec, S-S = 5 sec
** FI schedules were schedules of electric shock presentation
*** FR schedules were schedules of electric shock presentation

and used to construct the schedule for the next condition. Specifically, this median value was used to program a fixed-ratio (FR) schedule that was added to the FI 5-min schedule in the following way. At the beginning of a 5-min fixed-interval period, the ratio count was set to zero. If the monkey completed the ratio before the end of the fixed interval, a shock was delivered upon completion of the ratio as well as immediately following the response that terminated the interval. If, during the interval, the monkey made fewer responses than the ratio requirement, then only the response that terminated the fixed interval was shocked. Following the fixed-interval shock, the ratio count was set to zero and the process repeated. If a shock were delivered via the ratio schedule, then for the rest of that fixed-interval period the ratio schedule did not operate. Thus, a maximum of two shocks was possible in each fixed-interval period. Although it is not a "pure" conjoint schedule because the FI and FR schedules were not totally independent, we have chosen to refer to this procedure as conjt FR FI. The values of the fixed ratio were 116 for Monkey 523 and 95 for Monkey 525. We chose the median values to determine the fixed ratio because we wanted to ensure that the subject's behavior made contact with the ratio contingency, but not in such a way that a fixed-ratio shock would be delivered during every interval, to make it less probable that punishing effects might develop too rapidly.

Subsequently a near direct replication of the first set of manipulations was attempted. First, we reinstituted the conjt shock-postponement FI 5-min schedule for several sessions, and then the avoidance contingencies were removed so that only the FI 5-min schedule was in effect. After 86 sessions of FI alone for Monkey 523 and after 158 sessions for Monkey 525, during which responding was well maintained, we again added a conjoint FR schedule of shock presentation. As before, median numbers of responses per shock were determined under the FI schedule and the medians from the last 10 sessions under FI were used to determine the FR value for each monkey. The FR values used were 123 for Monkey 523 and 111 for Monkey 525.

Results

The cumulative records in the top frames of Figure 1 show performance near the end of training under the initial shock-postponement condition. The next two frames show responding engendered by the next condition in which the fixed-interval five-minute (FI 5-min) schedule of shock *presentation* was superimposed upon the shock-postponement schedule. The records in Figure 1 are from the 7th and 16th sessions of exposure to this procedure for Monkeys 523 and 525, respectively.

The cumulative records in the third frames of Figure 1 show the performance that resulted under the simple FI 5-min schedule of shock presentation. The records are from the 134th consecutive session of this procedure for Monkey 523 and from the 66th session for Monkey 525. For both monkeys the FI 5-min schedule resulted in similar temporal patterns of lever pressing. At the beginning of an interval, there was a pause followed by a

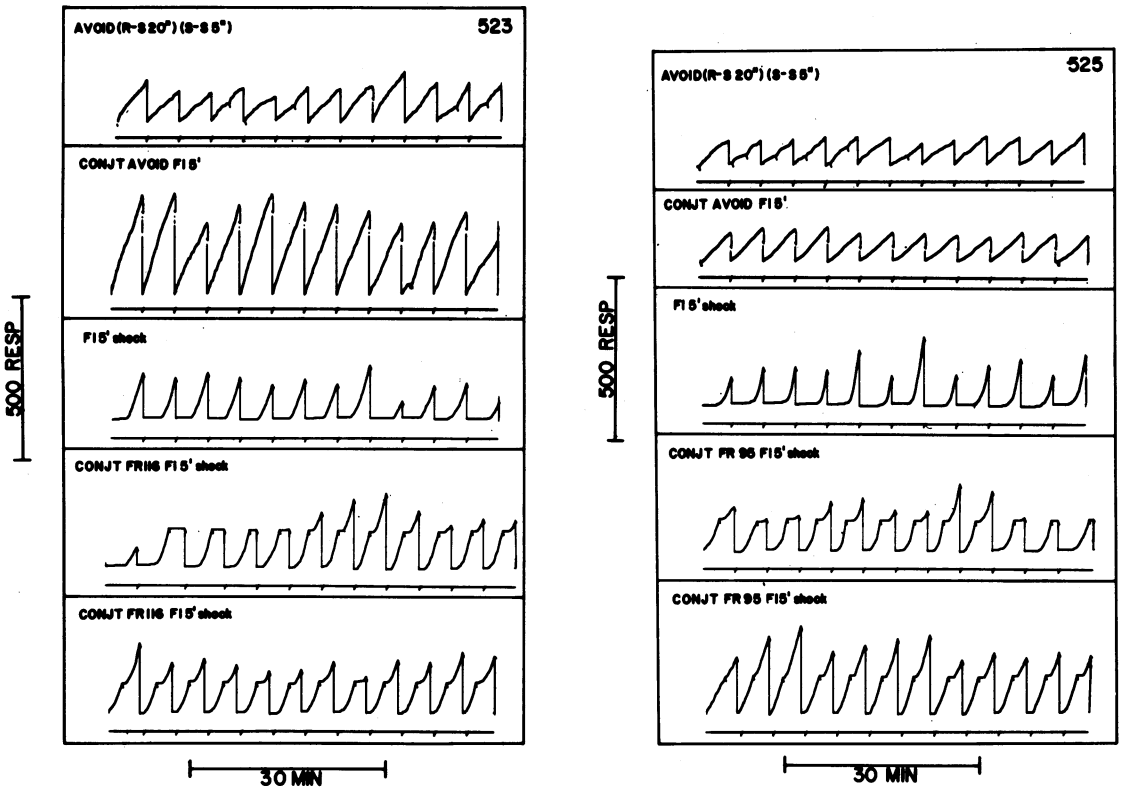


Fig. 1. Cumulative response records of lever pressing by Monkey 523 (left panels) and Monkey 525 (right panels). Y-axes: cumulative responses; X-axes: continuous time. The response pen reset to the baseline either every five minutes (topmost panels) or upon delivery of electric shock by the FI 5-min schedule (lower 4 panels). Diagonal marks ("pips") on the response records indicate the delivery of shock. Hatch marks on the event line indicate initiation of the 5-min fixed-interval schedule. Additional description can be found in the text.

period of accelerated responding until the electric shock was delivered.

The fourth panels of Figure 1 show cumulative records from the first (Monkey 523) or second (Monkey 525) session of exposure to the conjt FR FI schedule. Monkey 523 experienced a shock via the ratio schedule in the second interval. This shock occasioned a pause that was eventually followed by a lever press that terminated the fixed interval and also resulted in shock delivery. In all subsequent cycles, the fixed ratio was completed, and pauses followed each FR shock. Later in the session, responses began to appear prior to the end of the 5-min fixed interval. The data for Monkey 525 (fourth panel) typify early performance under the conjt FR FI schedule. Fixed-ratio shocks were delivered in every cycle, were followed by pauses, and then a variable number of responses would occur prior to delivery of the fixed-interval shock. Often very few responses (sometimes just one) would intervene between the fixed-ratio and fixed-interval shocks, as indicated in the last two cycles of the record shown.

The bottom panels of Figure 1 show later performance under the conjt FR FI schedule. Pauses at the beginning of the 5-min cycles were much shorter than they had been under the simple FI 5-min schedule, and overall lever-press rates were higher. Both FR and FI shocks were followed by pauses which were, in turn, followed by positively accelerated responding until the next shock. This was a very stable and reproducible pattern of responding for a considerable number of sessions. Figure 2 displays daily average response rates over the last 10 sessions of exposure to the FI 5-min schedule and then over the subsequent 70 sessions of exposure to the conjt FR FI schedule. For Monkey 525 the pattern of responding shown on the bottom frame of

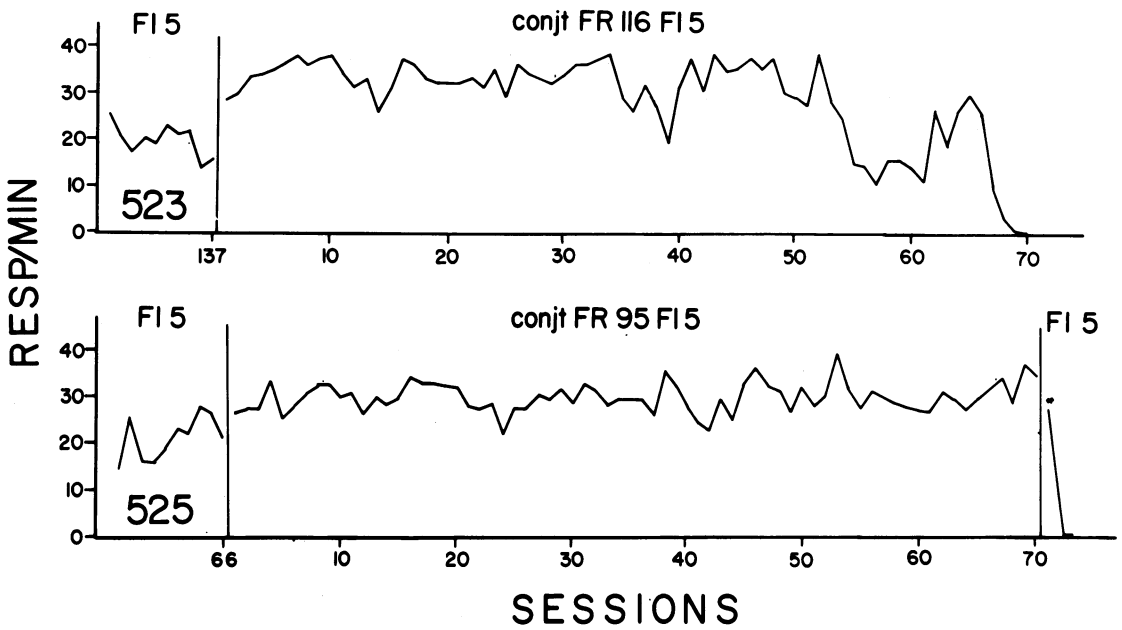
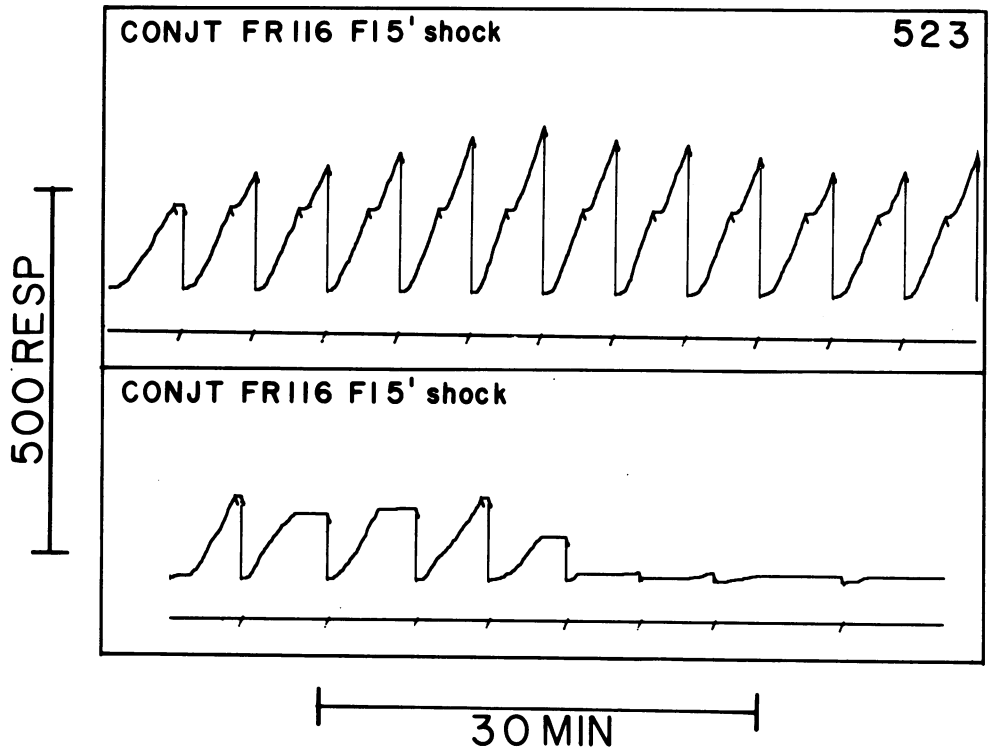


Fig. 2. Daily mean response rates over sessions for Monkey 523 (top graph) and Monkey 525 (bottom graph). Y-axes: responses per minute: X-axes: consecutive sessions. Shown are data from the last 10 sessions of exposure to the FI 5-min schedule of electric-shock presentation, data from 70 sessions under conjt FI FR schedules, and, for Monkey 525, data from three sessions when the conjoint schedule was replaced by the FI 5-min schedule. In Session 71 for Monkey 525, a response-independent shock was delivered at the end of a 15-min pause that occurred shortly after the beginning of the session.

Figure 1 was maintained over the 70 sessions it was in effect. For Monkey 523, however, after the 52nd session, the pattern of responding began to change and responses rates decreased. The nature of this change can be observed in the top two frames of Figure 3. Shown are records from the 52nd and 67th sessions. Session 52 was the last in which reproducible patterns of responding were maintained throughout the session. Between Sessions 52 and 67 responding was less reproducible from cycle to cycle as illustrated in the lower panel for Monkey 523. A pattern that appeared often was one in which slightly fewer than 116 responses would be made in a cycle, followed by a pause that eventually was terminated by a response that resulted in the delivery of the FI shock. Since responding was not being well maintained in Monkey 523, the shock intensity was raised to 9 mA during Session 70 only. This change had no effect.

At the time that Monkey 523's lever pressing had all but disappeared, Monkey 525 was returned to the FI 5-min schedule for three sessions. Surprisingly, Monkey 525's lever pressing deteriorated as soon as the FR schedule was removed. The bottom panels of Figure 3 show this effect. The upper cumulative record is from the last session under the conjoint schedule. The lower record is from the second session after removal of the FR schedule. The first session under FI alone began as did the one shown, i.e., a period of accelerated responding was abruptly terminated and followed by a pause. During the first session of FI alone, after this pause had gone on for about 15 min, we simulated a lever press from the computer terminal and thus delivered the first FI shock response independently. Subsequently, Monkey 525 began lever pressing and completed the session. On the next two days, no response-independent shocks were administered, and records like the one shown in the bottom frame of Figure 3 resulted.

The monkeys occasionally were observed via closed circuit television during sessions. Two features of responding are worth noting. First under the simple FI schedules, when lever pressing was well maintained, behavior in general showed remarkable temporal regularity. The sequences of actions through each cycle of the FI were extremely similar from



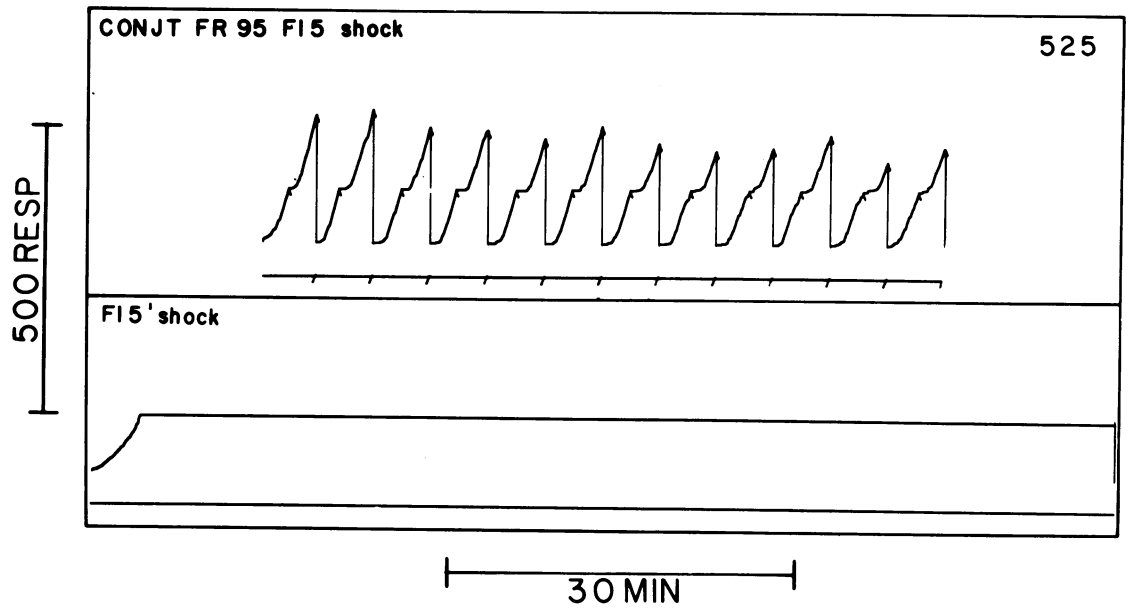


Fig. 3. Cumulative response records of lever pressing by Monkey 523 (upper two panels) and Monkey 525 (lower two panels). Details of recording are the same as for Figure 1. See text for additional description.

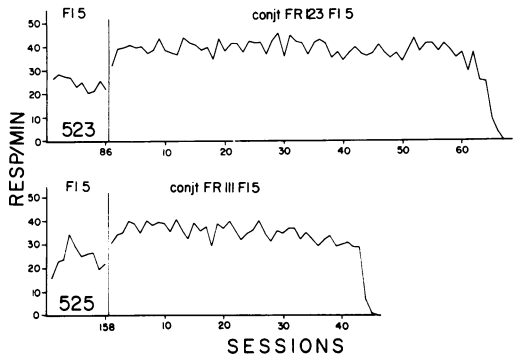


Fig. 4. Daily mean response rates for Monkey 523 (top graph) and Monkey 525 (lower graph) during the last 10 sessions under an FI 5-min schedule and during the second exposure to a conjt FI FR schedule. Details are the same as in Figure 2.

cycle to cycle. After watching the subject through a few repetitions of the fixed interval, it was possible to predict with great accuracy what behavioral pattern would appear next. Second, when lever pressing was not well maintained, and pauses appeared at unusual times, the monkeys remained essentially motionless, or "frozen," during the periods of pausing.

The results of the replication are summarized in Figures 4 and 5. Figure 4 shows daily mean response rates over the last 10 sessions under the FI 5-min schedule and over all the sessions of conjt FR FI. Figure 5 shows selected cumulative records. Responding under the simple FI 5-min schedule appeared much as it had the first time responding was established under this schedule; each cycle was characterized by a pause followed by accelerated responding until shock was delivered. The cumulative records in the top panels of Figure 5 are from the final session under FI 5-min for each subject.

Responding under the conjt FR FI schedule also developed as it had previously. The cumulative records in the second panels of Figure 5 are from the first session under the conjt FR FI schedule. The first few FR shocks were followed by pauses that were terminated by response-produced shocks, and subsequently two periods of positively accelerated responding per cycle developed. Reliable and reproducible rates and patterns of responding quickly developed under the conjt FR FI schedule and were maintained over a substantial number of sessions (Figure 4). The cumulative records in the third panels of Figure 5 are from the 62nd and 39th sessions under the conjt FR FI schedule for Monkeys 523 and 525, respectively, and are representative of the responding that was maintained to those points.

As indicated in Figure 4 response rates dropped precipitously after extended exposure

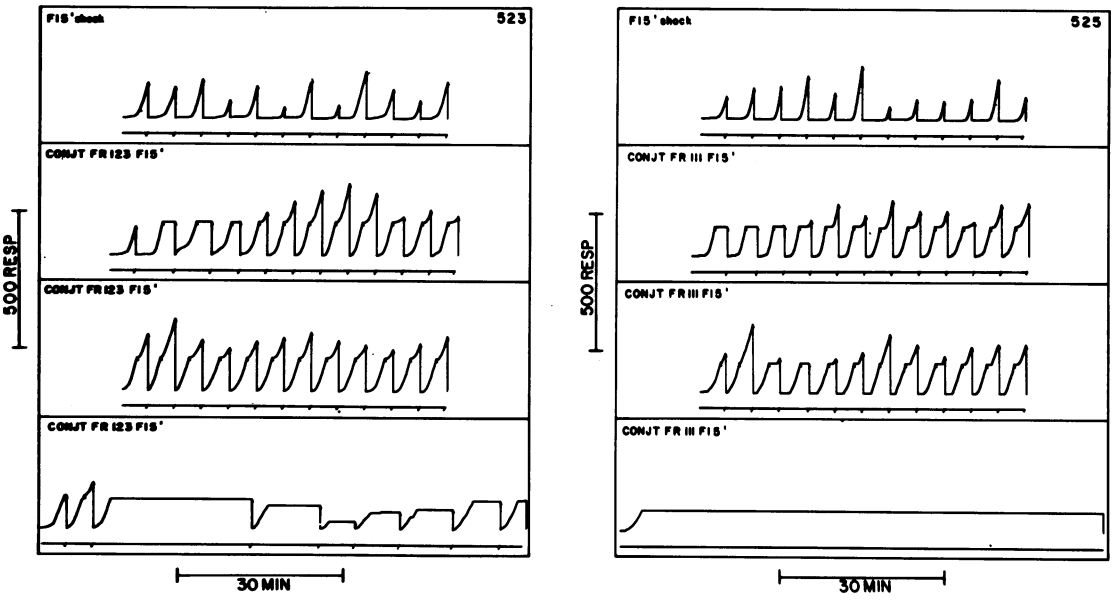


Fig. 5. Cumulative response records of lever pressing by Monkey 523 (left panels); and Monkey 525 (right panels) before and during the second exposure to a conjt FI FR schedule of electric-shock presentation. Details are the same as for Figure 1. See text for additional explanation.

to the conjt FR FI schedule. Neither the daily average rates nor inspection of the daily cumulative records gave any indication that behavior was changing prior to the rapid decline in responding. The cumulative records in the bottom frames of Figure 5 are from the 65th session of conjt FR FI for Monkey 523 and from the 45th session for Monkey 525. Patterns of responding were similar to those seen the first time the monkeys ceased lever pressing: a period of accelerated responding at the beginning of a cycle was abruptly terminated by a pause of long duration. Once again, video-monitor observation of the subjects revealed the monkeys to be essentially immobile during these periods of pausing.

EXPERIMENT II

This experiment examined the effects of a smaller ratio on responding maintained under a fixed-interval schedule of shock presentation.

Because data from our lab (cf. Branch, 1979) and others (cf. Kelleher & Morse, 1968; Malagodi, Gardner, Ward, & Magyar, 1981; McKearney, 1968) suggest that lever pressing by squirrel monkeys can be maintained indefinitely under fixed-interval schedules of shock presentation, it seemed likely that failures to maintain lever pressing in our first experiment were due in some way to the ratio contingencies we had added. Further, since it has been demonstrated clearly that responding controlled by fixed-ratio schedules can have discriminative properties (Branch, 1974; Hobson, 1975; Pliskoff & Goldiamond, 1966; Rilling & McDiarmid, 1965), it is possible that the addition of fixed-ratio contingencies might eventually have made impending shock delivery more discriminable. Since smaller ratios presumably can discriminatively control behavior more precisely (by virtue of Weber's Law: see Hobson, 1975), this interpretation predicts that responding under a conjt FR FI schedule might cease more rapidly with a smaller ratio. To test this interpretation, we added an FR 30 schedule of shock presentation to ongoing responding controlled by the FI 5-min schedule of shock presentation.

METHOD

Subjects

Monkeys 523 and 525 served again, as Experiment II followed immediately upon completion of Experiment I.

Procedure

Table 2 summarizes the procedures of Experiment II. First, the conjt shock-postponement FI 5-min procedure was reinstituted for a few sessions for both monkeys (see Table 2), and then the avoidance contingencies were removed, leaving just the FI 5-min schedule in effect. Monkey 525's lever pressing was well maintained under the FI 5-min schedule of shock presentation, but Monkey 523's was not. Monkey 523, therefore, was exposed to the conjt shock-postponement FI 5-min schedule for 37 additional sessions before being returned to the simple FI 5-min schedule.

After responding under the FI 5-min schedule for 38 (Monkey 523) or 120 (Monkey 525) sessions, a fixed-ratio 30-response contingency was added. The schedule was arranged in a manner identical to that of Experiment I. That is, at the beginning of each fixed interval, the ratio count was set to zero. The 30th lever press resulted in shock delivery, whereupon the ratio contingency was not in effect for the rest of the interval. Delivery of shock via the interval contingency then began a new cycle.

The remaining procedures listed in Table 2 were employed in unsuccessful attempts to reestablish lever pressing under the simple fixed-interval schedule. In addition to prior exposure to a conjt shock-postponement FI 5-min schedule two other methods were tried with both subjects. First, a special "limited hold" was added to the schedule. This contingency specified that if no response was made within 30 sec after the 5-min fixed interval had elapsed, the electric shock was delivered independently of responding and a new fixed interval initiated.

Second, we tried to establish a pattern of positively accelerated responding by means of a shock-stimulus-complex termination procedure (cf. Kelleher & Morse, 1964) before proceeding to the simple FI 5-min schedule. First, 30-sec timeout periods (all lights off, no shocks, and responses without effect) occurred after each shock. Next, the shock-stimulus-complex termination procedure was instituted. Under this arrangement, after 5 min had elapsed from the beginning of a cycle, shocks were delivered independently of responding once every second. The first response after 5 min elapsed, however, terminated the train of shocks and produced the 30-sec timeout period. Under

Table 2

Procedures and Numbers of Sessions in Experiment II

Monkey 523		*Monkey 525*	
Condition Procedure	*Sessions*	*Condition Procedure*	*Sessions*
1. Conjt shock postponement + FI 5-min	3	1. Conjt shock postponement + FI 5-min	5
2. FI 5-min	11	2. FI 5-min	120
2a. Conjt shock postponement + FI 5-min	37		
2b. FI 5-min	38		
3. Conjt FI 5-min + FR 30	41	3. Conjt FI 5-min + FR 30	24
4. Conjt shock postponement + FI 5-min	4	4. Conjt shock postponement + FI 5-min	2
5. FI 5-min	46	5. FI 5-min	15
6. Conjt shock postponement + FI 5-min	5	6. Conjt shock postponement + FI 5-min	32
7. FI 5-min	64	7. FI 5-min	18
		7a. Conjt shock postponement + FI 5-min	6
		7b. Conjt shock postponement + FI 5-min (R-S = 40 sec)	16
8. FI 5-min LH 30 sec (shock delivered response-independently if LH expired)	36	8. FI 5-min LH 30 sec (shock delivered response-independently if LH expired)	36
9. FI 5-min LH 30 sec TO 30 sec (30-sec timeout after each shock)	14	9. FI 5-min LH 30 sec TO 30 sec (30-sec timeout after each shock)	15
10. FI 5-min termination of shock-stimulus complex	32	10. FI 5-min termination of shock-stimulus complex	27
11. FI 5-min LH 30 sec TO 30 sec	40	11. FI 5-min LH 30 sec TO 30 sec	29
		12. FI 5-min TO 30 sec + shock postponement during last minute of each FI	41
		13. VI 3-min	17
		14. Conjt shock postponement + VI 3-min	8
		15. VI 3-min LH 30 sec (shock delivered response-independently if LH expired)	113

this procedure, it was possible to avoid all shocks by making a response between 300 and 301 sec from the beginning of an interval.

Several other procedures also were tried with Monkey 525. Prior to introduction of the "limited hold" procedure to this subject, the R-S interval was lengthened to 40 sec during exposure to the conjt shock-postponement FI 5-min schedule in the hope of developing a more pronounced "scallop" under the conjoint schedule before proceeding to the simple FI schedule. Other procedures used with Monkey 525 included exposure to a conjt shock-postponement FI 5-min procedure in which the postponement contingency operated only during the last minute of each 5-min fixed interval, and also an attempt at making a transition from a conjt shock-postponement variable-interval 3-min (VI 3-min) schedule to a simple VI 3-min schedule. The order of these procedures is outlined in Table 2.

Results

Figure 6 depicts session-by-session response rates under the last 10 sessions of the FI 5-min schedule alone and rates during all sessions under the conjt FI 5-min FR 30 schedule. For both subjects, responding under the conjoint schedule abruptly decreased after having

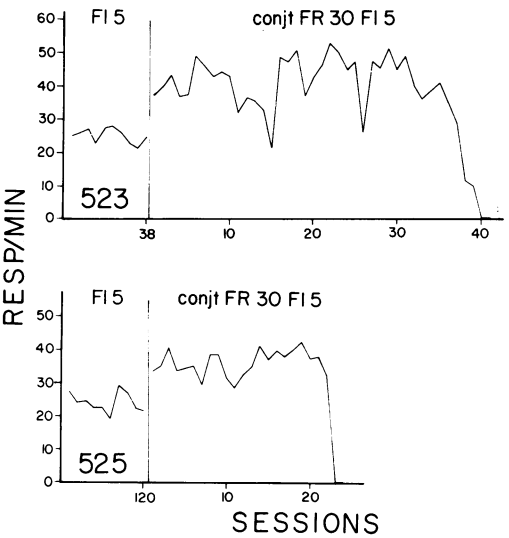


Fig. 6. Daily mean response rates for Monkey 523 (upper graph) and Monkey 525 (lower graph) before and during exposure to a conjt FI 5-min FR 30 scehdule of electric-shock presentation. Details are the same as for Figure 2.

reached an apparent steady state. Fewer sessions passed before responding decreased than had elapsed when larger FR schedules previously had been added to the FI schedule (Experiment I).

As shown in the top frames of Figure 7, lever pressing under the FI 5-min schedule once again assumed typical characteristics. The records shown are from the last session of FI 5-min before the FR 30 schedule was added. The next lower frames show records from the first session in which the conjt FR 30 FR 5-min schedule was in effect, and the third frames show records from the 29th and 19th sessions under the conjoint schedule for Monkeys 523 and 525, respectively. As observed previously, each shock was followed by a pause, and overall rates were higher under the conjoint schedule than they had been under FI 5 min. Note that pauses prior to the initiation of the FR 30 were considerably shorter than those observed with the larger ratios. The lowest frames display records from the 37th session for Monkey 523 and from the 23rd for Monkey 525. The last few sessions for Monkey 523 resulted in cumulative records similar to the one shown: early in the session responding abruptly terminated. Each time, lever pressing ceased shortly before a shock was scheduled to be delivered via the FI schedule. For Monkey 525, the last two sessions were characterized by the emission of fewer than 10 lever presses right at the beginning of the session, followed by a lengthy pause. Observation over closed-circuit television revealed that during the long pauses the monkeys were motionless as they had been previously.

Following exposure to the conjt FR 30 FI 5-min schedule, we were able to maintain performance under the FI 5-min schedule in neither Monkey 523 nor Monkey 525. For both subjects the failure of response maintenance was characterized by abrupt cessation of lever pressing during a period of positively accelerated responding. As described in the *Procedure* section, a number of attempts to re-establish responding were undertaken and are outlined in Table 2.

With neither monkey were we able to maintain appropriate patterning when the special "limited hold" contingency was introduced. During the first five to ten sessions, most shocks were delivered by the fixed-interval contingency, but subsequently many "limited-hold" shocks were delivered.

The shock-stimulus-complex termination procedure produced high rates of positively accelerated responding in both subjects, but

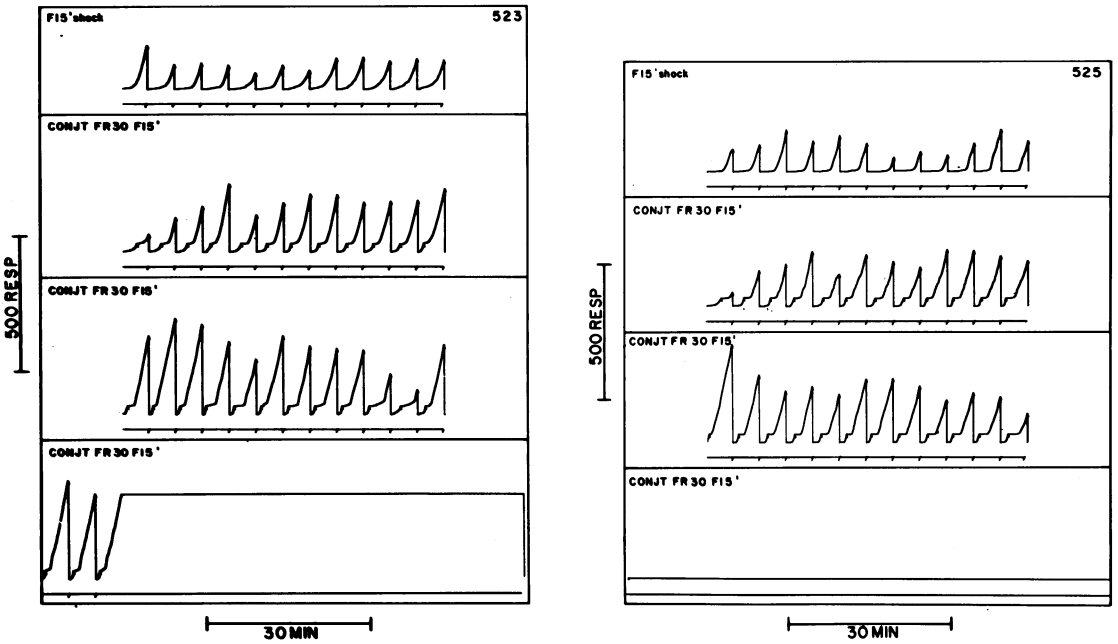


Fig. 7. Cumulative response records of lever pressing by Monkey 523 (left panels) and Monkey 525 (right panels) before and during exposure to the conjt FR 30 FI 5-min schedule of electric-shock presentation.

following a transition to the fixed-interval schedule of shock presentation (with the "limited hold" contingency in effect) responding quickly declined.

We were unable to maintain responding in Monkey 525 under the variable-interval contingency as well.

EXPERIMENT III

This experiment examined responding under variable-ratio schedules of electric-shock presentation and was conducted concurrently with Experiment II. If some regularity in the number of responses per shock contributed to the decline in responding observed in Experiment I, then perhaps it is possible that ratio contingencies of shock presentation will not result in cessation of responding if the number of responses per shock is variable. Also, it has been shown clearly that responding can be maintained under variable-interval schedules of electric-shock presentation (McKearney, 1972, 1973). Thus, variability in the time from shock to shock is not sufficient to cause responding maintained by electric-shock presentation to decrease as it did in Experiment I. Consequently, we determined to examine the effects of variable-ratio (VR) schedules in Experiment III.

Method

Subject

Monkey 526 served.

Procedure

Table 3 summarizes the procedures of Experiment III.

First, Monkey 526 was trained to lever press under an FI 5-min schedule of electric-shock presentation using the same method as that initially used for the other two monkeys in Experiment I (see Table 3). Once again, the numbers of responses per interval were recorded. This time, however, the values from the last 10 sessions under the FI schedule were used to construct 10 variable-ratio (VR) schedules. Each VR schedule had 12 values which corresponded to the twelve values obtained in a session under the FI 5-min schedule. Thus, the VR schedules were "yoked" to performance under the FI 5-min schedule. The yoked VR schedules were presented in the same order as the sessions from which they had been determined. Thus, the VR schedule constructed from data of the 72nd session was presented first, followed by the VR yoked to the 73rd session, and so on until all 10 VR schedules had been employed, then the cycle was repeated. The VR values can be found in Table 3.

Table 3

Procedures for Monkey 526 in Experiment III

Condition Procedure	*Sessions*
1. Shock postponement	12
2. Conjt shock postponement + FI 5-min	9
3. FI 5-min	7
4. Conjt shock postponement + FI 5-min	13
5. FI 5-min	81
6. Yoked VR (to FI 5 data) (VR values: 118, 103, 101, 108, 108, 155, 132, 109, 102, 109)	16
7. FI 5-min	20
8. FI 2-min	35
9. Yoked VR (to FI 2 data) (VR values: 73, 72, 68, 63, 64, 69, 68, 63, 74, 61)	23
10. FI 5-min	117

After 16 sessions under the yoked VR schedules, the FI 5-min schedule was reinstituted. We next reduced the fixed interval to 2 min and systematically replicated our first VR experiment. That is, once again 10 yoked VR schedules were determined from the last 10 sessions under the FI 2-min schedule, and then presented in the same order as the sessions from which they were taken. Finally the FI 5-min schedule was reinstituted.

Results

The first two panels of Figure 8 and the top three panels of Figure 9 show the results of the first introduction of a VR schedule. As Figure 8 indicates, responding was not well maintained under the yoked VR schedules, eventually dropping to very low levels such that all twelve scheduled shocks were not delivered in the space of sessions that were extended to over three hours. Figure 9 illustrates the nature of the decline in responding. The top three panels show data from Sessions 72, 82, and 92, i.e., sessions in which the number of responses per shock was the same. Session 82 was the first session under the VR schedule, and the rate-decreasing effect of the ratio contingency was apparent in this session in that the time taken to receive the 12 shocks was

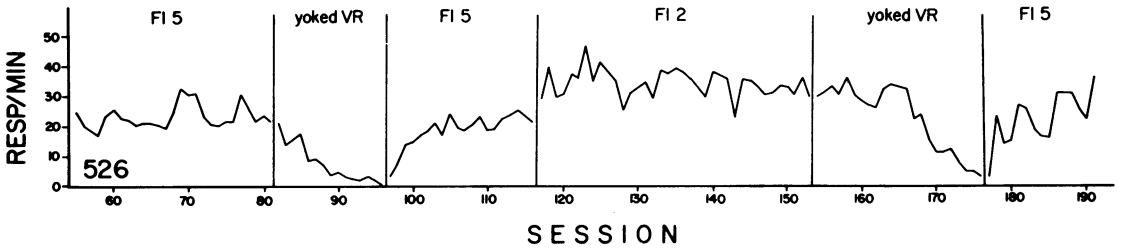


Fig. 8. Daily mean response rates for Monkey 526 during exposure to fixed-interval schedules and "yoked" variable-ratio schedules of electric-shock presentation. Sessions are numbered from the first session under the FI 5-min schedule.

greater than that taken in the session from which the ratio values were obtained. By Session 92, rates were substantially reduced, but the positively accelerated patterns were still evident.

Responding quickly recovered when the FI schedule was put back into effect. At this time we surmised that perhaps responding had declined under the VR schedules because the VR value was too high, i.e., that perhaps "ratio strain" (cf. Ferster & Skinner, 1957) had occurred.

The results of the systematic replication beginning with FI 2 are displayed in the fourth and fifth panels of Figure 8 and in the bottom three panels of Figure 9. Again, lever pressing was not well maintained by the yoked VR schedules, although it was maintained for more sessions than was the case with the larger VR schedules. The nature of the decline (see Figure 9) was very similar to that observed with the larger VRs. That is, rate was lower in the very first session (Figure 9—Panel 5), and as rate declined the positively accelerated pattern of responding remained. The effect on the cumulative records was similar to what would occur if one simply "stretched" the records horizontally. In no session was an abrupt cessation of responding similar to that seen with the conjt FR FI schedules observed.

The last panel of Figure 8 shows that when an FI 5 schedule was reintroduced beginning in Session 176, responding quickly recovered. Consistent, well-patterned, lever pressing was maintained under the FI 5-min schedule for an additional 87 sessions not shown in Figure 8. No other experiments were conducted with this subject.

DISCUSSION

In all three of the experiments reported here, ratio contingencies disrupted responding that was maintained under interval schedules of shock presentation. In Experiments I and II, addition of a fixed-ratio shock contingency eventually resulted in abrupt cessation of responding concurrently maintained by a fixed-interval schedule of shock presentation. In Experiment III replacement of a fixed-interval schedule of shock presentation by a variable-ratio schedule resulted in a gradual decline in responding even though the numbers of responses per shock under the VR schedule were "yoked" to values obtained under the FI schedule. Apparently, some aspect of ratio contingencies acted to prevent responding from being supported indefinitely. Identification of which aspect (or aspects) was important, however, is difficult.

Given our findings that responding stopped abruptly rather than gradually when FR schedules were added to FI schedules, we first hypothesized that when the number of responses prior to shock presentation becomes highly discriminable, responding will stop. Several features of the present data argue against this hypothesis. First, responding was not maintained under either a variable-ratio schedule (Monkey 526, Figures 8 and 9) or under a variable-interval schedule (Monkey 525) even though the number of responses per shock varied considerably under these procedures (although Monkey 525's failure to respond under the VI schedule is difficult to interpret because of its history of ceasing to respond several previous times). Additionally, when the FR 30 schedule was added to the FI 5-min schedule for Monkey 523, responding ceased abruptly just before a shock scheduled by the FI contingency rather than just before the presumably more discriminable fixed-ratio shock.

Addition of the FR shock schedule to the FI schedule reduced the differential shocking

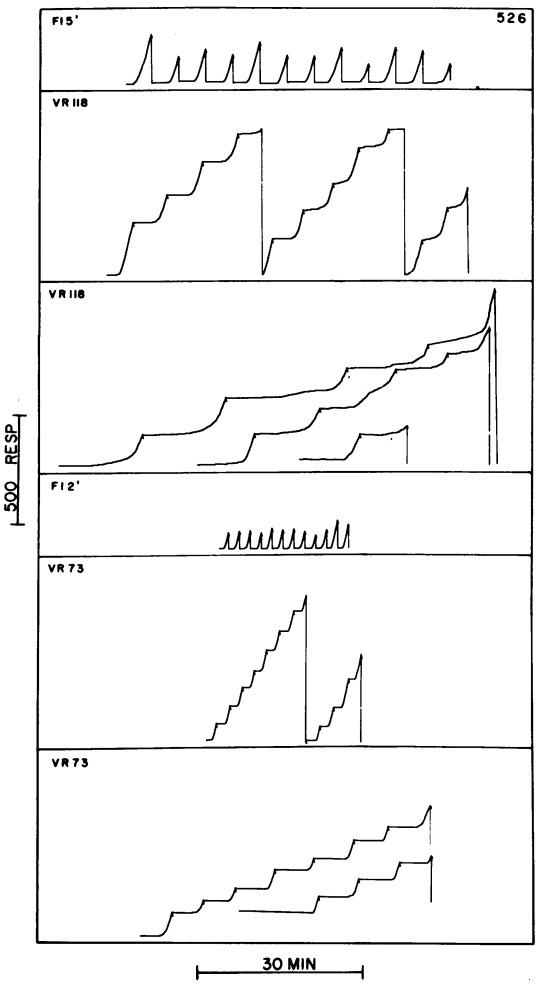


Fig. 9. Cumulative response records of lever pressing by Monkey 526. Y-axes: cumulative lever presses. X-axes: continuous time. The upper-most and fourth panels show records from sessions in which a fixed-interval schedule of electric-shock presentation was in effect. In these panels the pen reset to the baseline after each shock. Remaining panels are records from sessions in which a variable-ratio schedule was in effect. The records in panels 3 and 6 have been collapsed for compact presentation. Diagonal marks on the records indicate shock delivery. In the top three records and in the bottom three records the number of responses per shock is matched. See text for additional details.

of long interresponse times (IRT's), and substitution of the VR schedule for the FI schedule eliminated such differential contingencies. Galbicka & Branch (1981) have shown that IRTs can be suppressed differentially by electric shock and have speculated that differential IRT contingencies may play a role in the maintenance of behavior by schedules of electric-shock presentation. Specifically, they suggest that interval contingencies of shock presentation result in differential suppression of long IRTs which can, under appropriate circumstances, lead to an increase in the frequency of shorter IRTs and thus increase response rates. The present results are not inconsistent with such a view.

Interestingly, the nature of the failure of response maintenance differed depending on the way in which ratio contingencies were added. When an FR schedule was superimposed upon ongoing responding under an FI schedule, response cessation was characterized by an extremely abrupt halt, whereas when a VR schedule was substituted for an FI schedule of shock presentation, responding gradually declined. Future research should determine if this difference is due to conjoint interval-ratio contingencies versus ratio contingencies alone or due to fixed- versus variable-ratio contingencies. McKearney's (1970) data suggest that perhaps the former difference is the crucial one. His monkey that was exposed to a simple FR 30 schedule of shock presentation revealed a gradual decline in response rate over the eight sessions of exposure to the procedure. Another potential source of the differing cessation patterns was the differing relation between responding and shock frequency arranged by each of the schedules.

The present data serve to confirm previous findings that responding can be maintained for long periods of time under fixed-interval schedules of electric-shock presentation, i.e., response-produced shock (cf. Kelleher & Morse, 1968; McKearney, 1968). Not only was schedule-appropriate temporal patterning generated by the fixed-interval schedules, but also by the conjoint FI FR schedules prior to cessation of responding. Addition of the FR schedules initially produced increases in response rate and a pause-respond pattern during the ratio that is similar to that observed under simple fixed-ratio schedules of food presentation (cf. Ferster & Skinner, 1957; it should be noted, however, that the rates under the ratio schedules often were more positively accelerated than those usually seen under FR schedules of food presentation). Additionally, shorter ratios produced shorter preratio pauses, another finding that is consistent with observations with food presentation as a consequent event (Felton & Lyon, 1966; Powell, 1968). Thus, when responding was maintained, effects were similar

to those seen under conditions in which positive reinforcement is said to occur.

The present data also bear indirectly on a "safety" account of responding maintained by schedules of response-dependent electric-shock presentation. (See Malagodi et al., 1981, for an extended discussion of "safety theory.") According to such an account, responding under response-produced shock procedures depends on shock signaling a period of safety (i.e., no shocks) immediately following its presentation. If that were the case responding should have been supported by the conjoint FI FR schedules, because under asymptotic performance (see Figures 1, 3, and 5) each shock was followed by a period free of shock. Were "safety" all that is needed to maintain responding, then lever pressing under the conjoint FI FR schedules would not have stopped.

A potentially troubling aspect of the present data is the comparatively long time that had to elapse before responding abruptly halted under the conjoint FI FR schedules. Inspection of Figures 2, 4, and 6 shows that by many criteria of stability a steady state of responding had been established well prior to the cessation of responding. Yet responding eventually underwent large changes. Neither pause-measures nor index-of-curvature measures revealed any instability once rate reached an apparent steady state. Perhaps other more "molecular" measures of responding would have provided indications of the underlying instability that eventually led to response cessation. These findings emphasize that extreme care and conservatism must be employed when studying responding maintained by schedules of response-produced shock, and that as many measures as feasible be employed. Direct assessment of the quantitative properties of ongoing responding may be critical to effective study of this phenomenon.

The present results indicate limits to the conditions under which responding can be maintained indefinitely under schedules of response-dependent electric-shock presentation. As these findings are augmented by others describing precisely the conditions necessary for the maintenance of such responding, our understanding of this intriguing phenomenon will increase.

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Received September 2, 1980
Final acceptance February 19, 1981