SCHEDULES USING NOXIOUS STIMULI. III. RESPONDING MAINTAINED WITH RESPONSE-PRODUCED ELECTRIC SHOCKS¹

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Responding was maintained in two squirrel monkeys under several variations of a 10-min fixed-interval schedule of electric shock presentation. The monkeys were first trained under a 2-min variable-interval schedule of food presentation, and then under a concurrent schedule of food presentation and shock presentation. In one monkey, when shocks (12.6 ma) followed each response during the last minute of an 11-min cycle ending with a timeout period, responding was increased during the first 10 min and suppressed during the last minute of each cycle. When the shock schedule was eliminated, both the enhancement and suppression disappeared, and a steady rate of responding was maintained under the variable-interval schedule. When the food schedule was eliminated, the shock schedule maintained a characteristic fixed-interval pattern of responding during the first 10 min, but suppressed responding during the last minute of each cycle. The fixed-interval pattern of responding was maintained when the timeout period was eliminated and when only one shock could occur at the end of the cycle. In the second monkey, responding under the concurrent food and shock schedule was suppressed when responses produced shocks after 3-min. Under an 11-min cycle, responding continued to be maintained at increasing shock intensities. When the food schedule was eliminated, a fixed-interval pattern of responding was maintained under a 10-min schedule of shock presentation (12.6 ma). Whether response-produced electric shocks suppressed responding or maintained responding depended on the schedule of shock presentation.

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Discussion

There is abundant evidence that responding maintained under schedules of food presentation can be suppressed when responses produce electric shocks; the pattern of suppression typically depends upon how the punishing electric shock is scheduled (see Azrin and Holz, 1966, for a discussion of punishment). For example, Azrin (1956) showed in the pigeon that a fixed-interval schedule of electric shock presentation in one component of a multiple

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schedule changed the steady rate of key-pecking maintained by a variable-interval schedule of food presentation to a pattern of deceleration preceding the scheduled shock in that component. The initial plan of the present experiment was to use a concurrent schedule of food presentation and shock presentation to produce similar patterns of decelerated responding in the squirrel monkey. Two monkeys were studied under fixed-interval schedules of shock presentation at different parameter values (3 min and 10 min). When we found in one monkey (S-43) that the rate of responding increased rather than decreased under the 10-min schedule of shock presentation, we studied this phenomenon in detail. We then explored conditions under which responding could be similarly enhanced in the second monkey (S-44) by a fixed-interval schedule of shock presentation. In both monkeys, responding controlled by the 10-min fixed-interval schedule of shock presentation was maintained for months after the variable-interval schedule of food presentation was eliminated.

The present paper gives a detailed account of experiments with the two monkeys. For Monkey S-43, we will describe the conditions under which the increases in responding first occurred (Exp. I) and then the subsequent experiments in which this phenomenon was studied (Exp. II, III, and IV). For Monkey S-44, we will consider the initial suppression of responding under the concurrent schedule of food presentation and 3-min fixed-interval schedule of shock presentation (Exp. V) and the subsequent experimental manipulations that eliminated the suppression and maintained increased rates of responding (Exp. VI, VII, VIII, IX). The many procedural details that will be described are included because of our presently incomplete understanding of the factors contributing to the terminal performances. The primary purpose of this paper is to describe conditions under which electric shock can suppress or maintain responding depending upon how the shock is scheduled.

METHOD

Subjects

Two mature, male squirrel monkeys (*Saimiri sciureus*) with no previous training were used (S-43 and S-44). The monkeys were handled according to the procedures described by

Kelleher, Gill, Riddle, and Cook (1963). Except where noted, they were maintained at 80% of their free-feeding weights.

Apparatus

A restraining chair similar to the one described by Hake and Azrin (1963) was used (see Kelleher and Morse, 1964). Each monkey was restrained in the seated position by a waist lock, its tail held motionless by a small stock. Electric current was delivered through two hinged brass plates, which rested lightly on a shaved portion of the tail. A noncorrosive electrode paste (EKG Sol®) applied to the tail ensured a low resistance electrical contact between the plates and the tail. The electric shock was 580 v ac, 60 cps, delivered for 45 msec to the plates through a series resistor selected to produce the designated current (nominal value) when there was no resistance between the plates. This resistance was 58,000 ohms for 10 ma and 38,600 ohms for 15 ma. At the latter intensity, the observed current flow through the tail of each monkey was 12.6 ma. Shock intensities lower than 12.6 ma are reported as the nominal value because systematic observations were not made on the impedance of the tail at these intensities. The response key (Lehigh Valley Electronics rat lever, LVE 1352) was mounted on the right side of a metal wall facing the monkey. When the key was pressed with a force of 22 g or more, a response was recorded. Each response produced an audible relay click. Just above the key was a stimulus panel which could be transilluminated by a red light (Industrial Electronics Engineers, One Plane Digital Display Unit, Model No. 10256Q). The metal wall contained a recessed area directly in front of the monkey. A solenoid-operated dipper could provide access to liquid food (Ellison and Riddle, 1961) through a hole in the bottom of the recessed area. During food delivery the recessed area was illuminated by two 6-w white bulbs. The entire chair unit was enclosed in a ventilated refrigerator shell. General illumination was provided by an overhead light (25-w GE type 101F) operated from 110 v ac through a 500-ohm resistor. White noise was always present.

Procedure

Both monkeys were trained in the presence of a red light under a schedule in which each

response produced access to 0.25 ml of liquid food for 3 sec. Then the schedule was changed to a 2-min variable-interval schedule of food presentation. Every 10 min there was a 1-min timeout period during which the experimental chamber was dark, and responses had no scheduled consequences. Each session ended after the tenth 10-min period under the variable-interval schedule. Sessions were usually conducted daily Monday through Friday.

Subsequently, fixed-interval schedules of response-produced electric shock were superimposed on the 2-min variable-interval schedule of food presentation (VI 2-min). Different parameter values were used with the two monkeys. For Monkey S-43, the first response occurring after 10 min produced a 10-ma electric shock (FI 10-min) followed by a 1-min timeout; if a response did not produce a shock, the timeout period occurred automatically at 11 min. For Monkey S-44 (Exp. V), the 10-min fixed-interval schedule was reduced to 3 min (FI 3-min); if a response did not produce a shock, the timeout occurred automatically at 3 min and 18 sec.

Analysis of Results

Average rates of responding for each session were computed in responses per second from readings on digital counters and elapsed time meters. From the total number of responses recorded in each tenth of the first 10 min (or 3 min) of each cycle, the average time taken for the first quarter of the responses in the cycle to occur was computed by linear interpolation. This estimated quarter-life value provides an indication of the temporal patterning of responding, which is relatively independent of rates of responding (Herrnstein and Morse, 1957; Gollub, 1964). For convenience in comparing data from cycles of different durations, the average quarter life is expressed as a percentage of the duration of the cycle (Gollub, 1964). Responding was also recorded on cumulative-response recorders.

EXPERIMENT I: INITIAL PERFORMANCES UNDER A CONCURRENT VARIABLE-INTERVAL (VI) SCHEDULE OF FOOD PRESENTATION AND FIXED-INTERVAL (FI) SCHEDULE OF ELECTRIC SHOCK PRESENTATION (MONKEY S-43)

During the few sessions under the VI 2-min schedule of food presentation, the rate of re-

sponding was about 0.20 responses per sec; the quarter-life values were near 25%, suggesting steady responding in each cycle (Fig. 1A). Under the fixed-interval schedule of shock presentation, which was introduced in Session 12, the first response occurring after 10 min produced a 12.6-ma electric shock (FI 10-min) followed by a 1-min timeout; if a response did not produce a shock, the timeout period occurred automatically at 11 min. The rate of responding decreased to near zero by Session 13 and subsequently ranged from 0.01 to 0.10 responses per sec; quarter-life values varied around 25% (Fig. 1B). Although the schedule of shock presentation suppressed responding, there was no pattern of negatively accelerated responding. When scheduled shocks were omitted in Sessions 27 to 43, rates of responding recovered to between 0.15 and 0.20 responses per sec, and quarter-life values varied unsystematically between 26% and 35% (Fig. 1C and 2A).

The reintroduction of scheduled shocks in Session 44 decreased rates of responding, but less than initially. Rates of responding gradually recovered from 0.11 responses per sec in

Fig. 1. Rates of responding and quarter-life values under concurrent VI 2-min (food) FI 10-min (12.6-ma shock) (Monkey S-43). A and C: VI 2-min (food) only. B and D: concurrent VI (food) FI 10-min (shock). Sessions 14 to 19 terminated after the twentieth rather than the tenth timeout period; thus, the data from these sessions are based on longer session durations. In Sessions 19 to 30, each food delivery comprised two successive presentations of 0.25 ml of liquid food. The arrows indicate sessions for which cumulative response records are shown in Fig. 2.

Session 47 to 0.24 responses per sec in Session 53 (Fig. 1D and 2B, C, D). Interestingly, quarter-life values, which were near 25% in Sessions 44 and 45, were from 30% to 39% in Sessions 47 to 53 (Fig. 1D). Also, the cumulative-response records show clear instances of a pattern of positively accelerated responding within some 10-min intervals (Fig. 2B-D). The recovery of responding under concurrent schedules of food and shock presentation has been observed in many studies (see Azrin and Holz, 1966). But the pattern of positively accelerated responding that developed with the FI 10-min schedule of shock presentation was unexpected. We studied this phenomenon for more than two years.

EXPERIMENT II: ENHANCED RESPONDING
ALTERNATING WITH SUPPRESSED RESPONDING
UNDER DIFFERENT SCHEDULES OF SHOCK
PRESENTATION (MONKEY S-43)

This experiment studied the effects of altering the schedule of shock presentation so that, at times, each response would produce a shock. Beginning with Session 54, the 1-min timeout

periods occurred every 11 min independently of responding; the VI 2-min schedule of food presentation was in effect throughout the 11 min. As before, the first response occurring after 10 min had elapsed produced a 12.6-ma electric shock (FI 10-min). In addition, each subsequent response during the eleventh minute also produced the electric shock (FR 1). During the next 135 sessions, drugs were given on 15 occasions; the temporary drug-induced changes in responding will not be discussed.

Average rates of responding were initially suppressed under the conditions of this experiment. In Session 56, the mean rate fell to its minimum of 0.10 responses per sec; the quarter-life was 19.1%. Although responding in the last minute of each cycle remained almost completely suppressed, average rates of responding subsequently increased. In Sessions 64 to 73, average rates ranged from 0.15 to 0.22 responses per sec, while quarter-life values ranged from 32.4 to 39.3%. In Sessions 102 to 111, average rates ranged from 0.47 to 0.60 responses per sec, while quarter-life values ranged from 45.7 to 54.2%. A gradual trend

Fig. 2. Performance under concurrent VI 2-min (food) FI 10-min (12.6-ma shock) (Monkey S-43). Ordinate: cumulative number of responses; abscissa: time. Food presentations are marked by a short diagonal stroke on the cumulative record; shock presentations by a stroke on the event record. The pen reset to the baseline at the end of each cycle. The paper did not move during the 1-min timeout periods between cycles. A: Session 43, VI (food) only. B-D: Sessions 47, 50, 53, concurrent VI (food) FI (shock). Note the positive curvature in the cumulative response records of some cycles after the shock schedule was reintroduced.

toward higher average rates of responding and patterns of more positively accelerated responding in the first 10 min of each cycle continued over many sessions (Fig. 3).

An available reinforcement arranged under the VI 2-min schedule before a timeout was not attainable following the timeout after Session 114. There was only one session per week from Session 112 to 127. After these procedural changes, quarter-life values were little affected, but average rates of responding increased further, ranging between 0.73 and 0.95 responses per sec in Sessions 115 to 127. With five sessions per week from Session 128 to 168, there was no further trend in average rates of responding or quarter-life values.

The stable performance under the concurrent schedule of food presentation and shock presentation had three distinctive features (Fig. 3D). Following the timeout, a steady, low rate of responding occurred during the first several minutes of the interval; a high rate of responding was sustained until a shock was produced by the first response occurring in the eleventh minute. Usually, no responses occurred during the remainder of the eleventh minute. This pattern of responding was stable for more than 100 sessions.

During the next 10 sessions no shocks were presented; only the VI 2-min schedule of food presentation was in effect (Sessions 169 to 187). The omission of the shock schedules changed the pattern of responding almost immediately (Fig. 4A). During the first cycle and thereafter, the rate of responding that was occurring at the end of the tenth minute was sustained throughout the eleventh minute of each cycle. A high rate of responding occurred throughout the second, third, and fourth cycles; a lower rate of responding occurred throughout the last three cycles. During the next four sessions, high rates of responding occasionally occurred in individual cycles, especially near the beginning of the session. The performance in the last session under the VI 2-min schedule alone is shown in Fig. 4B. Omitting the shock schedule decreased the average rate of responding, increased the rate of responding in the eleventh minute, and eliminated the characteristic changing pattern of responding within each cycle (quarter-life decreased to about 30%). The rate of responding during the initial minute of each cycle was not changed.

When shocks were again delivered following

each response in the eleventh minute, the stable performance shown in Fig. 3D was recovered. The rate of responding in the eleventh minute immediately decreased (Fig. 4C, D). During the first session (Fig. 4C), the previous pattern of a low rate followed by a sustained high rate of responding occurred in some cycles. The pattern of responding during the second session (Fig. 4D) was even more similar to the earlier performance, except that some responding occurred throughout the eleventh minute. In subsequent sessions, responding in the eleventh minute decreased to near zero. Average rates of responding increased, ranging from 0.92 to 1.16 responses per sec in Sessions 197 to 202; quarter-life values remained between 50% and 60% (Fig. 5A).

The results obtained in this experiment suggested that the schedule of electric shock presentation maintained: (1) the higher average rate of responding in the latter part of each 10-min period; (2) the suppression of responding in the eleventh minute; and (3) the characteristic pattern of responding. The characteristics of responding further suggested that the presentation of shock following each response in the eleventh minute constituted two functional parts: a 10-min FI component (responding enhanced) and then an FR 1 component (responding suppressed). The steady low rate of responding at the beginning of each cycle

Fig. 3. Performance under concurrent VI 2-min (food) and two-component FI 10-min FR 1 (12.6-ma shock) (Monkey S-43). Recording as in Fig. 2; the pen reset to the baseline at the end of each 11-min cycle. A-D: Sessions 66, 103, 117, and 168. Note the development of positively accelerated responding in the first 10 min and of suppressed responding in the eleventh minute of each cycle.

appeared to be maintained by the VI schedule of food presentation. The contribution of the schedule of food presentation to this performance was evaluated by eliminating the VI 2-min schedule in Exp. III.

EXPERIMENT III: MAINTENANCE OF RESPONDING UNDER THE TWO-COMPONENT FI 10-MIN FR 1 SCHEDULE OF SHOCK PRESENTATION ALONE (MONKEY S-43)

The VI 2-min schedule of food presentation was omitted beginning with Session 203; only the two-component shock schedule remained in effect. The first response after 10 min had elapsed produced the 12.6-ma electric shock (FI 10-min); each subsequent response during the eleventh minute also produced the electric shock (FR 1). As in Exp. II, a 1-min timeout occurred at the end of each 11-min cycle.

The cumulative response records in Fig. 6 show the initial and the maintained performance under the shock schedule alone. In the first session after the VI schedule was omitted

Fig. 4. Effects of omitting the two-component shock schedule (Monkey S-43). Recording as in Fig. 3; the pen reset to the baseline at the end of each 11-min cycle or when 1100 responses had accumulated. A: Session 169, initial performance under VI 2-min (food) with shock schedule omitted. B: Session 187, final performance under food schedule only. C, D: Sessions 188 and 189, initial performance under concurrent VI 2-min (food) FI 10-min FR 1 (12.6-ma shock). Note the disappearance of the positive curvature when shocks were omitted and its gradual return under the concurrent schedule.

Fig. 5. Rates of responding, quarter-life values, and average number of responses in the first minute of each cycle under the concurrent food and shock schedule and under the two-component FI 10-min FR 1 shock schedule only (Monkey S-43). A: concurrent food and shock schedule. B: two-component shock schedule only; after the dotted line (Session 217), the monkey was given free access to food in the living cage. The main effect of eliminating the VI schedule was that responding decreased in the first minute of each cycle. The arrows indicate sessions for which cumulative response records are shown in Fig. 6.

(Fig. 6A) the response pattern was little changed from the performance in Exp. II. The responding at the beginning of each cycle decreased after the VI schedule of food presentation was eliminated (Fig. 5B). The quarter-life values increased only slightly because most of the responding continued to occur late in the interval. In the session shown in Fig. 6B, no responses occurred (and no shocks were delivered) in the third or fifth intervals; each of these intervals was followed by an interval in which many responses occurred. Because of this type of alternation, the average rates of responding were somewhat variable from session to session during this phase (Fig. 5B).

The two-component schedule of shock presentation alone maintained a characteristic pattern of responding over a six-month period (Sessions 203 to 343). The monkey was allowed free access to food in its living cage after Session 217 and was not deprived again. Average rates of responding continued to be variable, but the quarter-life values were little changed (Fig. 5B). Some cumulative response records illustrating characteristics of performance during this period are shown in Fig. 6C, D, E. Most cycles began with a period of

Fig. 6. Characteristic performances under the two-component FI 10-min FR 1 shock schedule (Monkey S-43). Recording as in Fig. 4. A-E: Sessions 203, 211, 252, 301, and 338. The pattern of responding during the first 10-min of each cycle shows the positive curvature characteristic of performance under fixed-interval schedules; under the FR 1 schedule in the last minute of each cycle, responding was suppressed. Arrows indicate cycles that terminated without a shock presentation (B).

no responding followed by an increase to a high rate of responding that was sustained until a shock was produced by the first response occurring after 10 min; during the remainder of the eleventh minute, responding was usually suppressed completely. As with fixed-interval schedules of food presentation, the number of responses per interval varied widely. Average rates of responding varied over a two-fold range, while quarter-life values varied only about 10%.

After 140 sessions under the two-component shock schedule alone, the shock intensity was reduced from 12.6 ma to 5 ma. The average rate of responding changed little during the next five sessions (Fig. 7A, B). When the shock intensity was further reduced to 1 ma (Session 349), average rates of responding decreased to

about 0.25 responses per sec (Fig. 7C). When the shock intensity was increased to 12.6 ma again, average rate of responding increased more than two-fold (Fig. 7D).

During the 170 sessions of this experiment in which the shock intensity was 12.6 ma, Monkey S-43 responded more than 700,000 times (mean of 4227 responses per session) and produced more than 1900 electric shocks. During the interpolated 13 sessions in which the shock intensity was reduced to 5 ma and then to 1 ma, S-43 responded about 20,000 times (mean of 1548 responses per session). During this entire period, responding was suppressed under the FR 1 schedule of shock presentation in the eleventh minute of each cycle. In Exp. IV, the schedule was modified by eliminating the FR 1 schedule, the 1-min timeout period, or the scheduled electric shocks.

EXPERIMENT IV: MAINTENANCE OF RESPONDING UNDER MODIFICATIONS OF THE FI 10-MIN SCHEDULE OF SHOCK PRESENTATION (MONKEY S-43)

The fixed-interval performance was maintained under the FI 10-min schedule after the FR 1 component was eliminated. In Sessions 374 to 387, the first response occurring after 10 min was followed by an electric shock (12.6 ma) and a timeout of about 2-min. The duration of the timeout depended upon when a response occurred in the eleventh minute. If no response occurred, a 1-min timeout was

Fig. 7. Rates of responding and quarter-life values under the two-component FI 10-min FR 1 schedule at different shock intensities (Monkey S-43). The rate of responding decreased when the shock intensity was 1 ma (C). The arrow indicates a session for which the cumulative response records are shown in Fig. 6E.

presented at the end of the eleventh minute without a shock. As before, each session terminated after 10 cycles. This is simply an FI 10-min schedule with a 1-min limited hold followed by a timeout. During most sessions under FI 10-min, patterns of responding were similar to those in the FI 10-min component during Exp. III. Average rates of responding, quarter-life values, and number of shocks per session for 13 sessions under FI 10-min followed by timeout are shown in Fig. 8A.

Next, the timeout periods were eliminated from the two-component shock schedule. In Sessions 388 to 408 each response during the eleventh minute of a cycle produced a shock; each 11-min cycle was followed immediately by the start of the next cycle without a timeout. The elimination of the timeout produced a transient change in the pattern of responding during the first 10 min of some cycles (Fig. 9A, B). Initially, responding increased during the early part of some intervals (decreased average

quarter-lives in Fig. 8B). Responding in the eleventh minute when there was no timeout developed more slowly and persisted after the average quarter-life values had again increased (increased shocks per session in Fig. 8B and 9). Thus, there was a three- to four-fold increase in the number of shocks delivered during these sessions compared to the sessions under the two-component schedule with timeout periods (Exp. III).

The two-component schedule of shock presentation was eliminated for two sessions (Fig. 8C and 10A, B). The patterns of responding were similar to those that occur during extinction after training under a fixed-interval schedule of food presentation (Fig. 10A, B). The rate of responding gradually decreased to near zero by the end of the second session (Fig. 10B). Since neither shocks nor timeout periods occurred, the sessions were not divided into cycles. The quarter-life values for these sessions were calculated for the first 10 min of the successive 11-min periods of the session.

When shocks were scheduled again during the eleventh minute of each cycle, the previous pattern of responding redeveloped in the first session, but the rate of responding remained low (Fig. 10C). By the third session, performance had stabilized (Fig. 8D and 10D). Reintroducing the 1-min timeout after each cycle (in Session 409) had no clear effect during the last four sessions of the experiment.

The experiment was interrupted for three months after Session 412 because of an accidental injury to the monkey's tail. When the monkey had recovered, responding was not maintained under the FI 10-min schedule of shock presentation. Responding was re-established and then maintained under the VI 2-min schedule of food presentation for six sessions. Then, a concurrent VI 2-min schedule of food presentation and FI 10-min schedule of shock presentation with no timeout was in effect for 23 sessions. When the VI schedule of food presentation was eliminated, responding was again maintained under the fixed-interval schedule of shock presentation at shock intensities of first 3 ma and then 12.6 ma.

Fig. 8. Rates of responding, quarter-life values, and number of shocks in each session under modifications of the FI 10-min schedule of shock presentation (Monkey S-43). A: FI 10-min and timeout (maximum of 10 shocks per session). B and D: two-component FI 10-min FR 1, without timeout; after the dotted line (D), the 1-min timeout periods occurred again. C: extinction. The arrows indicate sessions for which cumulative response records are shown in Fig. 9 and 10. Note that rates of responding and quarter-life values both decreased during extinction (C) and that the shock frequency was higher when timeout periods were eliminated (B, D) than when timeout periods had followed the FR 1 component (see Fig. 6).

EXPERIMENT V: PERFORMANCES UNDER CONCURRENT SCHEDULES OF FOOD AND SHOCK PRESENTATION (MONKEY S-44)

The original purpose of these experiments had been to study patterns of decelerated re-

Fig. 9. Performance under two-component FI 10-min FR 1 schedule of shock presentation without timeout (Monkey S-43). Shock presentations are indicated by a diagonal stroke on both records; the termination of one cycle (and the beginning of the next cycle) is indicated by the pen resetting to the baseline. A-C: Sessions 388, 389, and 396. Note that without timeout periods there was less suppression during the FR 1 component than with timeout periods (Fig. 6).

sponding under concurrent variable-interval schedules of food presentation and fixed-interval schedules of electric shock presentation. The scheduled frequency of electric shocks was greater for Monkey S-44 than it had been for Monkey S-43. A pattern of suppressed responding did develop in Monkey S-44 under a concurrent schedule with a two-component FI 3-min FR 1 shock schedule.

There were several changes in parameter values of the shock schedule before responding was suppressed. Shock intensities of 10 ma and 12.6 ma, presented under an FI 10-min schedule before responding had stabilized under VI 2-min, had no marked effect on responding (Fig. 11A, B). The scheduled frequency of shocks was increased in Session 17 by changing the shock schedule from FI 10-min to FI 3-min. If a response did not produce a shock after 3 min, a 1-min timeout period occurred auto-

matically at 3 min and 18 sec. Each session terminated after the thirtieth timeout period.

The two-component FI 3-min FR 1 shock schedule was introduced in Session 19. As before, the first response occurring after 3 min had elapsed produced a 12.6-ma shock (FI 3-min). In addition, each response during the remainder of the 18-sec period also produced the shock (FR 1). The 1-min timeout periods occurred every 3 min and 18 sec independently of responding; the VI 2-min food schedule was in effect throughout the cycle. This two-component FI 3-min FR 1 shock schedule remained in effect until Session 215. Drugs were given on 30 occasions during this time; the temporary drug-induced changes in responding will not be discussed.

Under the two-component shock schedule, the rate of responding increased temporarily in Sessions 23 to 26, while the quarter-life

S43

Fig. 10. The extinction and redevelopment of performance under the two-component FI 10-min FR 1 schedule of shock presentation without timeout (Monkey S-43). Recording as in Fig. 9. A and B: Sessions 397 and 398, extinction. C and D: Sessions 399 and 401, two-component shock schedule.

values decreased slightly (Fig. 11C). Later, in Sessions 27 to 40 average rates of responding and quarter-life values decreased. All responding usually occurred during the first 1 to 2 min of each cycle and then ceased abruptly (Fig. 12A); shocks were infrequent. In subsequent sessions, average rates of responding within

each cycle were little changed (Fig. 11C and 12B).

The pattern of decelerated responding produced adventitiously a correlation between the VI schedule and the cycle even though food presentation in the VI schedule had been arranged independently of the cycle. Because

Fig. 11. Rates of responding and quarter-life values under concurrent VI 2-min (food) FI 10-min (shock) or FI 3-min (shock) (Monkey S-44). A: VI (food) only. B: Concurrent VI (food) FI 10-min (10-ma shock); after the first dotted line, the shock intensity was 12.6 ma; after the second dotted line the shock schedule was FI 3-min; C: concurrent VI 2-min (food) and two-component FI 3-min FR 1 (shock); D: concurrent VI (food) FI 3-min FR 1 (shock) when an available reinforcement programmed in one cycle was not attainable in the next cycle. From Session 118 to 122, there was only one session per week. The arrows indicate sessions for which cumulative response records are shown in Fig. 12.

of the pronounced suppression, food presentation seldom occurred in the latter part of each cycle, but frequently followed the first response occurring in the next cycle (Fig. 12A, B). When the procedure was changed so that a potential food presentation scheduled before a timeout was no longer attainable after the timeout (Session 123), rate of responding and quarter-life value abruptly decreased (left of Fig. 11D). Responding usually occurred during only the first minute of each cycle and the frequency of food presentation decreased markedly (Fig. 12C). With further exposure to this schedule, the rate of responding gradually increased, eventually reaching a rate comparable to that which prevailed when the schedule of food presentation had been independent of timeout periods. Responding remained suppressed during the latter part of each cycle (Fig. 12D), and correspondingly the quarter-life values remained below 20% (right of Fig. 11D).

The immediate change in behavior when VI food presentations scheduled in one cycle were not available in the following cycle illus-

trates the kind of dynamic interaction that can occur between schedules of food and shock presentation. Before Session 123, complete suppression in the terminal part of a cycle increased the likelihood that the initial response in the following cycle would be reinforced under an interval ending in the previous cycle. When this possibility was eliminated, the initial decrease in frequency of reinforcement decreased the rate of responding and resulted in a further decrease in frequency of reinforcement. Thus, the marked suppression shown in Fig. 12C was not due to the shock schedule alone, but was rather a resultant of its interaction with the food schedule. Both the rate of responding and the frequency of food presentation in the early part of each cycle gradually increased over a period of several months. Although the VI 2-min schedule was in effect throughout each cycle, responding was being reinforced during only the initial part of each cycle, which could have contributed to an adventitious control by the cycle itself (Morse and Skinner, 1957). Holz and Azrin (1961, 1962) and Azrin and Holz (1966) have described in detail how schedules of response-produced electric shocks can control behavior by processes other than punishment.

Because Monkey S-44 had been suppressed under the two-component FI 3-min FR 1 schedule, it seemed especially important to make a deliberate attempt to develop patterns of enhanced responding similar to those obtained with Monkey S-43. These experiments with S-44 can be arbitrarily divided into four phases, each comprising repeated procedural changes: (1) attempts to attenuate the profound suppression that had been established; (2) development of responding under the concurrent variable-interval (food) fixed-interval (shock) schedule with low-intensity electric shocks; (3) modulation of responding under the concurrent schedules; (4) maintenance of responding under the fixed-interval schedule of shock presentation alone. Experiment VI describes the first phase.

EXPERIMENT VI: RECOVERY OF RESPONDING AFTER PROLONGED SUPPRESSION (MONKEY S-44)

The shock schedules were eliminated after Monkey S-44 had been studied for about 200

Fig. 12. Suppression of responding under concurrent VI 2-min (food) FI 3-min FR 1 (12.6-ma shock) (Monkey S-44). Ordinate: cumulative number of responses; abscissa: time. Food presentations are indicated by a diagonal stroke on the cumulative record. Shock presentations are indicated by a diagonal stroke on the event record. The pen reset to the baseline at the end of each cycle of 3 min and 18 sec. The paper did not move during the 1-min timeout period between cycles. A-D: Sessions 40, 122, 123, and 214. Note that responding was suppressed in the latter part of each cycle when the VI schedule was programmed independently of the cycle (A, B). When a reinforcement arranged in one cycle was not available in the next, responding was initially even further suppressed (C), but slowly returned to its previous level (D).

sessions under the concurrent VI 2-min schedule of food presentation and two-component FI 3-min FR 1 schedule of shock presentation. During Sessions 216 to 262, only a VI 2-min schedule of food presentation was in effect; 1-min timeout periods occurred every 3 min and 18 sec. Potential food presentation scheduled before a timeout was no longer attainable after the timeout. Under the VI schedule, quarter-life values increased slowly, approaching 25% by Session 250 (Fig. 13A). Average rate of responding also increased slowly (Fig. 13A), but the cumulative records showed that responding was still suppressed in the terminal part of some cycles. When the two-component FI 3-min FR 1 shock schedule (12.6 ma) was reintroduced for a single session (Session 263), responding was immediately suppressed (Fig. 13A).

Responding was soon maintained throughout each cycle when the cycle duration was increased from 3 min and 18 sec to 11 min in Session 274. When the two-component FI 10-min FR 1 shock schedule (12.6 ma) was intro-

duced for two sessions (Session 283 and 284), responding was again suppressed (Fig. 13B), and remained suppressed in the first and second cycles of the next five sessions. When scheduled shocks of lower intensity (5.0 ma) were introduced during part of Sessions 317 and 318, responding was suppressed (Fig. 13B), but recovered within a few cycles after the shock schedule was eliminated. At this time, it seemed that responding might be well enough maintained at low shock intensities so that some shocks would occur under the 10-min fixed-interval shock schedule.

EXPERIMENT VII: PERFORMANCE UNDER THE CONCURRENT FOOD AND SHOCK SCHEDULE AT DIFFERENT SHOCK INTENSITIES (MONKEY S-44)

The effects of different shock intensities were studied under the concurrent VI food and two-component FI 10-min FR 1 shock schedule and under the two-component shock schedule. At each shock intensity which maintained re-

Fig. 13. Rates of responding and quarter-life values under VI 2-min (food) after prolonged suppression under the concurrent food and shock schedule (Monkey S-44). A: cycle duration of 3 min 18 sec followed by timeout. B: cycle duration of 11 min followed by timeout. A drug was given before Sessions 246 and 250; the temporary drug-induced changes in responding are not shown.

sponding under the concurrent schedule, we studied responding under the shock schedule alone. Beginning with Session 321, the schedule was a concurrent VI 2-min schedule of food presentation and two-component schedule of shock presentation (FI 10-min FR 1) with 1-min timeout periods occurring every 11 min; each response during the eleventh minute of the cycle produced an electric shock. As before, potential food presentation scheduled before a timeout was no longer attainable after the timeout. Table 1 shows the sequence of procedures and the sessions during which they were in effect.

Although responding was still suppressed by the introduction of electric shocks at 2 ma, responding was well enough maintained at 1 ma under the concurrent schedule so that some shocks occurred under the FI 10-min shock schedule (Fig. 14A). When the VI 2-min schedule of food presentation was eliminated, there was some acceleration of responding at the beginning of some cycles (Fig. 14B, C); however, responding was suppressed in the latter part of each cycle. During the third session after the schedule of food presentation was eliminated, responding decreased to near zero (Fig. 14D). Similar results were obtained when the schedule of food presentation was eliminated at the lower intensities indicated in Table 1. Although responding was well maintained throughout each cycle under the con-

Fig. 14. Transition from concurrent food and shock schedule to two-component FI 10-min FR 1 schedule (1-ma shock) (Monkey S-44). Recording as in Fig. 3. A: Session 331, concurrent food and shock schedule. B, C, and D: Sessions 332, 333, and 334: schedule changed to two-component shock schedule alone after first cycle in B. Note the slight positive curvature in the cumulative response records of some cycles before responding ceased.

current schedule at the shock intensity of 0.3 ma, it was not maintained under the shock schedule alone.

EXPERIMENT VIII: EFFECTS OF ELIMINATING THE TIMEOUT STIMULUS BETWEEN CYCLES (MONKEY S-44)

Timeout periods ending each cycle contributed to the maintenance of suppressed

Table 1

Sessions in which different shock intensities were in effect under concurrent VI 2-min food and two-component FI 10-min FR 1 shock schedule or two-component shock schedule alone in Exp. VII (Monkey S-44).

Sessions	Shock Intensity (ma)	Schedule
321-322	2.0	Food and Shock
323-331	1.0	Food and Shock
332-334	1.0	Shock Only
335-355	0.5	Food and Shock
356-358	0.5	Shock Only
359	0.5	Food and Shock
360-362	0.3	Food and Shock
363-366	0.3	Shock Only
367-387	0.3	Food and Shock ¹
388-420	1.0	Food and Shock ²

¹Shock only for last 2.5 cycles of Session 377.

²Shock only for last eight cycles of Session 404.

responding in the terminal part of each cycle. After the timeout stimulus was eliminated, responding was well maintained under the two-component shock schedule even at relatively high shock intensities.

From Sessions 421 to 431, the procedure was identical to that in Exp. VII except that timeout periods were not accompanied by any stimulus change; that is, the experimental chamber was not darkened during the 1-min period between cycles. The 12-min periodicity between shock presentations was maintained, but the VI 2-min schedule was not in effect during the first minute after the shock period. The shock intensity was initially 1 ma.

When the timeout stimulus was eliminated,

the average rate of responding was low (0.13 responses per sec) in the first session. Subsequently, responding was well maintained throughout each session including the eleventh minute of each cycle (see first three cycles of Fig. 15A). When the shock intensity was increased to 3 ma in Session 425, responding during the eleventh minute was only partially suppressed (Fig. 15A, B). When the intensity was further increased to 12.6 ma (Session 431), responding was still maintained even in the eleventh minute of each cycle (Fig. 15B, C). In Sessions 421 and 431, the timeout periods had not been indicated by any stimulus change. In Session 432, the 1-min timeout periods were eliminated; each 11-min cycle was

Fig. 15. Performance under concurrent food and shock schedule at different shock intensities with timeout periods not indicated by stimulus change between cycles (Monkey S-44). Food presentations are indicated by diagonal strokes on the cumulative record; shock presentations by diagonal strokes on both cumulative and event records. The pen reset to the baseline at the beginning of each cycle. A and B: Sessions 425 and 431, timeout periods not indicated by stimulus change; the paper continued to move during the 1-min timeout period between cycles. C and D: Sessions 432 and 446, concurrent food and shock schedule after timeout periods eliminated and cycle duration reduced to 11 min. Note that responding was maintained at the 12.6-ma shock intensity.

followed immediately by the start of the next cycle (Fig. 15C). Initially, the average rate of responding decreased at 12.6 ma, but recovered in about 10 sessions. Beginning with Session 439, the variable-interval schedule was not in effect and food presentations could not occur during the eleventh minute of each cycle. The terminal performance (Session 446) under this procedure is shown in Fig. 15D.

Figure 16 shows performance under the two-component FI 10-min FR 1 shock schedule (12.6 ma) without timeout when the VI 2-min schedule of food presentation was eliminated. Responding was maintained for six sessions (Sessions 447 to 453), and there were pronounced accelerations of responding during most cycles and, in addition, a brief period of

responding immediately after the 1-min period in which each response was followed by shock. In the latter part of Session 451 and in Session 452, responding was not well maintained in the eleventh minute of each cycle (Fig. 16C, D).

In Session 453, no responding occurred until the sixth cycle (Fig. 16E); at the end of the eighth cycle, the 1-min timeout (accompanied by the stimulus change of darkening of the experimental chamber) was reintroduced and responding occurred again in the ninth and tenth cycles. But when no responding occurred at the beginning of Session 454 (not shown), the VI 2-min schedule of food presentation was reintroduced with the 1-min timeout period following each 11-min cycle. Respond-

Fig. 16. Transition to two-component FI 10-min FR 1 schedule (12.6-ma shock) without timeout periods (Monkey S-44). Recording as in Fig. 9. A-E: Sessions 447, 450, 451, 452, 453. Note the positive curvature in the cumulative response records of most cycles before responding ceased.

ing recovered and was maintained under this schedule with timeout (Sessions 454 to 462) and when the 1-min timeout periods were again eliminated (Sessions 463 to 465).

Although responding was not maintained for more than six sessions under the two-component shock schedule alone, it was clear that the elimination of the timeout stimulus had a marked effect upon performance under the concurrent food and shock schedule. By the end of this experiment, responding could be well maintained under the concurrent food and two-component shock schedule even at a shock intensity of 12.6 ma.

EXPERIMENT IX: MAINTENANCE OF RESPONDING UNDER AN FI 10-MIN SCHEDULE OF SHOCK PRESENTATION

In this experiment, the FR 1 component of the shock schedule was eliminated. Beginning with Session 466, the schedule was a concurrent VI 2-min schedule of food presentation and FI 10-min schedule of shock presentation (12.6 ma). Each cycle terminated with a shock presentation or at the end of 11 min if no response occurred in the eleventh minute; each cycle was followed immediately by the start of

the next cycle. Beginning with Session 474, food presentations could not occur after the ninth minute of each cycle.

Under this concurrent food and shock schedule, average rates of responding remained high; quarter-life values were between 25 and 30% (Fig. 17A). Beginning with Session 491, the schedule of food presentation was eliminated. The average rates of responding and quarter-life values under the FI 10-min schedule of shock presentation are shown in Fig. 17B. When the schedule of food presentation was eliminated, the pattern of responding became more characteristic of fixed-interval responding, as indicated by the increase in quarter-life in Fig. 17B and by the cumulative records in Fig. 18. As the rate of responding decreased, the pattern of responding became similar to that previously seen with Monkey S-43 (see Fig. 6 and 9). Low rates of responding in the early minutes of each interval were followed by increasing responding during the late minutes of the interval. With continued exposure to the FI 10-min schedule of shock presentation, responding in the early minutes of each interval occurred less frequently (Fig. 18E).

Fig. 17. Rates of responding and quarter-life values under concurrent VI 2-min (food) FI 10-min (12.6-ma shock) and under FI 10-min schedule of shock presentation only (Monkey S-44). A: concurrent food and shock schedule; after the dotted line, the VI schedule was not in effect during the tenth minute of each cycle. B: FI 10-min (12.6-ma shock); after the dotted line, the monkey was freely fed in the living cage. The arrows indicate sessions for which cumulative response records are shown in Fig. 18, 19, and 20.

Fig. 18. Transition from concurrent VI (food) FI 10-min (shock) to FI 10-min (shock) alone (Monkey S-44). A 1-min timeout period followed each shock presentation. Recording as in Fig. 2. A: Session 490, terminal performance under concurrent food and shock schedule. B-E: Sessions 491, 492, 493, and 494, initial sessions under FI 10-min schedule of shock presentation alone.

The fixed-interval performance that developed under the FI 10-min schedule of shock presentation was stable. During the 67 sessions under this schedule, the performance was disrupted twice. First, during Session 505, there was no general illumination in the experimental chamber; responding was completely suppressed during this session, which was terminated after five cycles. The characteristic fixed-interval performance was recovered in Session 506. The second disruption of the fixed-interval performance was less marked, and the cause was more obscure. Beginning with Session 517, the response key was replaced by a new key, which had the same physical characteristics. After Session 517, the monkey was freely fed in the home cage. Cumulative response records from Sessions 517 to 521 are shown in Fig. 19. During Session 517, the fixed-interval pattern was disrupted (Fig. 19A) and the average quarter-life decreased (Fig. 17B). In one interval of Session 519 and in four intervals of Session 520, no response occurred during the eleventh minute, and a new interval began without a shock presentation. During the three months that the fixed-interval schedule of shock presentation was in effect, these were the only five occasions (except dur-

Fig. 19. Disruption and recovery of performance under FI 10-min (12.6-ma shock) (Monkey S-44). Recording as in Fig. 2. A-E: Sessions 517, 518, 519, 520, and 521. Arrows indicate cycles that terminated without a shock presentation.

Fig. 20. Terminal performance under FI 10-min (12.6-ma shock) (Monkey S-44). Recording as in Fig. 2. A-D: Sessions 548, 550, 551, and 552. The pattern of responding during each cycle shows the positive curvature that characterizes performances under fixed-interval schedules.

ing Session 505) in which a shock did not occur at the end of the interval.

Terminal performance under the fixed-interval schedule of shock presentation at the shock intensity of 12.6 ma is shown in Fig. 20. Although the average rate of responding varied from 0.41 (Fig. 20A) to 0.79 (Fig. 20C) responses per sec, the pattern of responding continued to be reproducible.

DISCUSSION

That a response-produced electric shock can maintain fixed-interval performance is the main finding of the present series of experiments. A two-component fixed-interval fixed-ratio schedule of shock presentation was superimposed upon a variable-interval schedule of food presentation that maintained a steady rate of responding. The ongoing responding was modulated by electric shock presentation; after the variable-interval schedule of food presentation was eliminated, responding characteristic of fixed-interval schedules could be maintained by the shock schedule. Thus, periodic presentation of a salient electric shock can not only modulate responding, but can even maintain responding that leads to its presentation. Significantly, electric shocks of the same intensity that maintained responding under the fixed-interval schedule suppressed responding during the part of each cycle when each response was followed by

electric shock. The present results extend our previous conclusion (Morse and Kelleher, 1966) that the schedule of reinforcement can be more important in the control of behavior than the nature of the reinforcer.

The subject's history seems also to be important in determining how electric shocks control behavior. In animals with a history of responding under schedules of shock postponement, periodically presented response-independent electric shocks can enhance responding (Herrnstein and Sidman, 1958; Sidman, Herrnstein, and Conrad, 1957) or maintain responding (Kelleher, Riddle, and Cook, 1963; Waller and Waller, 1963). In animals with a history of suppressed responding under schedules of electric shock presentation, the suppressive effects of subsequent electric shocks, even of low intensity, may be greater (Azrin, 1960; Rachlin, 1966; Walters and Rogers, 1963). In the present study (Exp. V), the responding of Monkey S-44 was suppressed initially under the 10-min shock schedule when it followed the 3-min schedule, which had produced a pronounced suppression. On the other hand, with continued exposure to some schedules of shock presentation, responding can become less suppressed than it was initially (Azrin, 1960; Azrin and Holz, 1966). In Exp. I, when the shock schedule was introduced for a second time, the responding of Monkey S-43 was less suppressed than previously, and in Exp. VIII and IX, Monkey S-44 was no longer suppressed by the 12.6-ma electric shocks. Surely neither monkey would have responded under the final schedule of shock presentation without prior experience. Thus, the history of the shock exposures and shock intensities seems to be important both for enhancement of responding by response-produced shock and for suppression by response-produced shock. We have noted that spontaneous recovery of previously reinforced responding and spontaneous retrogression of previously punished responding occur under the same conditions (Kelleher and Morse, 1964). Reinforcement and punishment are analogous behavioral processes with complementary effects.

A particularly important aspect of an individual's history with respect to electric shocks is the prior pattern and actual rate of ongoing responding at the time an electric shock is presented. Electric shock appears to

have less suppressive effect when it follows a frequently occurring response than when it follows an infrequently occurring response (Morse, Mead, and Kelleher, 1967). After the responding of Monkey S-44 had been suppressed, the suppression was maintained for many sessions under the variable-interval schedule with only infrequent presentation of shocks of low intensity; however, when responding eventually developed under the concurrent food and shock schedule, it could be maintained under higher shock intensities and subsequently under the fixed-interval schedule (12.6 ma) alone. Although the maintained fixed-interval responding developed from a pattern of sustained responding, it did not depend merely on stereotypy of the performance. After the fixed-interval pattern had been established with Monkey S-43, responding was reduced to low levels by eliminating the shock schedule and redeveloped by presenting shocks again under the fixed-interval schedule.

A characteristic pattern of responding was maintained under several different schedule conditions in Exp. IV: under FI with timeout; under the two-component FI FR schedule with timeout; and under the two component schedule without timeout. Thus, neither the timeout nor the FR component was necessary for the maintenance of the fixed-interval performance by electric shock. When the timeout was present, responding was completely suppressed in the FR component, but occurred in the FI component under the two-component schedule without timeout. Usually the transitions were gradual when the procedures were changed, again suggesting the important contribution of the ongoing pattern of responding under a particular schedule in maintaining the performance.

Incidental observations on the effects of the variations in schedules and parameter values suggest some conclusions about the conditions under which electric shocks will suppress or enhance responding. Suppression was most evident when electric shocks of high intensity were scheduled to occur frequently. Initially, suppression during the fixed-interval component developed for Monkey S-44, studied under the 3-min fixed-interval schedule (Exp. V), but not for Monkey S-43, studied under the 10-min fixed-interval schedule (Exp. I). After Monkey S-44 had recovered from suppression under

the two-component shock schedule, the temporary introduction of shock had a greater suppressive effect during the terminal part of 3-min cycles than during the terminal part of 10-min cycles. The suppression was virtually complete for Monkey S-43 during the period in which each response produced a 12.6-ma shock, even while responding was being maintained under the 10-min fixed-interval schedule of shock presentation. These observations confirm previous findings that greater suppression of schedule-controlled responding by electric shock occurs as the intensity and frequency of shock presentation is increased (Appel, 1963; Appel and Peterson, 1965; Azrin, 1959, 1960; Azrin, Holz, and Hake, 1963; Filby and Appel, 1966; Rachlin, 1967). Conversely, it seems reasonable that the conditions that minimize suppression would be favorable for developing responding enhanced by electric shock.

The effects of stimuli that change behavior depend not only on the nature of the stimuli, but also upon the schedule according to which the stimuli are presented and the ongoing behavior at the time they are presented (Morse, 1966; Morse, Mead, and Kelleher, 1967). The effectiveness of food in engendering responding, for example, depends on how its presentation is scheduled and on the nature of the behavior that it follows. The control by schedule conditions was especially pronounced in these experiments, since shock had opposite effects on responding, depending upon the schedule. Responding was maintained by electric shocks presented under the FI 10-min schedule and suppressed by electric shocks presented under the FR 1 schedule. Depending upon how the shock was scheduled, performance showed characteristic effects of both reinforcement and punishment.

The performances studied in these experiments depended relatively more on the characteristics of the ongoing behavior and less on the intrinsic properties of the shock than is the case in many experiments using food. In most experiments using response-produced electric shock, there is some ongoing responding when the shock is introduced; whereas in most experiments using food as a reinforcer, it is initially presented following a response that is occurring infrequently. Since the effect of consequent stimuli depends in part on the quantitative properties of the preceding be-

havior, electric shock would be expected to have a wide range of effects when it is introduced following a range of patterns and rates of responding. Thus, observations that the effects of punishment are variable (Skinner, 1938) may reflect the dependence of consequent events on ongoing behavior more than any inherent difference between reinforcers and punishers.

When an event following some behavior increases the subsequent occurrence of that behavior, it does not mean that the same event consequent on some other behavior or scheduled in a different way would necessarily have the same effect. We have already noted that the effects of the electric shock depend upon the animal's experimental history and the schedule of shock presentation. Similarly, different schedules of food presentation can affect behavior in different ways. For example, responding under fixed-ratio schedules of food presentation and responding maintained by adventitious food presentation depend critically upon the experimental history of the animal. In the present experiments, responding was maintained by one schedule of electric shock presentation and suppressed by another. A reinforcer or punisher should not be conceptualized independently of the way it controls behavior.

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