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SCHEDULES USING NOXIOUS STIMULI. VI: AN INTERLOCKING SHOCK-POSTPONEMENT SCHEDULE IN THE SQUIRREL MONKEY[1]

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Responding was studied under various schedules of electric shock postponement and presentation in the squirrel monkey. Under an interlocking shock-postponement schedule, successive responses decreased the time by which a response postponed the next scheduled shock until a shock immediately followed the *n*th response. Some parameters of this schedule, which can be formally related to fixed-interval schedules, engendered a pattern of positively accelerated responding between shocks. This pattern did not occur under comparable parameter values of an alternative fixed-ratio, avoidance schedule under which each response postponed shock by a fixed duration and every *n*th response produced shock. Subsequently, performances were studied under schedules of shock presentation. Responding was never maintained under fixed-ratio schedules of shock presentation, but was maintained with a pattern of positive acceleration under an alternative fixed-ratio, fixed-interval schedule and under a fixed-interval schedule.

Schedule-controlled responding often depends upon how durations terminated by responses (interresponse times) are related to scheduled events (Ferster and Skinner, 1957; Morse, 1966). Patterns of sequential responding tend to be minimal under schedules that minimize the selective grouping of responses before scheduled events. For example, under an avoidance schedule in which each response postpones the delivery of an electric shock for a specified time (response-shock interval), the defining characteristics of the schedule ensure that sequences of successive responses cannot immediately precede an electric shock. Although patterning of sequential interresponse times has been observed (Anger, 1963; Wertheim, 1965), responding under such avoidance schedules tends to be steady.

If all interresponse times under a continuous avoidance schedule are less than the response-shock interval, no shocks will occur, but responding can also be engendered or maintained under schedules in which a minimum number of shocks must occur. For example, responding has been maintained under conditions in which responses: (1) produce a shift from one shock frequency to a lower shock frequency (Herrnstein and Hineline, 1966; Sidman, 1962); (2) do not alter the shock frequency (Kelleher, Riddle, and Cook, 1963; Waller and Waller, 1963); or (3) increase the shock frequency (Byrd, 1969; Kelleher and Morse, 1968; McKearney, 1968, 1969; Morse, Mead, and Kelleher, 1967).

The present paper describes performances under interlocking and alternative shock-postponement schedules in which relations between interresponse times and shocks could vary over a wide range. Under the interlocking fixed-ratio, shock-postponement schedule, successive groups of responses decreased the time by which a response postponed the next scheduled shock (Fig. 1, solid line) (see also, Berryman and Nevin, 1962; Powers, 1968; Skinner, 1958). Under the alternative fixed-ratio, avoidance schedule, the response-shock interval was constant, and every *n*th response produced shock (Fig. 1, dashed line). Patterns of positively accelerated responding between shocks, resembling fixed-interval performances, developed under the interlocking sched-

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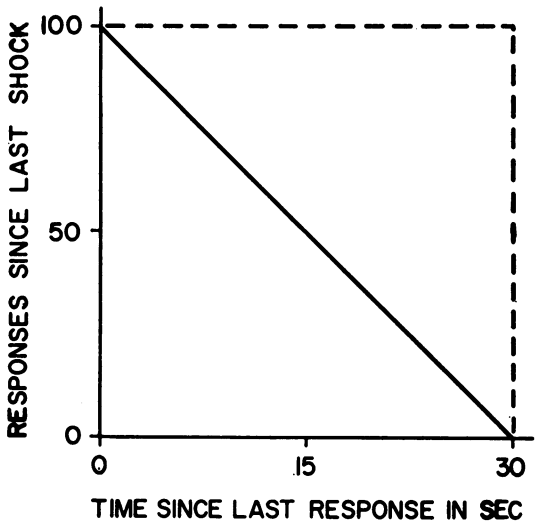

Fig. 1. Diagrammatic representation of interlocking shock postponement schedule (solid line) and alternative fixed-ratio, avoidance schedule (dashed line).

ule but not under the alternative schedule. Various schedules of response-produced shock were also studied.

METHOD

Subjects

Six mature male squirrel monkeys (*Saimiri sciureus*) with no previous training were used (S-67, S-68, S-69, S-70, S-72, and S-73). The monkeys were generally handled according to the procedures described by Kelleher, Gill, Riddle, and Cook (1963), except that the leash was sometimes removed during initial sessions. The monkeys had free access to food and water in their living cages.

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 the tail by two hinged brass plates that rested lightly on a shaved portion of the tail. A noncorrosive electrode paste (EKG Sol) ensured a low resistance electrical contact between the plates and the tail. The electric shock was 580 v ac, 60 Hz delivered to the plates through a series resistor for 200 msec. The response key (Lehigh Valley Electronics rat lever, LVE 1352) was mounted on the right-hand side of a metal wall facing the monkey. When the key was pressed with a force of 22 g (0.216 N) or more, a response was recorded. Each response produced the audible click of a relay. Just above the key was a stimulus panel that was transilluminated by a white light (6 w) during each session. General illumination during the session was provided by an overhead light (25-w GE type 101F bulb). The entire chair unit was enclosed in a ventilated refrigerator shell. Continuous white noise was used to mask extraneous sounds.

Schedules

Interlocking schedule. Figure 2 is a diagram of the interlocking schedule as it was actually arranged. The abscissa represents the time since the previous response; the ordinate represents cumulative responses since the previous shock. After a shock, each of the first nine responses postponed the next scheduled shock by 30 sec (or 10 sec); each of the tenth to the nineteenth responses postponed the shock for 27 sec (or 9 sec); shock postponement time continued to decrease every 10 responses until the delay was 3 sec (1 sec) after 90 responses, and 0 sec after 100 responses. The schedule can be specified in terms of the maximum number requirement (FR) and maximum shock postponement duration (R-S time). Threefold changes in the number require-

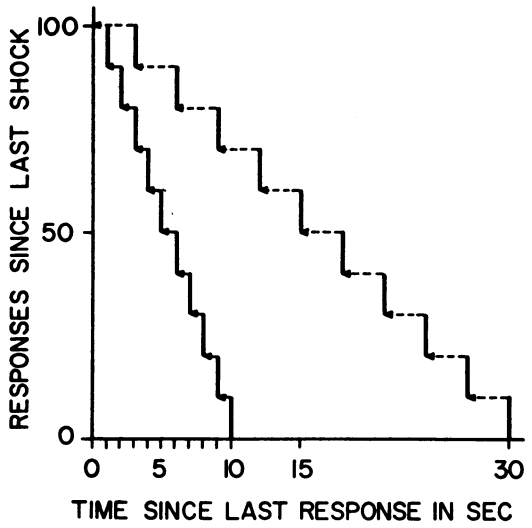

Fig. 2. Diagrammatic representation of interlocking shock postponement schedule at R-S times of 10 sec and 30 sec.

Table 1

Subject	*Sessions*	*Schedule*	*Shock Intensity*
S-69	1-58	interlocking FR 100, R-S time 10 sec	3 ma
	59-104	interlocking FR 300, R-S time 10 sec	3 ma
	105-120	FR 100 (FR 300, Session 105 only)	3 ma
	121-124	alternative FR 100, FI 5-min	3 ma
	125-149	interlocking FR 100, R-S time 10 sec	3 ma
	150-170	interlocking FR 100, R-S time 30 sec	3 ma
	171-233	interlocking FR 100, R-S time 30 sec (no S-S interval after Session 185)	10 ma
	234-245	FI 5-min	10 ma
S-70	1-112	interlocking FR 100, R-S time 10 sec	3 ma and 10 ma
	113-175	interlocking FR 100, R-S time 30 sec	10 ma and 3 ma
	176-246	interlocking FR 100, R-S time 10 sec (no S-S interval after Session 185)	3 ma
S-67	1-57	interlocking FR 100, R-S time 30 sec (modified after Session 44)	3 ma
	58-68	FR 100	3 ma
	69-75	FR 100 (shock interval 5 min)	3 ma
	76-118	alternative FR 100, FI 5-min	3 ma
	119-132	alternative FR 100, conjunctive FR 30 FI 5-min	3 ma
	133-157	alternative FR 100, FI 5-min (various shock intervals 10 sec to 6 min)	3 ma
	158-164	interlocking FR 300, R-S time 30 sec (no S-S interval)	3 ma
	165-234	FI 5-min	
S-68	1-45	interlocking FR 100, R-S time 30 sec	10 ma
	46-56	alternative FR 100, R-S interval 30 sec	10 ma
	57-85	alternative FR 300, R-S interval 30 sec	10 ma
	86-93	FR 300	10 ma
	94-97	alternative FR 100, FI 5-min (shock interval 10 min)	10 ma
	98-123	alternative FR 100, R-S interval 30 sec	10 ma
	124-143	interlocking FR 100, R-S time 30 sec	10 ma
	144-170	alternative FR 100, FI 5-min	10 ma
S-72	1-67	alternative FR 100, R-S interval 10 sec	3 ma and 10 ma
	68-71	FR 100	10 ma
	72-205	alternative FR 100, FI 5-min	10 ma and 3 ma
S-73	1-57	alternative FR 100, R-S interval 10 sec	3 ma and 10 ma
	58-73	alternative FR 100, FI 5-min (shock interval 5 to 10 min after Session 69)	10 ma and 3 ma
	74-119	alternative FR 100, R-S interval 10 sec	10 ma and 3 ma
	120-147	alternative FR 100, FI 5-min (shock interval 6 min after Session 124)	3 ma and 10 ma
	148-183	interlocking FR 100, R-S time 10 sec (no S-S interval)	10 ma
	184-191	FI 2-min	10 ma

ment (FR 100 and 300), the response-shock time (10 sec and 30 sec), and the shock intensity (3 ma and 10 ma) were studied. If no response occurred after a shock, the next shock was scheduled to occur after 10 sec (S-S interval), except as noted.

Alternative fixed-ratio, avoidance schedule. This schedule combined a fixed-ratio schedule of shock presentation with an avoidance schedule of shock postponement (Sidman, 1953), as diagrammed in Fig. 1. The response-shock interval and shock-shock interval were both 10 sec, the fixed-ratio was 100 responses, and shock intensities of 3 ma and 10 ma were studied. Shocks were delivered 10 sec after a previous response or immediately after 100 responses.

Schedules of shock presentation. Fixed-ratio, fixed-interval, and alternative fixed-ratio, fixed-interval schedules of shock pres-

entation were studied after performances had been developed under the schedules described above. Shocks were delivered immediately after the terminal response of the schedule except, as noted, when shock was delivered at fixed time periods independently of responding (shock interval).

Procedure

Sessions lasted 1 hr and were conducted daily, Monday through Friday. During the session, the keylight and overhead light were illuminated. During initial training under the interlocking schedule and alternative fixed-ratio, avoidance schedule, if no response occurred after a shock, the next shock was scheduled to occur under a 3-sec S-S interval. The S-S interval was increased to 10 sec after five to 10 sessions. Subsequently, the S-S interval was eliminated in some experiments under the interlocking schedule. In some experiments under the alternative fixed-ratio, fixed-interval schedule, shock intervals up to 10 min were used.

Four monkeys (S-67, S-68, S-69, and S-70) were studied initially under the interlocking shock postponement schedule; two monkeys (S-72 and S-73) were studied initially under the alternative fixed-ratio avoidance schedule. Subsequently, threefold changes in the number requirement, the shock-postponement duration, and the shock intensity were studied, as well as performances under the fixed-ratio, the alternative fixed-ratio, fixed-interval, and the fixed-interval schedules. The sequence of schedules and parameter values studied is shown in Table 1. Unless otherwise specified, there was an S-S interval of 10 sec under the interlocking and the alternative fixed-ratio avoidance schedules, and there was no S-S interval or shock interval under the schedules of shock presentation.

RESULTS

Characteristics of performance under the interlocking schedule. Stable patterns of responding with identifiable features developed under the interlocking schedule. A striking characteristic of performance under the interlocking schedule was the gradual increase in responding between shocks (Fig. 3). This pattern of increasing responding was clearest when shocks were regularly spaced in time,

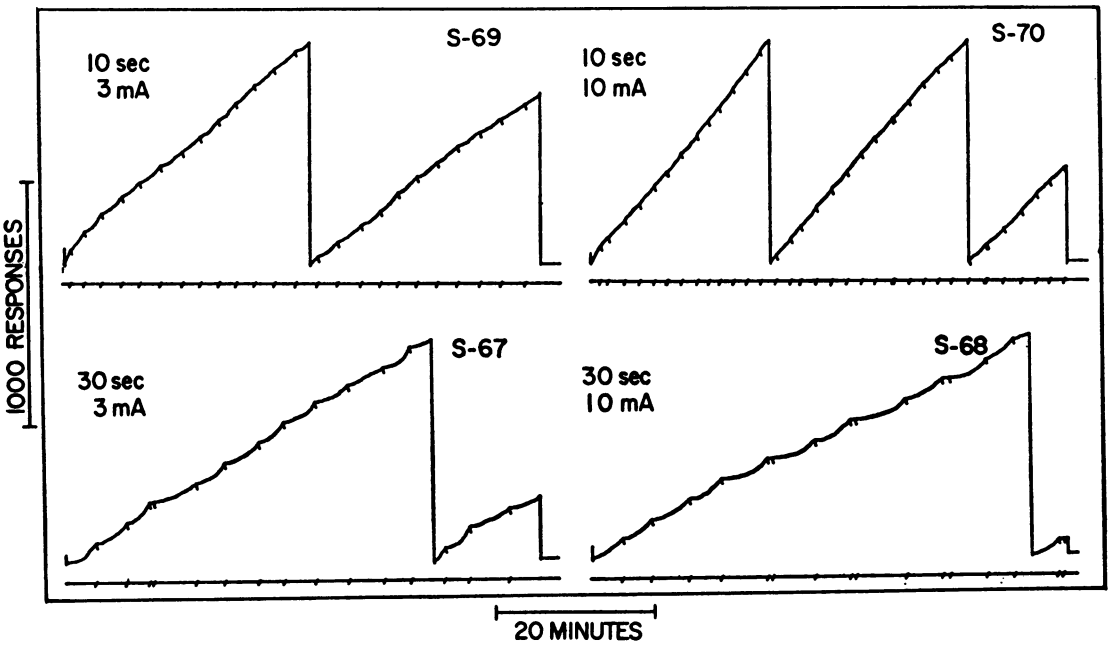

Fig. 3. Performances for four monkeys under the interlocking schedule after about 50 sessions (FR 100; R-S time and shock intensity as indicated on the records). Ordinate: cumulative responses; abscissa: time. The recording pen reset to the baseline whenever 1100 responses accumulated and at the end of each session. Short diagonal strokes on cumulative records and event records indicate presentations of electric shock. Note the many instances of positively accelerated responding between shocks, especially at R-S 30 sec.

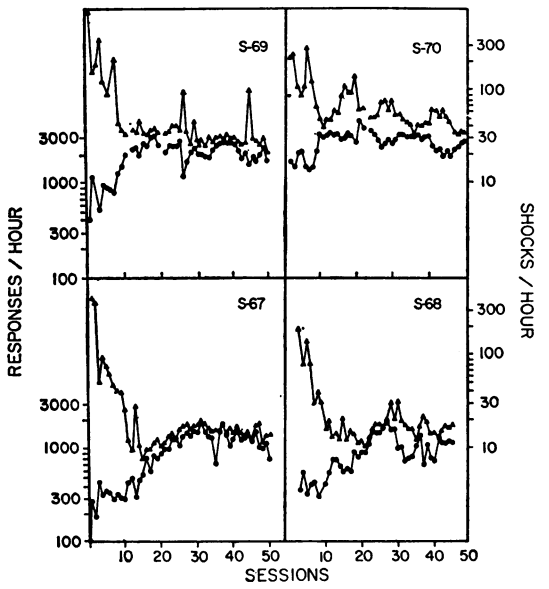

Fig. 4. Development of performance under the interlocking schedule. Ordinate (log scale): ●——● responses per hour, ▲——▲ shocks per hour; abscissa: sessions. Monkeys S-69 and S-70 (upper frames) were trained under interlocking FR 100, R-S time 10 sec. Monkeys S-67 and S-68 (lower frames) were trained under interlocking FR 100, R-S time 30 sec. The shock intensity was 3 ma for S-69 and S-67, 10 ma for S-68, and increased from 3 ma to 10 ma in Session 21 for S-70. The S-S interval was increased from 3 to 10 sec in Session 7 for S-67 and S-68 and in Session 11 for S-69 and S-70. Breaks in the curves indicate sessions for which data were lost. In all monkeys, response rates increased while shock frequency decreased for about 30 sessions; performances were relatively stable in subsequent sessions. Response rates and shock rates were higher with R-S 10 sec (upper frames) than with R-S 30 sec (lower frames).

but as the pattern developed, shocks tended to occur less regularly; thus, performance under the interlocking schedule fluctuated somewhat. Although there seemed to be optimal parameter values for the development of positively accelerated responding, this response occurred in each of the four monkeys initially studied under the interlocking schedule.

As performances developed under the interlocking schedule, rate of responding generally increased while shock frequency generally decreased (Fig. 4). Under the 10-sec R-S time, the average rate of responding was about 2500 responses per hour and shock frequency was about 35 shocks per hour; under the 30-sec R-S time, the average rate of responding was about 1200 responses per hour and shock frequency was 15 shocks per hour.

For Monkey S-70, responding developed with a shock intensity of 3 ma, but subsequently was not well maintained; when the shock intensity was increased to 10 ma, responding was more consistent throughout each session.

Variations in parameter values under the interlocking schedule. The effects of a threefold increase in the R-S time under the interlocking schedule are shown for S-70 in Fig. 5. Under the 10-sec R-S times, average response rates were about 2400 responses per hour (Fig. 5A) and 2600 responses per hour (Fig. 5C) and shock frequencies were about 36 per hour (Fig. 5A, C). When the R-S time was increased to 30 sec, average rate of responding decreased to about 1500 responses per hour and shock

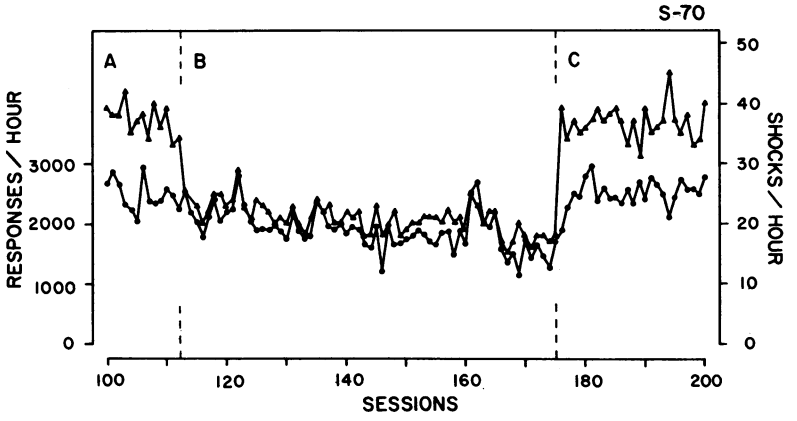

Fig. 5. Comparison of performances under the interlocking schedule at R-S 10 sec and R-S 30 sec (S-70). Ordinate: ●——● responses per hour, ▲——▲ shocks per hour; abscissa: sessions. A: terminal performance under R-S 10 sec; B: R-S 30 sec; C: R-S 10 sec. Shock intensity was decreased from 10 ma to 3 ma in Session 149. The S-S interval was eliminated in Session 186. Response rates and shock frequency were consistently lower when the R-S time was 30 sec than when it was 10 sec.

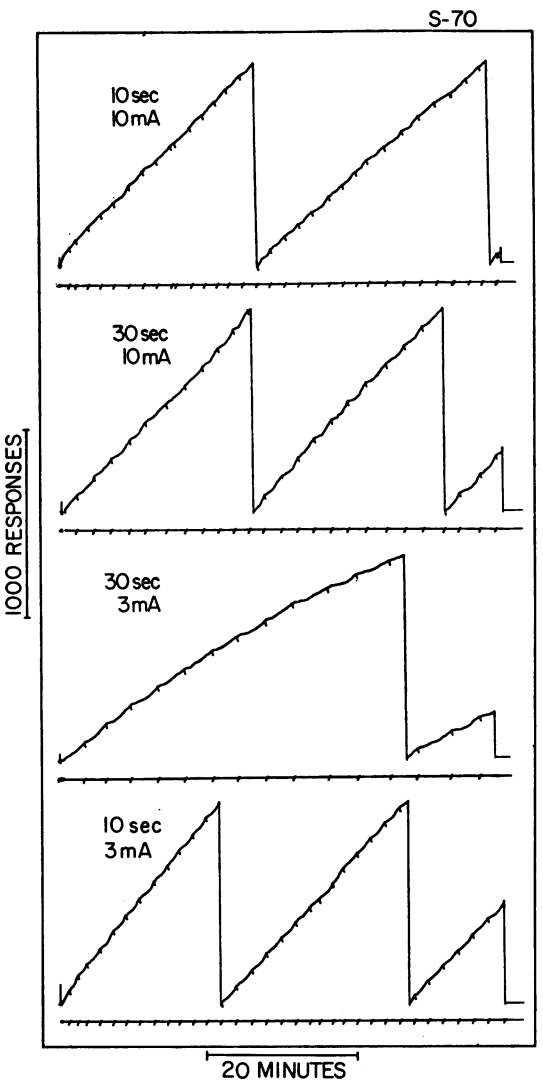

Fig. 6. Characteristics of performance under the interlocking schedule at R-S 10 sec and R-S 30 sec (S-70). Recording as in Fig. 3. The top record shows stable performance (Session 112) at R-S sec. The transition from R-S 10 sec to R-S 30 sec is shown in the second record (Session 113); rates of responding remained relatively high, and positive acceleration between shocks became more pronounced. The third record shows stable performance under R-S 30 sec (Session 167). The bottom records shows stable performance with subsequent exposure to R-S 10 sec (Session 245).

frequency decreased to about 17 per hour (Fig. 5B); these values did not change further when the shock intensity was decreased from 10 ma to 3 ma. The pattern of responding changed rapidly after the R-S time was increased to 30 sec; the positively accelerated responding between shock presentations was more pronounced (Fig. 6). When the R-S time was decreased to 10 sec again, the earlier performance was recovered (Fig. 5 and 6). Patterns of positively accelerated responding between shocks were more pronounced when the R-S time was 30 sec than when it was 10 sec in this monkey.

The effects of a threefold increase in the number requirement, R-S time, and shock intensity under the interlocking schedule were studied in Monkey S-69. When the number requirement was changed from 100 to 300 responses, rate of responding increased slightly, but shock frequency decreased from about 30 to 15 shocks per hour (Fig. 7A, B). Positively accelerated responding between shocks occurred at both number requirements (Fig. 8A-C). After intervening treatments, S-69 was studied again under the initial interlocking schedule (FR 100, R-S time 10 sec, 3 ma), and the earlier performance was slowly recovered (Fig. 7D-8D). Increasing the R-S time to 30 sec resulted in a decreased rate of responding to about 1400 responses per hour and shock frequency to about 15 per hour (Fig. 7E); however, patterns of positively accelerated responding were no more pronounced than under the 10-sec R-S time (Fig. 8E, F). The elimination of the S-S interval in Session 186 did not appreciably change the performance of S-69 (or S-70) even though shocks had been occasionally delivered under the S-S interval; for example, see Fig. 8B. Positively accelerated responding between shocks occurred at both fixed-ratio parameter values, both shock intensities, and both R-S times.

Comparisons of the interlocking schedule with an alternative fixed-ratio, avoidance schedule. Two monkeys (S-72 and S-73) were studied initially under an alternative fixed-ratio, avoidance schedule that had certain parameters in common with the interlocking schedule (FR 100, 10-sec R-S interval, 3 ma). As performances developed, average rates of responding were low; shock frequencies were high and variable, but became more stable after the shock intensity was increased from 3 to 10 ma (Fig. 9). Average rates of responding were about 1500 responses per hour and average shock frequencies were about 22 per hour. Neither of the monkeys trained under the alternative schedule developed positively accelerated responding between shock presentations.

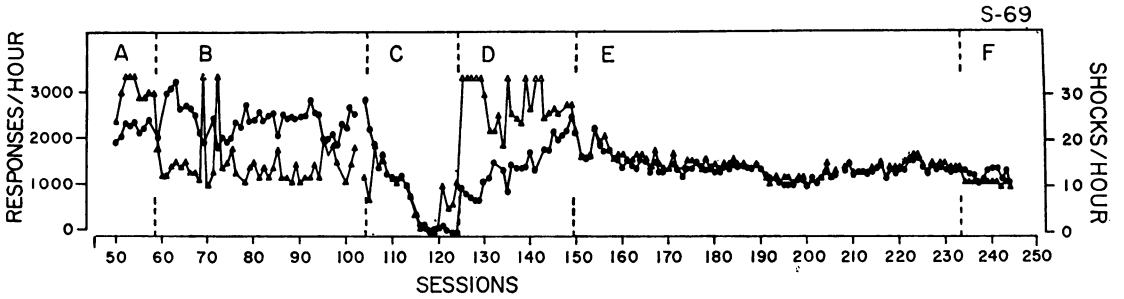

Fig. 7. Performance under interlocking schedules and various schedules of shock presentation (S-69). Ordinate: ●——● responses per hour, ▲——▲ shocks per hour; abscissa: sessions. Open triangles indicate shock frequencies greater than 30 shocks per hour. A: terminal performance under interlocking FR 100, R-S time 10 sec; B: interlocking FR 300, R-S time 10 sec; C: FR 300 (Session 105 only), FR 100, and alternative FR 100, FI 5-min schedule after Session 121; D: interlocking FR 100, R-S time 10 sec; E: interlocking FR 100 R-S 30 sec; F: FI 5-min schedule of shock presentation. In Session 171, the shock intensity was increased from 3 to 10 ma; in Session 186, the S-S interval was eliminated. Responding decreased to near zero under the FR schedules and did not recover until the interlocking schedule was reintroduced.

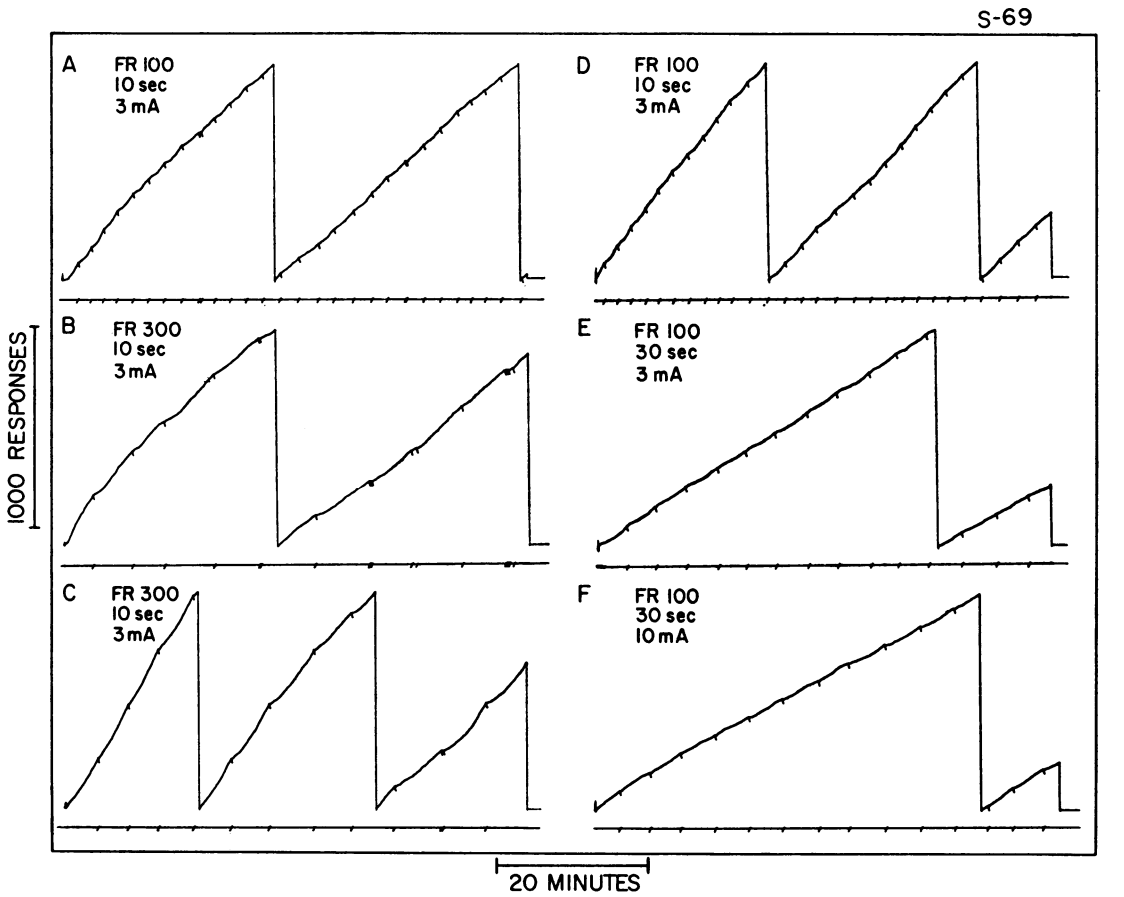

Fig. 8. Characteristics of performance under the interlocking schedule at various parameter values (S-69). Recording as in Fig. 3. A: stable performance under interlocking FR 100, R-S 10 sec (Session 58); B: transition to interlocking FR 300, R-S 10 sec (Session 59); C: terminal performance under interlocking FR 300, R-S 10 sec, showing some positively accelerated responding between shock presentations (Session 104); D: terminal performance under interlocking FR 100, R-S 10 sec (Session 149); E: under interlocking FR 100, R-S 30 sec (Session 170) rates of responding were lower than with R-S 10 sec; F: increasing the shock intensity from 3 to 10 ma had little effect (Session 232).

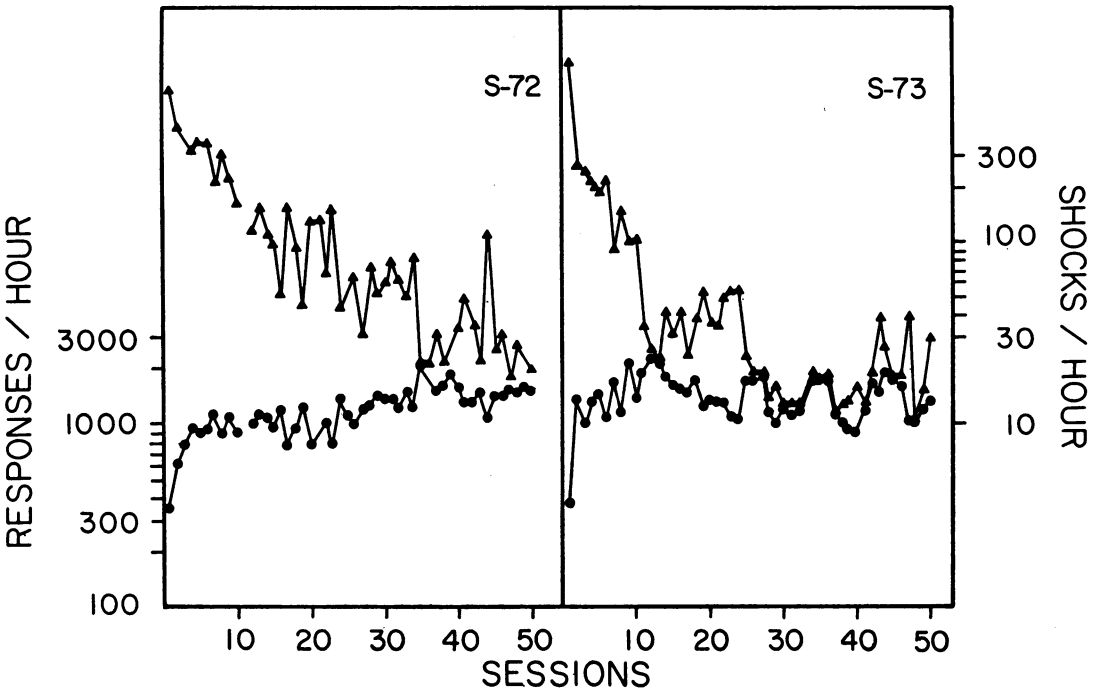

Fig. 9. Development of performance under the alternative fixed-ratio (FR 100), avoidance (R-S interval 10 sec, 3 ma) schedule. Ordinate (log scale): ●——● responses per hour, ▲——▲ shocks per hour; abscissa: sessions. Shock intensity was increased from 3 ma to 10 ma in Session 35 for S-72 and in Session 25 for S-73.

One monkey (S-73) studied initially under the alternative schedule (FR 100, R-S interval 10 sec) was studied at a later time under the interlocking schedule (FR 100, R-S time 10 sec). Figure 10 shows patterns of responding under the alternative schedule (on the left) and under the interlocking schedule (on the right). As performance developed under the interlocking schedule, positively accelerated responding between shock presentations became more pronounced. Rates of responding and shock frequencies were appreciably higher under the interlocking schedule than under the alternative schedule (Fig. 11).

Another monkey (S-68) studied initially under the interlocking schedule (FR 100, R-S time 30 sec) was next studied under the comparable alternative schedule (FR 100, R-S interval 30 sec). Average rates of responding decreased under the alternative schedule to about 400 responses per hour while shock frequencies decreased only slightly (Fig. 12A). When the response requirement under the alternative schedule was increased from 100 to 300, average rates of responding increased to about 800 responses per hour while shock frequencies decreased to about three shocks per hour (Fig. 12B).

Within the first session after the change from the interlocking to the alternative schedule, the pattern of positively accelerated responding between shocks was less evident (Fig. 13, middle left) and in subsequent sessions disappeared (bottom left). The terminal performance (after intervening treatments) under the alternative fixed-ratio, avoidance schedule is shown at the upper right of Fig. 13; there was no positively accelerated responding between shocks. When S-68 was again studied under the interlocking schedule, the pattern of positively accelerated responding developed rapidly (Fig. 13, middle and bottom right), and rates of responding and shock frequency increased (Fig. 12E).

Performance under fixed-ratio, fixed-interval, and alternative fixed-ratio, fixed-interval schedules of shock presentation. Responding was never maintained indefinitely under the fixed-ratio schedules of shock presentation that were studied (FR 100 and FR 300). Monkeys were studied under fixed-ratio schedules after interlocking schedules (S-67 and S-69) or

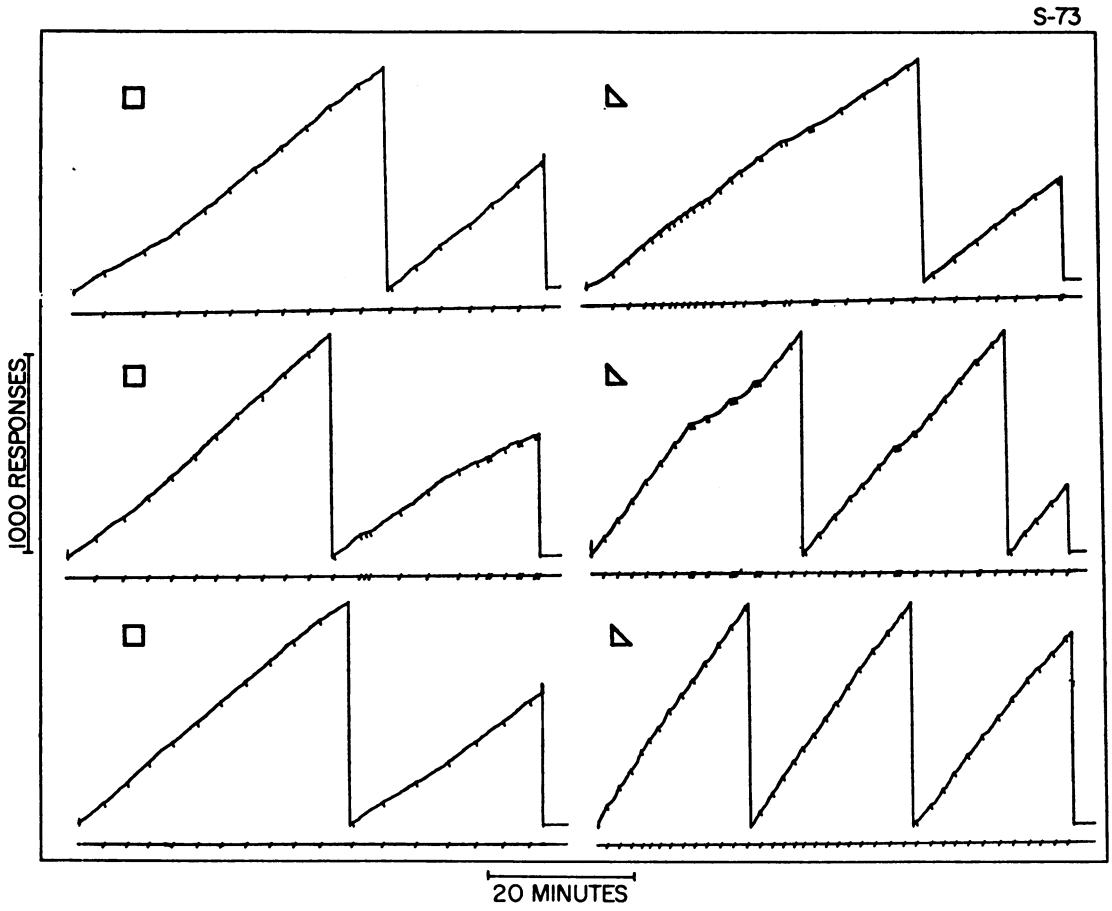

Fig. 10. Characteristics of performance under interlocking schedules and alternative FR, avoidance schedules (S-73). Recording as in Fig. 3. Under the alternative schedule (left records; denoted by squares) responding generally occurred at a steady rate (Sessions 56, 57, and 118). Under the interlocking schedule (right records; denoted by triangles) patterns of positively accelerated responding developed (Sessions 149, 164, and 183).

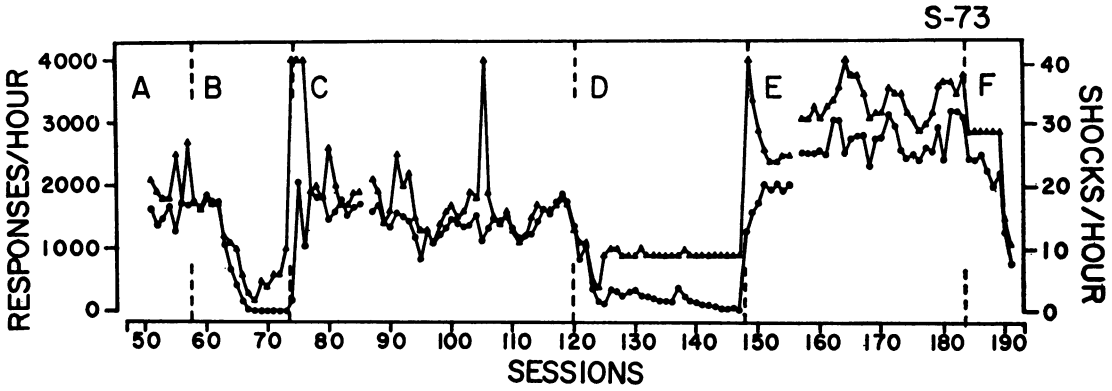

Fig. 11. Performance under alternative FR, avoidance schedules, interlocking schedules, and various schedules of shock presentation (S-73). Ordinate: ●——● responses per hour, ▲——▲ shocks per hour; abscissa: sessions. Open triangles indicate shock frequencies greater than 40 shocks per hour. A: alternative FR 100, avoidance R-S interval 10 sec; B: alternative FR 100, FI 5-min with shock interval of 5 to 10 min after Session 69; C: alternative FR 100, avoidance R-S interval 10 sec; D: alternative FR 100 FI 5-min with shock interval 6 min after Session 124; E: interlocking FR 100, R-S time 10 sec with no S-S interval; F: FI 2-min.

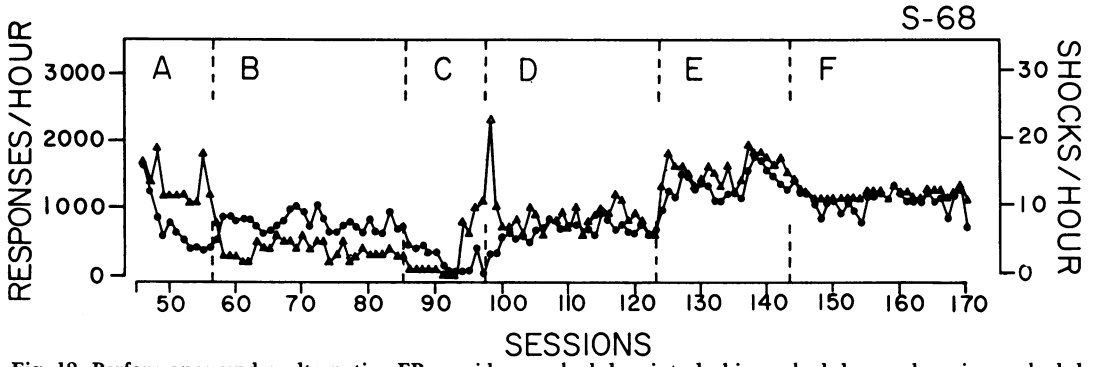

Fig. 12. Performance under alternative FR, avoidance schedules, interlocking schedules, and various schedules of shock presentation (S-68). Ordinate: ●——● responses per hour, ▲——▲ shocks per hour; abscissa: sessions. Open triangle indicates shock frequency greater than 20 shocks per hour. A: alternative FR 100, avoidance R-S interval 30 sec; B: alternative FR 300, avoidance R-S interval 30 sec; C: responding decreased to near zero under FR 300 (Sessions 86-93) and failed to recover under alternative FR 300 FI 5-min (Sessions 94-97); D: under alternative FR 100, avoidance R-S interval 30 sec, responding recovered; E: interlocking FR 100, R-S time 30 sec; F: alternative FR 100, FI 5-min schedule of shock presentation maintained responding.

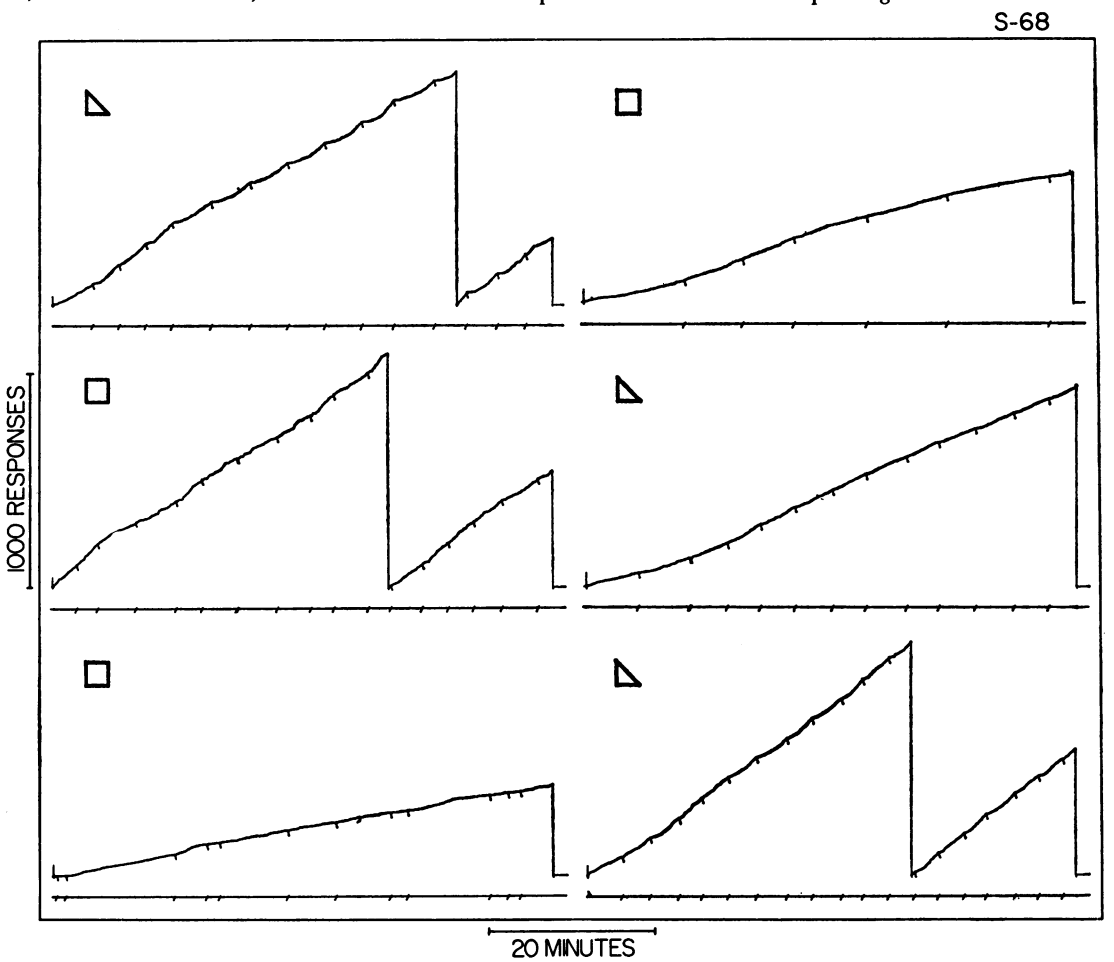

Fig. 13. Characteristics of performance under interlocking schedules and alternative FR, avoidance schedules (S-68). Recording as in Fig. 3. Responding was positively accelerated between shocks under interlocking FR 100, R-S time 30 sec (upper left record, Session 41), but not in the first session, under alternative FR 100, avoidance R-S interval 30 sec (middle left record, Session 46). Steady rates of responding were maintained under alternative FR 100, avoidance R-S interval 30 sec (lower left record, Session 56, and upper right record, Session 122). Responding increased under interlocking FR 100, R-S time 30 sec (middle right record, Session 124) and positively accelerated responding developed again (lower right record, Session 139).

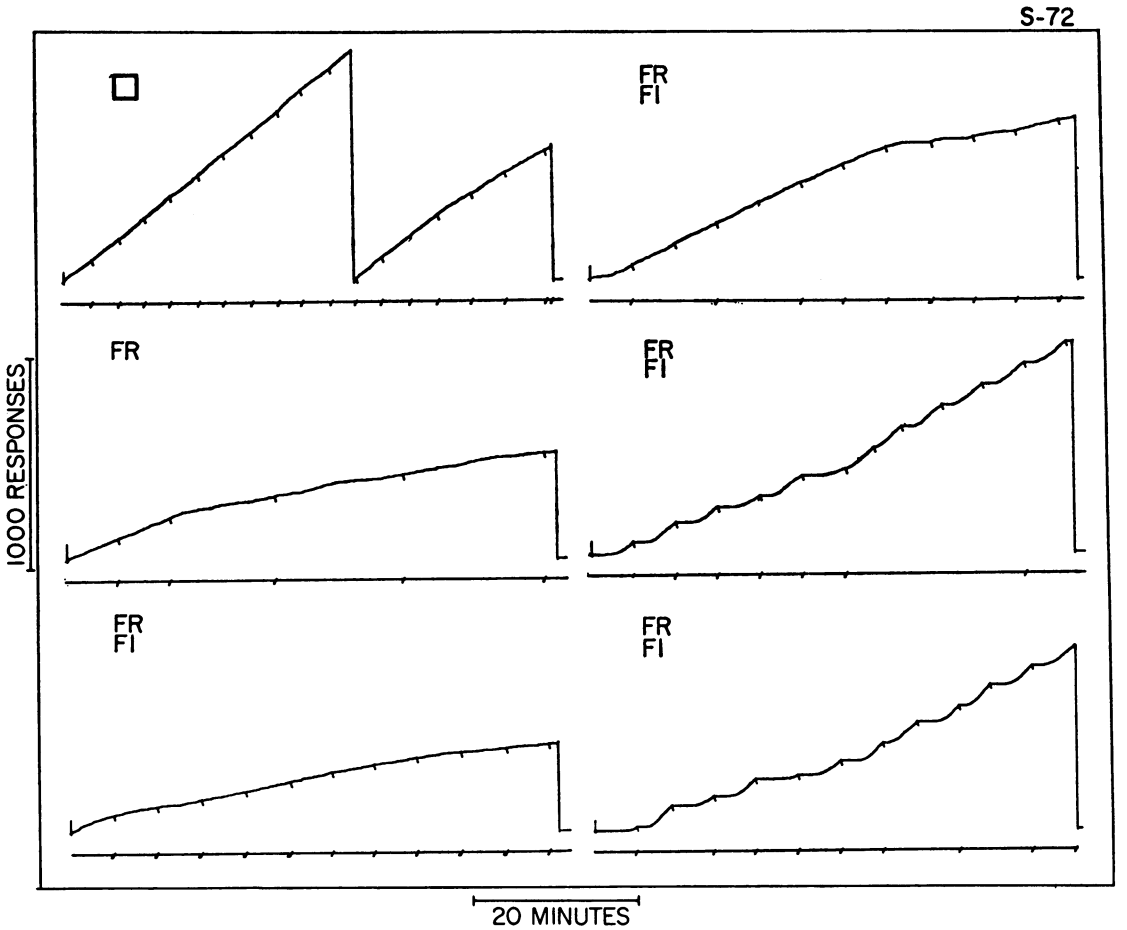

Fig. 14. Characteristics of performance under an alternative FR 100, avoidance schedule of shock postponement (Session 67), an FR 100 schedule (Session 71), and an alternative FR 100, FI 5-min schedule (Sessions 72, 87, 119, and 123) of shock presentations (S-72). Ordinate: cumulative responses; abscissa: time. The recording pen reset to the baseline whenever 1100 responses accumulated and at the end of each session. Short diagonal strokes on cumulative records and event records indicate presentations of electric shock, except that shocks presented under the fixed-ratio component of the FR, FI schedule are not shown on the event record. Responding was not maintained under the FR 100 schedule of shock presentation, but was maintained with a characteristic pattern of positively accelerated responding under the alternative FR 100, FI 5-min schedule of shock presentation.

alternative fixed-ratio avoidance schedules (S-68 and S-72). In all instances, the rate of responding under the fixed-ratio schedules progressively decreased to relatively low levels. The addition of a fixed-interval component (alternative fixed-ratio, fixed-interval schedules of shock presentation) failed to engender responding in two monkeys (S-68 and S-69), but increased the frequency of responding in Monkey S-72 (Fig. 14). When Monkey S-68 was again studied under the alternative fixed-ratio, fixed-interval schedule after 20 sessions under an interlocking schedule, responding was maintained (Fig. 12E, F), and patterns of positively accelerated responding gradually developed. Terminal performances under the alternative FR 100, FI 5-min schedule of shock presentation are shown in Fig. 15 for Monkey S-72.

The rate of responding of Monkey S-67 under the fixed-ratio schedule of shock presentation gradually decreased to two responses per hour in Session 69 (Fig. 16B). The introduction of response-independent shocks, presented every 5 min, gradually increased responding (Fig. 16C and 17B). Responding further increased under the alternative FR 100, FI 5-min schedule of shock presentation, and the pattern of positively accelerated responding became more pronounced. When

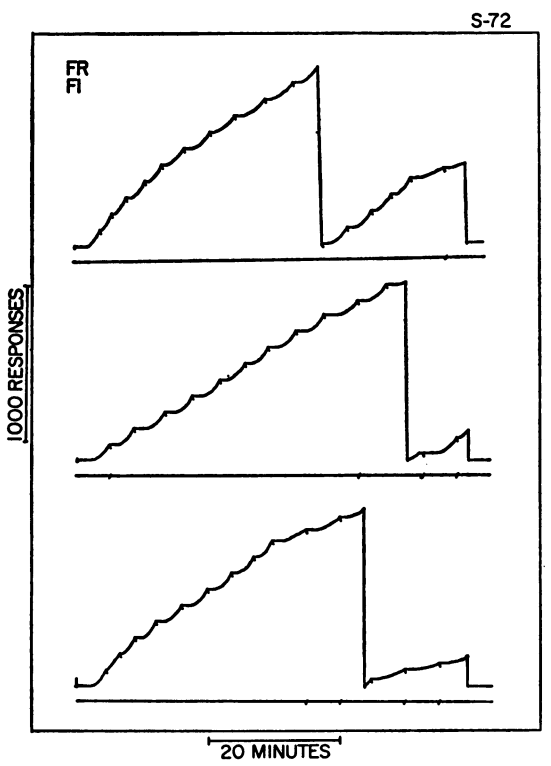

Fig. 15. Terminal performance under alternative FR 100, FI 5-min in Sessions 202, 203, and 204 (S-72). Recording as in Fig. 14.

the alternative schedule of shock presentation was modified so that shocks occurred under the 5-min fixed-interval component only after at least 30 responses had occurred (conjunctive FI 5-min, FR 30), rate of responding decreased and the pattern was altered to a more abrupt acceleration of responding (Fig. 17D, E). Similar results have been obtained under a conjunctive FR, FI schedule of food presentation (Herrnstein and Morse, 1958). Responding abruptly decreased to near zero after a minor apparatus failure in Session 131 (Fig. 16D) and was not maintained at its previous level under alternative FR 100, FI 5-min (Fig. 16E). Under an interlocking FR 300, R-S time 30-sec schedule, rate of responding increased during seven sessions to about 1700 responses per hour (Fig. 16F, 17F).

Stable responding was maintained under a 5-min fixed-interval schedule of shock presentation in Monkey S-67 for more than 50 sessions. Eventually, the pattern of positively accelerated responding disappeared during the latter part of each session and the rate of responding decreased. It was observed that the monkey was pulling its leash, which greatly decreased responding in Sessions 222 and 223. When the leash was removed during subsequent sessions, characteristic patterns and rates of responding were recovered (Fig. 18). Several characteristics of performance under the fixed-interval schedule of shock presentation are shown in Fig. 19. The types of deviations from the pattern of positively accelerated responding between shocks are similar to the "run throughs", "knees", "bites", and "second-order effects" observed under fixed-interval schedules of food presentation by Ferster and Skinner (1957) and Skinner (1938).

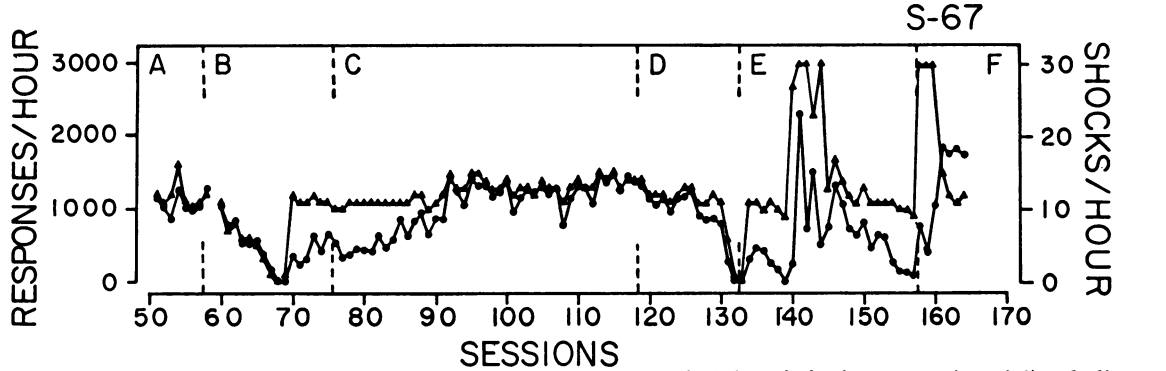

Fig. 16. Performance under interlocking schedules and various schedules of shock presentation (S-67). Ordinate: ●——● responses per hour, ▲——▲ shocks per hour; abscissa: sessions. Open triangles indicate shock frequency greater than 30 shocks per hour. A: interlocking FR 100, R-S time 30 sec but modified so that R-S time was infinite until the tenth response; B: FR 100 with shock interval 5 min after Session 68; C: alternative FR 100, FI 5-min; D: alternative FR 100, conjunctive FR 30, FI 5 min; E: alternative FR 100, FI 5-min with various shock intervals; F: interlocking FR 300, R-S time 30 sec with no S-S interval. In Session 131, it was found that one of the two keylights had burned out.

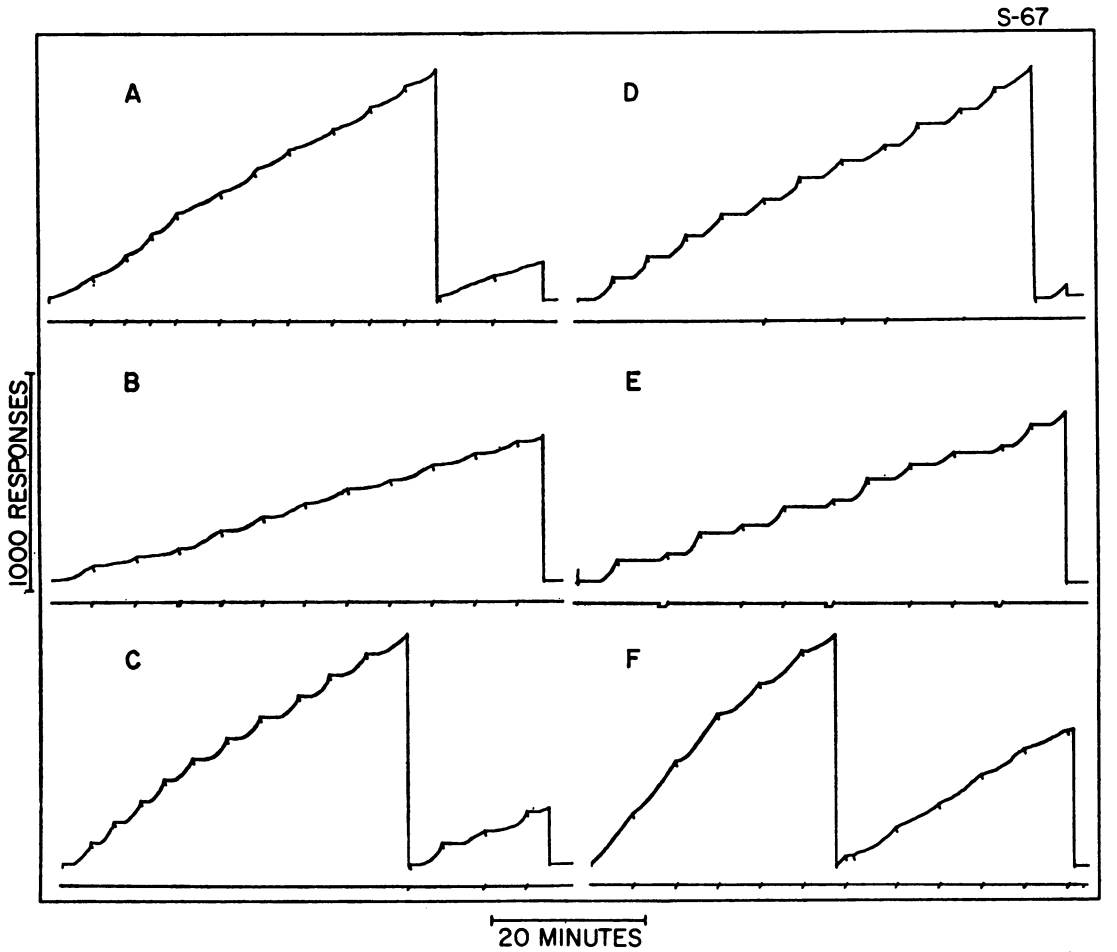

Fig. 17. Characteristics of performances under interlocking schedules of shock postponement and various schedules of shock presentation (S-67). Recording as in Fig. 14. A: FR 100 (Session 58); B: FR 100, shock interval 5 min (Session 75); C: alternative FR 100, FI 5-min (Session 118); D, E: alternative FR 100, conjunctive FR 30 FI 5-min (Sessions 124, 132); F: interlocking FR 300, R-S time 30 sec with no S-S interval (Session 164). A pattern of positively accelerated responding was maintained when shocks were presented every 5 min (B). Responding increased and the pattern was more pronounced under the alternative FR, FI schedule of shock presentation (C). The addition of the conjunctive component decreased responding and altered the pattern to a more abrupt acceleration of responding (D, E).

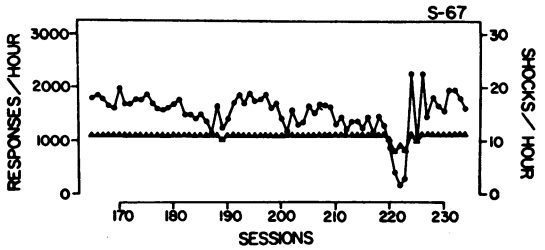

Fig. 18. Performance under FI 5-min schedule of shock presentation (Monkey S-67). Ordinate: ●——● responses per hour, ▲——▲ shocks per hour; abscissa: sessions. In Session 221, it was found that one of the two keylights had burned out and that the monkey was persistently pulling at its leash. Beginning with Session 224, the monkey's leash was removed before each session, except for Session 225.

DISCUSSION

The pattern of positively accelerated responding that develops under the interlocking schedule is significant for the analysis of schedule-controlled performances because the duration of the periodicity does not correspond to any simple time parameter of the schedule. The positively accelerated responding that develops under fixed-interval schedules is often attributed (intuitively but wrongly) to a "temporal discrimination" of the interreinforcement interval, but there is no fixed interreinforcement interval under the interlocking schedule. Thus, the interlock-

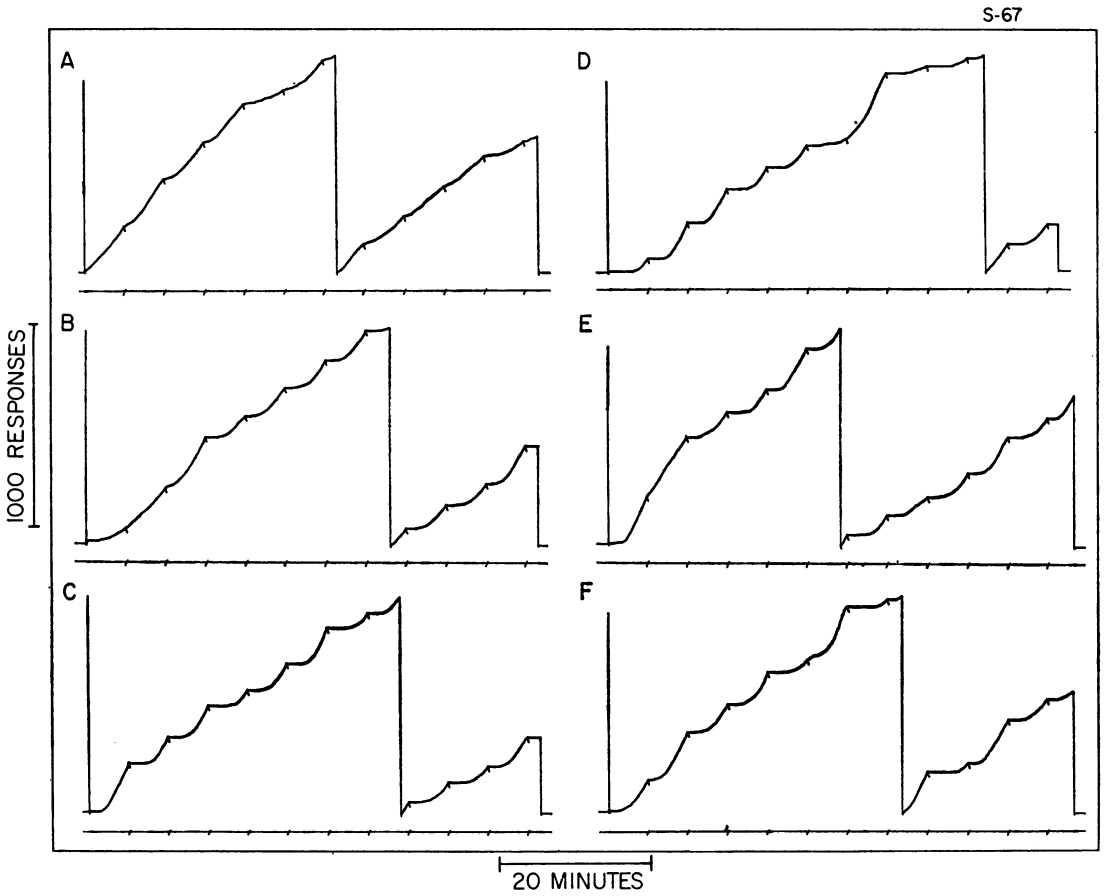

Fig. 19. Characteristics of performance under FI 5-min schedule of shock presentation (Monkey S-67). Recording as in Fig. 3. A: Session 165 (initial session); B: Session 177; C: Session 185; D: Session 186; E: Session 194; F: Session 195. Records were selected to illustrate common variations from the prototypic patterns of positively accelerated responding that occur under fixed-interval schedules (C); for example, instances of positively accelerated responding throughout two fixed-interval components (B, D), decelerations in responding (E), and "running through" (E, F).

ing schedule emphasizes that positively accelerated responding can have a dynamic basis.

The pattern of responding depends more upon interactions between features of the schedule and the individual's responding under the interlocking schedule than under many commonly used schedules (Ferster and Skinner, 1957; Skinner, 1966). A highly reproducible pattern of responding can produce a relatively constant duration between shock presentations under the interlocking schedule, just as there can be constant interreinforcement times under fixed-ratio schedules or the alternative fixed-ratio, avoidance schedule used in the present study. A constant interreinforcement duration in itself does not ensure a pattern of positively accelerated responding; rather, this pattern appears to develop under conditions favoring sequences of responding.

Under interval schedules, unlike ratio or continuous avoidance schedules, antecedent interresponse times change the likelihood that interresponse times will be reinforced. As the sum of antecedent interresponse times increases, the probability that the next response, with a fixed interresponse time, will be reinforced also increases (Morse and Herrnstein, 1955; Morse, 1966). The interlocking schedule is similar in that increasing numbers of responses, independently of interresponse-time duration, increase the likelihood that a shock will occur after a fixed time. In this respect, the formal properties of the interlocking schedule are like those of fixed-interval sched-

ules. The left side of Fig. 20 shows certain relations that prevail under a 30-sec fixed-interval schedule. When the sum of previous interresponse times is 0, then a response after 30 sec will be reinforced; when their sum is 15 sec, a response after 15 sec will be reinforced; as the sum of antecedent interresponse times approaches 30 sec, responses with shorter and shorter interresponse times will be reinforced. The right side of Fig. 20 shows relations that prevail under interlocking FR 100, R-S time 30 sec. The first response postpones shock for 30 sec; the fiftieth response postpones shock for 15 sec; as the number of responses approaches 100, the duration of shock postponement becomes shorter and shorter. Thus, the interlocking schedule is a "number analogue" of the summation of interresponse time durations in fixed-interval schedules (see also Millenson, 1966). A major difference in the two representations is that the line in the fixed-interval diagram indicates the availability of reinforcement and the line in the interlocking diagram indicates the occurrence of shock. Although there are other important differences between fixed-interval and interlocking schedules, the similarities in the relations shown in Fig. 20 may elucidate the basis for the similar patterns of positively accelerated responding.

Under the interlocking and the alternative schedules of shock postponement, shock frequencies were decreased by responding. For example, under the interlocking FR 100, R-S time 30-sec schedule, the shock frequency could be reduced to about five shocks per hour by steady responding with 15-sec interresponse times, or to about two shocks per hour by optimum patterning of interresponse times. Average response rates and shock frequencies much exceeded these values under both interlocking and alternative schedules of shock postponement. Under the alternative fixed-ratio, fixed-interval schedule, the fixed-ratio schedule, and the fixed-interval schedule of shock presentation, and also under the interlocking schedule with no S-S interval, shocks were not presented unless responding occurred.

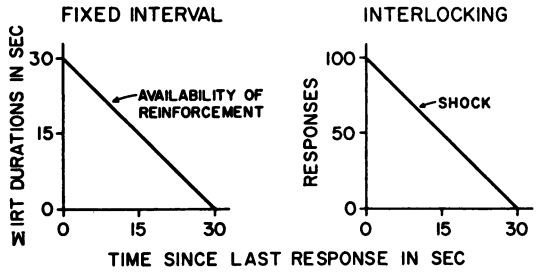

Fig. 20. Diagram illustrating a quantitative similarity in the effect of cumulative IRT durations under a fixed-interval schedule and cumulative responses under an interlocking schedule. Under FI 30-sec, a response after 30 sec will be reinforced without antecedent responses; a response after 15 sec will be reinforced if the sequence of antecedent responses had a total IRT duration of 15 sec; a response after 1 sec will be reinforced if the sequence of antecedent IRTs had a total duration of 29 sec. Under the interlocking FR 100, R-S time 30-sec schedule, the first response postpones shock for 30 sec; the fiftieth response postpones shock for 15 sec; the ninety-ninth response postpones shock for 1 sec; and the one hundredth response produces shock.

After a history of responding under other schedules, Monkeys S-67, S-68, and S-72 were maintained under the alternative fixed-ratio, fixed-interval schedule for many sessions. The fixed-interval component seemed to be essential for the maintenance of responding under this alternative schedule. Responding was never maintained under fixed-ratio schedules alone. Whenever a fixed-ratio schedule operated alone, the rate declined over consecutive sessions, but the addition of the fixed-interval component increased responding in S-72 (but not S-68 and S-69).

In Monkey S-67, after responding declined under the fixed-ratio schedule, the addition of a 5-min shock interval, and then a 5-min fixed-interval component, maintained a pattern of positively accelerated responding. Further, responding was not maintained in S-67 when the alternative fixed-ratio, fixed-interval schedule was changed to a conjunctive fixed-ratio, fixed-interval schedule. Finally, responding in S-67 was maintained for 70 sessions, and S-69 and S-73 for shorter periods, under a fixed-interval schedule of shock presentation alone. These diverse results indicate that fixed-interval schedules of shock presentation engendered responding, whereas fixed-ratio schedules of shock presentation did not maintain responding at the parameters used in this experiment.

Responding was not maintained in all subjects by the schedules of shock presentation. For example, although Monkeys S-72 and S-73 had comparable performances under the alternative fixed-ratio, avoidance schedule, the alternative fixed-ratio, fixed-interval schedule of

shock presentation maintained responding in Monkey S-72 but not in S-73. In the other instances in which responding was not maintained under the alternative fixed-ratio, fixed-interval schedule, the fixed-interval component was introduced after responding had already declined under the fixed-ratio schedule. At the present time not enough systematic data are available to evaluate quantitatively the antecedent conditions and present parameter values under which schedules of shock presentation will maintain responding.

Two different stable patterns of responding maintained under the same schedule parameters, one before and one after an intervening treatment, have been called metastable (Staddon, 1965). Performances under some of the conditions studied in the present experiments were reproducible after intervening treatments, whereas other performances were metastable. While performances under the interlocking and alternative fixed-ratio, avoidance schedules were reproducible, especially after changes in the R-S time parameter (see Fig. 5, 7), the effects of shock intensity under these schedules depended somewhat upon the subject's performance, and appeared to be more critical during the initial development of responding. For example, a shock intensity of 3 ma did not maintain a steady level of responding in S-70 or S-73 during initial training, but subsequently did maintain responding. Similarly, changing the shock intensity from 3 to 10 ma after 170 sessions had no appreciable effect on the performance of S-69. Previously we noted that the schedule conditions necessary to develop a characteristic performance were more critical than the conditions needed to maintain the performance (Morse and Kelleher, 1966). In general, performances under schedules of shock presentation appear to be more metastable than performances under schedules of shock postponement. Since the development of responding under schedules of shock presentation depends upon ongoing behavior, it is not surprising that responding might remain changed after a momentary disruption.

While it is generally accepted that schedules of food presentation engender patterns of responding with characteristics that depend upon the specific schedule contingencies, different schedules using electric shocks have been studied little until recently, perhaps because performance under such procedures has been characterized in such general terms as "aversive control", "avoidance", or "escape" rather than in terms of the schedule itself. We have previously found that termination of a stimulus-shock complex under fixed-ratio and fixed-interval schedules engenders performances characteristic of these schedules (Morse and Kelleher, 1966). The present experiments extend and confirm several earlier studies (Byrd, 1969; Kelleher and Morse, 1968; McKearney, 1968, 1969; Morse, Mead, and Kelleher, 1967), showing that responding can be maintained under fixed-interval schedules of shock presentation alone. The performances that developed under the interlocking and the alternative fixed-ratio, avoidance schedules further indicate that different schedules using electric shock engender characteristic performances. The inherent properties of the interlocking schedule of shock postponement make it useful for analyzing positively accelerated responding.

REFERENCES

Anger, D. The role of temporal discriminations in the reinforcement of Sidman avoidance behavior. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 477-506.

Berryman, R. and Nevin, J. A. Interlocking schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1962, **5**, 213-223.

Byrd, L. D. Responding in the cat maintained under response-independent electric shock and response-produced electric shock. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 1-10.

Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.

Hake, D. F. and Azrin, N. H. An apparatus for delivering pain shock to monkeys. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 297-298.

Herrnstein, R. J. and Hineline, P. N. Negative reinforcement as shock-frequency reduction. *Journal of the Experimental Analysis of Behavior*, 1966, **9**, 421-430.

Herrnstein, R. J. and Morse, W. H. A conjunctive schedule of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1958, **1**, 15-24.

Kelleher, R. T., Gill, C. A., Riddle, W. C., and Cook, L. On the use of the squirrel monkey in behavioral and pharmacological experiments. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 249-252.

Kelleher, R. T. and Morse, W. H. Escape behavior and punished behavior. *Federation Proceedings*, 1964, **23**, 808-817.

Kelleher, R. T. and Morse, W. H. Schedules using noxious stimuli. III. Responding maintained with

response-produced electric shocks. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 819-838.

Kelleher, R. T., Riddle, W. C., and Cook, L. Persistent behavior maintained by unavoidable shocks. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 507-517.

McKearney, J. W. Maintenance of responding under a fixed-interval schedule of electric shock presentation. *Science*, 1968, **160**, 1249-1251.

McKearney, J. W. Fixed-interval schedules of electric shock presentation: extinction and recovery of performance under different shock intensities and fixed-interval durations. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 301-313.

Millenson, J. R. Probability of response and probability of reinforcement in a response-defined analogue of an interval schedule. *Journal of the Experimental Analysis of Behavior*, 1966, **9**, 87-94.

Morse, W. H. Intermittent reinforcement. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 52-108.

Morse, W. H. and Herrnstein, R. J. *An analysis of responding under three different forms of fixed interval reinforcement.* Paper presented at Eastern Psychological Association meetings, Philadelphia, 1955.

Morse, W. H. and Kelleher, R. T. Schedules using noxious stimuli. I. Multiple fixed-ratio and fixed-interval termination of schedule complexes. *Journal of the Experimental Analysis of Behavior*, 1966, **9**, 267-290.

Morse, W. H., Mead, R. N., and Kelleher, R. T. Modulation of elicited behavior by a fixed-interval schedule of electric shock presentation. *Science*, 1967, **157**, 215-217.

Powers, R. B. Clock-delivered reinforcers in conjunctive and interlocking schedules. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 579-586.

Sidman, M. Avoidance conditioning with brief shock and no exteroceptive warning signal. *Science*, 1953, **118**, 157-158.

Sidman, M. Reduction of shock frequency as reinforcement for avoidance behavior. *Journal of the Experimental Analysis of Behavior*, 1962, **5**, 247-257.

Skinner, B. F. *The behavior of organisms: an experimental analysis.* New York: Appleton-Century-Crofts, 1938.

Skinner, B. F. Diagramming schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1958, **1**, 67-68.

Skinner, B. F. Operant behavior. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 12-32.

Staddon, J. E. R. Some properties of spaced responding in pigeons. *Journal of the Experimental Analysis of Behavior*, 1965, **8**, 19-27.

Waller, M. B. and Waller, P. F. The effects of unavoidable shocks on a multiple schedule having an avoidance component. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 29-37.

Wertheim, G. A. Some sequential aspects of IRTs emitted during Sidman-avoidance behavior in the white rat. *Journal of the Experimental Analysis of Behavior*, 1965, **8**, 9-15.

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