JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1994, 61, 135–153 NUMBER 2 (MARCH)

THE PUZZLE OF RESPONDING MAINTAINED BY RESPONSE-CONTINGENT SHOCK

MICHAEL T. LAURENCE, PHILIP N. HINELINE, AND PHILIP J. BERSH

TEMPLE UNIVERSITY

Four squirrel monkeys were first exposed to a sequence of procedures that reliably generate responding maintained by brief response-contingent electric shocks arranged according to a fixed-interval schedule. After responding had become stable on the fixed-interval schedule, additional contingencies were added in tandem, whereby after completion of the interval, the spacing of responses affected shock delivery. In one procedure, responses had to be spaced more widely than their previous median value if shock were to be delivered. In the other procedure, responses had to be spaced more closely to produce shock. On the first of these procedures, decreased but stable response rates would indicate that shock functioned as a positive reinforcer; on the second, increased response rates would indicate the positively reinforcing function. Instead, response rates accelerated on the procedure that targeted more widely spaced responses for shock delivery, and decelerated or ceased on the procedure that arranged for shocks to be produced by more closely spaced responses. Consistent with other recent findings, these results question the interpretation of performances maintained by response-contingent shock as engendered by positive reinforcement and are consistent with aversive-control interpretations. The details of that aversive control are not entirely clear, however, and these same procedures would be informative if applied to shock-maintained behavior that is generated in other ways.

Key words: shock-maintained responding, fixed-interval shock schedules, punishment of interresponse times, shock postponement, shock-frequency reduction, response-contingent shock, positive reinforcers, aversive control, lever press, squirrel monkeys

A stimulus whose occurrence is contingent upon a response is identified as a positive reinforcer if, as a result of its contingent delivery, responding is maintained, or if there is a subsequent increase in rate of responding. Under some conditions, responding is maintained indefinitely when the only response-contingent event is a brief electric shock. Furthermore, the pattern of responding may be the same as that observed under the same schedule when an appetitive stimulus is contingent upon the response. In addition, variables may have parallel influence on responding that is maintained by contingent shock and by contingent appetitive stimuli. Thus, higher intensities of contingent shock maintain higher response rates (Morse & Kelleher, 1977); response rates vary inversely with the interval duration on fixed-interval (FI) shock schedules (McKearney, 1969); and a shock-correlated stimulus maintains responding under a second-order schedule (Byrd, 1972). Accordingly, it appears that contingent shock may function as a positive reinforcer. It has been proposed that, under some conditions, contingent shock is a reinforcer in the same way as food and water are reinforcers for the behavior of food-deprived and water-deprived subjects. This has led to the further claim that schedules of reinforcement are sufficiently powerful to eliminate differences between the effects of contingent shock and contingent appetitive reinforcers (Morse & Kelleher, 1977).

However, there are major differences between the effects of conventional positive reinforcers and the effects of contingent shock. A contingent stimulus that is positively reinforcing for the behavior of a given subject will increase the rate of a previously unconditioned operant. In contrast, contingent shock may maintain responding, as noted above, or may elicit particular responses (Hutchinson, 1977;

The experiment reported here was first presented as part of the PhD dissertation of the first author (Laurence, 1980). More recently, it was presented in a festschrift symposium honoring Joseph V. Brady, and the present article is offered in acknowledgment of his extensive contributions to our field. Support for the research was provided by a Biomedical Research Support Grant and a grant from the Thaddeus Bolton Fund, both through Temple University. Preparation of the manuscript was facilitated by a Research and Study Leave granted from Temple University to the second author, and by NSF Grant INT-9015810. Reprints can be obtained from the first author at 3902 Adrienne Drive, Alexandria, Virginia 22309, or from the other authors at Department of Psychology, Temple University, Philadelphia, Pennsylvania 19122.

Hutchinson, Renfrew, & Young, 1971), but it does not lead to operant conditioning, as in the shaping of new response patterns. Contingent shock maintains responding only after responding has developed as a result of positive or negative reinforcement, or following conjoint exposure to positive and negative reinforcement. Furthermore, not all schedules of contingent-shock presentation maintain responding. Interval schedules—especially with fixed intervals—are effective, but ratio schedules do not maintain responding even when yoked to a prior FI schedule that has maintained responding (Branch & Dworkin, 1981). In multioperant procedures, animals emit the behavior that is subject to the higher rate of positive reinforcement; by contrast, they emit the response subject to the lower rate of response-produced shock presentation (Pitts & Malagodi, 1991). These considerations suggest that response maintenance by contingent shock may not be appropriately characterized as positive reinforcement.

An alternative view of the maintenance of responding by contingent shock construes it as a by-product of aversive control, involving shock-elicited responding, differential punishment depending on the spacing of responses (interresponse times, or IRTs), and/or negative reinforcement by shock-frequency reduction. An increasing body of evidence supports this view. For example, as noted above, when responding is maintained by response-contingent shock on two concurrently available FI schedules, monkeys choose the longer of the two FI schedules of response-contingent shock presentation, despite the fact that the rate of contingent shock delivery is thereby decreased (Pitts & Malagodi, 1991). By contrast, choice between schedules of positive reinforcement consistently favors the richer (i.e., higher rate of reinforcement) schedule. Indeed, this definition of reinforcement value links negative reinforcement with an extensive literature on choice among alternative sources of positive reinforcement (Baum, 1973).

As a possible basis for response maintenance through aversive control, differential punishment of IRTs could occur if shock delivery were correlated with the spacing of responses so that, for example, shock occurred with higher probability when a response followed a previous response after a relatively long interval. The effectiveness of interval schedules in response maintenance by contingent shock alone has been attributed to the punishment of long IRTs on such schedules, leading to an increase in the frequency of short IRTs and, thus, to higher overall rates of responding. That interpretation is consistent with the observation that ratio schedules of response-contingent shock do not maintain responding, whereas interval schedules do (Branch & Dworkin, 1981); that view is also supported by research demonstrating that explicit punishment of IRTs greater than t (not simply as a by-product of FI schedules of shock presentation) increases overall response rates and maintains responding indefinitely (Galbicka & Branch, 1981). Such effects of explicitly arranged punishment occur even when the possibility of negative reinforcement of IRTs by shock-frequency reduction is eliminated (Galbicka & Platt, 1984). Although Galbicka and Platt's procedure rules out shock-frequency reduction as a necessary condition for responding, it is not clear that this variable should be dismissed entirely, especially with respect to the initial emergence of the behavior in question (as we shall discuss later).

The research reported here provides an additional examination of small-scale contingencies, using procedural characteristics that are standard for shaping behavior via positive reinforcement but implementing them with respect to responding that is being maintained by response-contingent shock. A complementary pair of schedules was based upon the spacing of the animal's responses. One schedule delivered shocks for IRTs less than a value of t that was selected to match the median IRT of the monkey's prior shock-maintained performance. The other schedule delivered shock for IRTs greater than t. If contingent shock functions as a positive reinforcer, both schedules should have maintained responding—at high rates in the former case and at low rates in the latter case. On the other hand, if contingent shock differentially punishes IRTs in this situation, or negatively reinforces (by shock-frequency reduction) responses that violate the IRT criterion, shock contingent on IRTs less than t may maintain responding but should engender low rates, whereas shock contingent on IRTs greater than t should produce higher response rates, in line with other research (Galbicka & Branch, 1981; Galbicka & Platt, 1984).

Table 1
Experimental procedures.

Fyodor	Ivan	Alexey	Dimitri
Adaptation	Adaptation	Adaptation	Adaptation
Avoidance (AV)	Avoidance (AV)	Avoidance (AV)	Avoidance (AV)
Conjoint AV and FI 5-min:shock	Conjoint AV and FI 5-min:shock	Conjoint AV and FI 5-min:shock	Conjoint AV and FI 5-min:shock
	Avoidance	Avoidance	
	Conjoint AV and FI 5-min:shock	Conjoint AV and FI 5-min:shock	
FI 5-min:shock	FI 5-min:shock	FI 5-min:shock	FI 5-min:shock
Tandem FI 5-min DRL:shock	Tandem FI 5-min DRH:shock	Tandem FI 5-min DRL:shock	Tandem FI 5-min DRH:shock
FI 5-min:shock	FI 5-min:shock	FI 5-min:shock	FI 5-min:shock
	Conjoint AV and FI 5-min:shock		Conjoint AV and FI 5-min:shock
	FI 5-min:shock		FI 5-min:shock
Tandem FI 5-min DRH:shock	Tandem FI 5-min DRL:shock		
FI 5-min:shock	FI 5-min:shock		

METHOD

Subjects

The subjects were 4 adult male squirrel monkeys (*Saimiri sciureus*), identified as Fyodor, Ivan, Alexey, and Dimitri. Maintained in individual cages with free access to food and water, they weighed between 890 and 1,055 g and were experimentally naive at the start of the experiment.

Apparatus

The experiment was conducted in a primate apparatus similar to the one described by Hake and Azrin (1963). During sessions, a monkey was restrained in a seated position by means of an acrylic waist-lock, with its tail secured in a small clamp. Electric shocks, generated by a BRS-Foringer® shock generator (Model SG-901), were delivered to two brass plates that rested on a shaved portion of the monkey's tail. Electrode paste was used to ensure low resistance between the tail and the electrodes.

A BRS-LVE rodent lever (Model 121-05) was mounted on the front wall 13 cm from the center and 22.4 cm above the waist-lock. Presses of 0.2 N operated a solenoid that provided exteroceptive feedback to the subject and activated the control circuitry. Centered 6.4 cm above the lever were three translucent white Plexiglas disks measuring 5.8 cm in diameter and spaced 6.7 cm apart (center to center). During experimental sessions these disks were illuminated by No. 1820 bulbs.

The entire apparatus was enclosed in a sound-attenuating chamber that was illuminated by a 15-W incandescent lamp and ventilated by a fan at all times. White masking noise (50 dB) was also presented throughout each session. Electromechanical control and solid-state data recording equipment was located in a separate room.

Procedure

All monkeys were given initial training according to the general procedure described by McKearney (1968) to engender responding maintained by response-contingent shock. Then the sequences of procedures that provided key comparisons were counterbalanced between pairs of subjects. A comparative sequence illustrating this procedure is presented in Table 1; the numbers of sessions of exposure for each monkey to each procedure are shown in the Appendix.

After a brief period of adaptation to the experimental environment with no experimental contingencies in effect, the monkeys were first trained on the shock-postponement procedure devised by Sidman (1953). In the absence of lever pressing, shocks of 300 ms duration were delivered at 10-s intervals (the S-S interval). A lever press could postpone the next scheduled shock until 30 s later (the R-S interval). Additional responses during that R-S interval further postponed the next scheduled shock by restarting the 30-s R-S interval. Thus, if 30 s never elapsed between responses, all shocks could be avoided throughout a session. At the start of this training, the intensity of the shocks was set at 2 mA, and a 10-in. chain was attached to the lever. Over successive sessions, the shock intensity was increased in 1-mA increments, and the chain was progressively shortened. By the 10th session of training, the chain was eliminated and the shock intensity was set at 5 mA for Fyodor, Ivan, and Dimitri, and at 6 mA for Alexey. All of the above sessions were conducted daily and were 100 min in length.

A fixed-interval schedule was then added conjointly with avoidance. That is, Sidman's shock-postponement procedure continued as before, while an arrangement was superimposed whereby the first response emitted by the monkey 5 min following the start of the session, or 5 min following the most recent response-produced shock, produced a shock. The response-produced shocks were of the same intensity and duration as those arranged under the Sidman contingency. Daily sessions lasted until 20 response-produced shocks were delivered, or until 120 min had elapsed. Finally, the avoidance (AV) component of this conjoint AV FI 5-min:shock schedule was eliminated, and the monkeys were exposed to the FI 5-min: shock schedule alone. Under this procedure the only scheduled consequence for responding was the delivery of a shock. Again, daily sessions lasted until 20 response-produced shocks had been delivered, but no longer than 120 min.

Under the next procedure, a tandem contingency based on the spacing of individual responses was added to the fixed interval. That is, a shock was produced only when both 5 min had elapsed since the most recent response-produced shock (or since the start of the session) and two or more responses were spaced with particular interresponse times in relation to time *t*. The value of *t* was individually determined for each monkey. This value was based on an analysis of the IRTs during the terminal 30 s of each fixed interval of the final three sessions of FI 5-min:shock training that preceded the imposition of the tandem contingency. Using the medians of these samples of IRTs, the tandem contingencies were arranged so that shock delivery would result from increasing response rates in some cases (DRH) and from decreasing response rates (DRL) in others, with the sequences of these alternatives counterbalanced across monkeys.[1]

In the procedure in which decreased response rate produced shock, an IRT of at least *t* s was specified (tandem FI 5-min DRL: shock). That is, upon completion of the FI 5-min component of the schedule, the first response started a clock set for *t* s. If the next response was emitted before this clock had timed out, the clock was reset and the *t*-s period restarted. The first response that followed the timing out of the clock resulted in the delivery of a shock and started the next FI 5-min component of the schedule. Thus, if a monkey on this procedure reduced its response rate after the completion of the FI 5-min component, spacing its responses at least *t* s apart, a shock was produced. If the monkey did not reduce, or instead increased, its response rates, the delivery of the scheduled shocks was postponed, and the DRL component of the schedule remained in effect. As noted above, the median IRT was selected as the monkey's *t* value so that, at least initially, approximately half of the IRTs resulted in response-produced shocks under this tandem schedule. Over sessions, the *t* value was increased in increments of 0.2 and 0.3 s as long as the monkeys continued to meet the schedule requirements and produce the shocks. Table 1 and the Appendix indicate the point in the overall sequence at which this procedure occurred for each monkey, and Table 2 summarizes the *t* values imposed for each animal during training on this procedure.

In the tandem procedure in which increased response rates produced shock, responses spaced more closely than *t* s were specified (tandem FI 5-min DRH:shock). That is, when 5 min had elapsed following the most recent response-produced shock (or following the start of the session), and two responses occurred with a separation of *t* s or less, a shock could be delivered, subject to the following additional provision: For this procedure, a value *n* was also designated, denoting pairs of responses satisfying the "less-than-*t*-s IRT" criterion.

[1] The terms DRL and DRH simply refer to schedules of response-contingent presentation of shock. Although these terms originated in the study of intermittent positive reinforcement, their use here should not be taken to imply that shock functions as a positive reinforcer.

Table 2

Summary of t values used in the tandem FI 5-min DRL: shock procedures. In this procedure, t was the interresponse time (in seconds) that had to be exceeded if a response was to produce shock after the fixed interval had elapsed.

Fyodor		Ivan		Alexey	
Sessions	t	Sessions	t	Sessions	t
103–104	0.3	174–176	0.7	148–150	0.7
105–107	0.5	177–178	0.9	151–154	0.9
108–111	0.7	179–181	1.1	155–159	1.1
112–113	1.0	182–184	1.3	160–167	1.3
114–116	1.2	185–186	1.5	168–175	1.5
117–140	1.5	187–189	1.7	176–190	1.7
		190–195	1.9		
		196–218	2.1		

For each monkey's initial exposure to this procedure, n was set at 2; when two pairs of closely spaced responses had occurred, a shock was delivered. Thus, the first response emitted upon completion of the FI 5-min component of the schedule started a clock set at t s. For shock delivery to occur, a second and then a third response had to occur while the clock was timing. Each response that was emitted while the clock was timing reset the clock, allowing the monkey the full t-s interval to emit the next response. If the clock timed out before the second or third responses were emitted, the clock remained in the timed-out state until a response restarted it. Once the response-produced shock was delivered, the next FI 5-min component began.

To recapitulate this procedure for $n = 2$: If a monkey increased its response rate after completing the FI 5-min component, emitting three responses spaced t s or less apart, it produced the scheduled shock. If the monkey did not increase, or instead decreased, its response rate and therefore did not meet the IRT requirement, delivery of the shocks was postponed and the DRH component of the schedule remained in effect. Over sessions, the value of n was increased in increments of one pair as long as the monkey continued to meet the schedule requirements and produce the shocks. For Fyodor and Ivan, the n value was finally set at six and four pairs, respectively. The initially imposed value of $n = 2$ for Dimitri remained unchanged over the course of his exposure to the tandem FI 5-min DRH:shock schedule. Manipulation of the n value of this schedule was made necessary by mechanical limitations of the control equipment, which otherwise would have prevented the imposition of sufficiently small t values.

As previously noted, the initial value of t for each monkey was determined in the same manner for both the tandem DRL and the tandem DRH procedures. These values, as well as subsequent adjustments in t during exposure to the DRH procedure to assess sensitivity to the IRT requirement, are indicated in Table 3.

For both the tandem FI 5-min DRL:shock and the tandem FI 5-min DRH:shock procedures, each daily session was continued until 20 response-produced shocks had been delivered, or until 120 min had elapsed. Following exposure to each of the tandem schedules (the numbers of sessions in these exposures are indicated in the Appendix), the monkeys were

Table 3

Summary of n and t values used in the tandem FI 5-min DRH:shock procedure. To satisfy the DRH contingency, pairs of responses had to be separated by intervals shorter than t (in seconds); n was the number of such pairs that had to occur consecutively, each with IRT less than t, for a shock to be produced after the 5-min fixed interval had elapsed.

Fyodor			Ivan			Dimitri		
Sessions	n	t	Sessions	n	t	Sessions	n	t
171–173	2	0.3	111–113	2	0.8	95–97	2	0.3
174–175	3	0.3	114–120	3	0.8	98–104	2	0.5
176–178	4	0.3	121–127	4	0.8			
179–181	5	0.3						
182–184	6	0.3						
185–187	6	0.2						
188–200	6	0.1						
201–205	6	0.3						
206–210	6	0.5						

returned to the FI 5-min:shock schedule. If under this schedule a monkey failed to respond and produce the scheduled shocks, a response-independent shock was delivered 30 s after the start of the session; after this procedure, the next shock would usually be response produced. If this procedure failed to result in resumed responding, the conjoint AV FI 5-min: shock schedule was reimposed (see Table 1). A response-independent shock-delivery procedure was also employed during the initial exposures of Ivan and Alexey to the conjoint AV FI 5-min:shock and FI 5-min:shock schedules when response rates were substantially reduced or erratic. When this procedure was ineffective in recovering responding, the monkeys were returned to the avoidance schedule alone. The sessions in which the response-independent shock procedure was employed are footnoted in the Appendix.

In the procedures for initial training or for providing baselines of stable responding, training was continued for a minimum of 20 sessions to a maximum of 30 sessions, or until the following stability criterion was met: no more than 5% variation over five successive sessions around the mean for the same five sessions. Exceptions to these general rules were made when additional procedures were imposed to recover or maintain responding on the FI 5-min:shock schedule. Training on each tandem schedule was continued until the effect of the schedule was demonstrated.

RESULTS

When exposed to a tandem FI 5-min DRL: shock schedule, in which low rates of responding were required for shock delivery to occur, the monkeys responded at high rates, postponing the scheduled shocks. When exposed to a tandem FI 5-min DRH:shock schedule, in which high rates of responding were required for shock delivery to occur, low rates of responding emerged, and the scheduled shocks were again postponed. In the case of the 2 monkeys exposed to both schedules, the results of each tandem schedule were unaffected by the order of exposure. Results obtained with first exposures to the tandem DRL schedule are presented first; those obtained with first exposures to the tandem DRH schedule are presented next; then, the second exposures to each schedule (exposure to a given schedule after prior exposure to its converse) are presented. Thereafter, transition effects and IRT distributions will be examined.

First Exposures to the Tandem FI-DRL Contingency

The top panels of Figures 1 and 2 show the baseline performances of Alexey and Fyodor on the fixed-interval schedule of response-produced shock, just before the DRL contingency was superimposed. The cumulative records reset at each shock to emphasize the consistency of the patterns wherein response rates accelerated within the 5-min intervals, as is typical of positively reinforced responding on fixed-interval schedules. These patterns, as well as the event records just below the cumulative records indicating shock deliveries, show that the shocks were produced at regular intervals.

The middle panel in each figure shows the effect of superimposing the tandem DRL contingency (tandem FI 5-min DRL:shock). Response rates were consistently elevated (from a mean of 0.58 responses per second to 1.46 per second for Alexey and from 1.12 to 2.13 per second for Fyodor). In addition, the shocks were more widely and irregularly spaced. During the sessions presented, Alexey produced 17 shocks, with a mean intershock interval of 7.4 min, whereas Fyodor produced only seven shocks, with a mean intershock interval of 15.7 min. This indicates that, instead of slowing down and satisfying the DRL contingency for producing shock, the monkeys tended to prevent the shocks on this procedure. The bottom panel of each figure, showing the first session of return to the baseline FI 5-min schedule, indicates systematic and fairly quick return to the stable baseline patterns of responding.

First Exposures to the Tandem FI-DRH Contingency

The top panels of Figures 3 and 4 show the baseline performances of Dimitri and Ivan, respectively, on the fixed-interval schedule of response-produced shock, just before the DRH contingency was superimposed. The plotting conventions and resulting patterns are similar to those of Figures 1 and 2, again revealing positively accelerated responding that is characteristic of behavior on fixed-interval schedules of positive reinforcement. Again, these

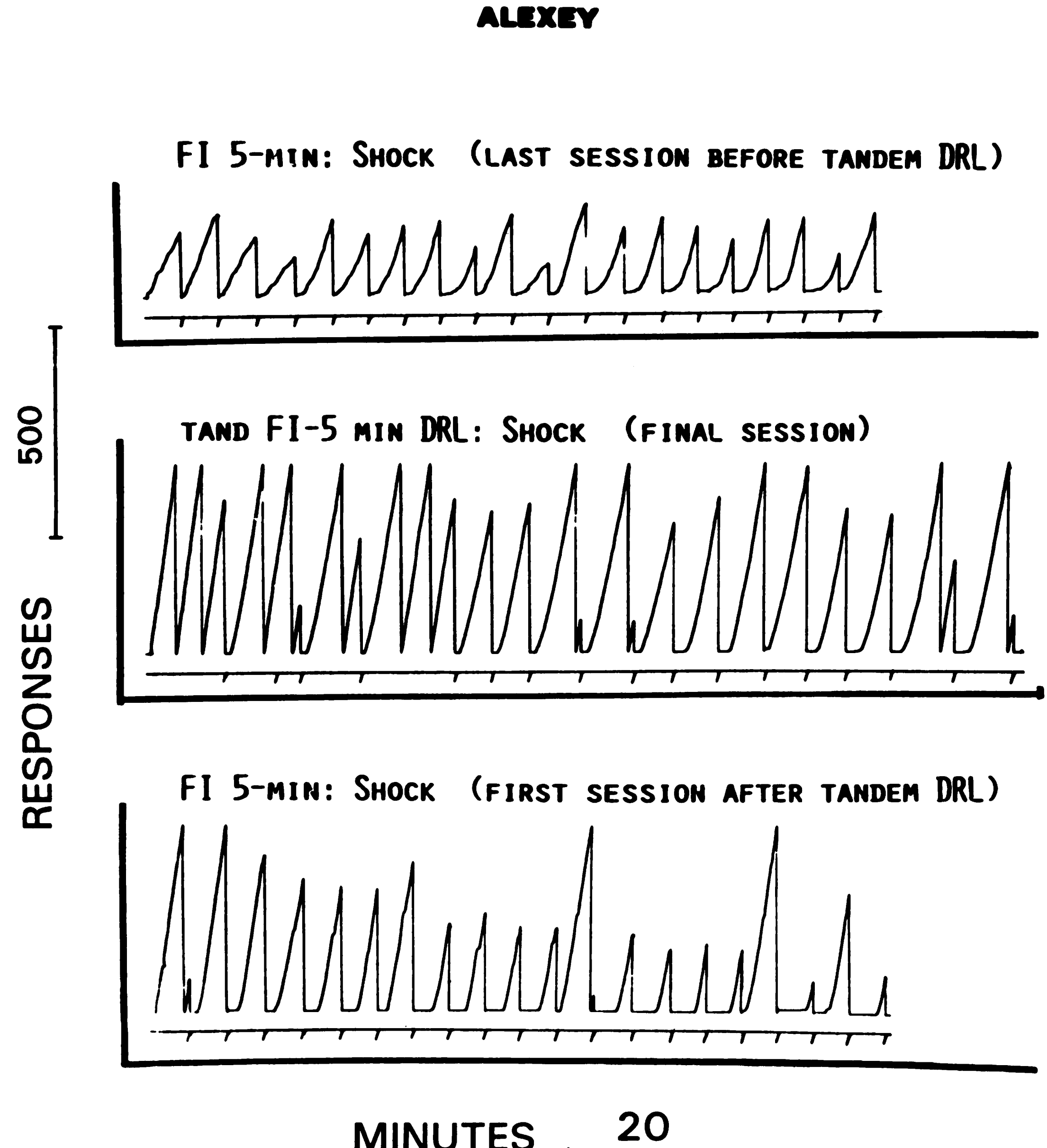


Fig. 1. Cumulative records based on the responding of a squirrel monkey, Alexey, during three experimental phases. The top panel is taken from Session 147, which was this monkey's last session of exposure to the FI 5-min: shock schedule prior to the addition of a tandem contingency. The middle panel shows Alexey's response patterns during his 43rd and final session of exposure to that added contingency (Session 190), which constituted a tandem FI 5-min DRL:shock schedule. The bottom panel shows the first session of return to the FI 5-min schedule alone (Session 191). Time is shown from left to right; the pen moved one step up the vertical axis for each response, and was reset following the delivery of a response-produced shock or at 500 responses, whichever came first. Shock deliveries are indicated by downward deflections of the pen on the event record just below the cumulative record.

patterns, as well as the event records just below the cumulative records indicating shock deliveries, show that the shocks were produced at regular intervals.

The effects of adding the tandem DRH contingency are shown in the middle two panels of Figure 3 (Dimitri) and the center panel of Figure 4 (Ivan). This schedule (tandem FI

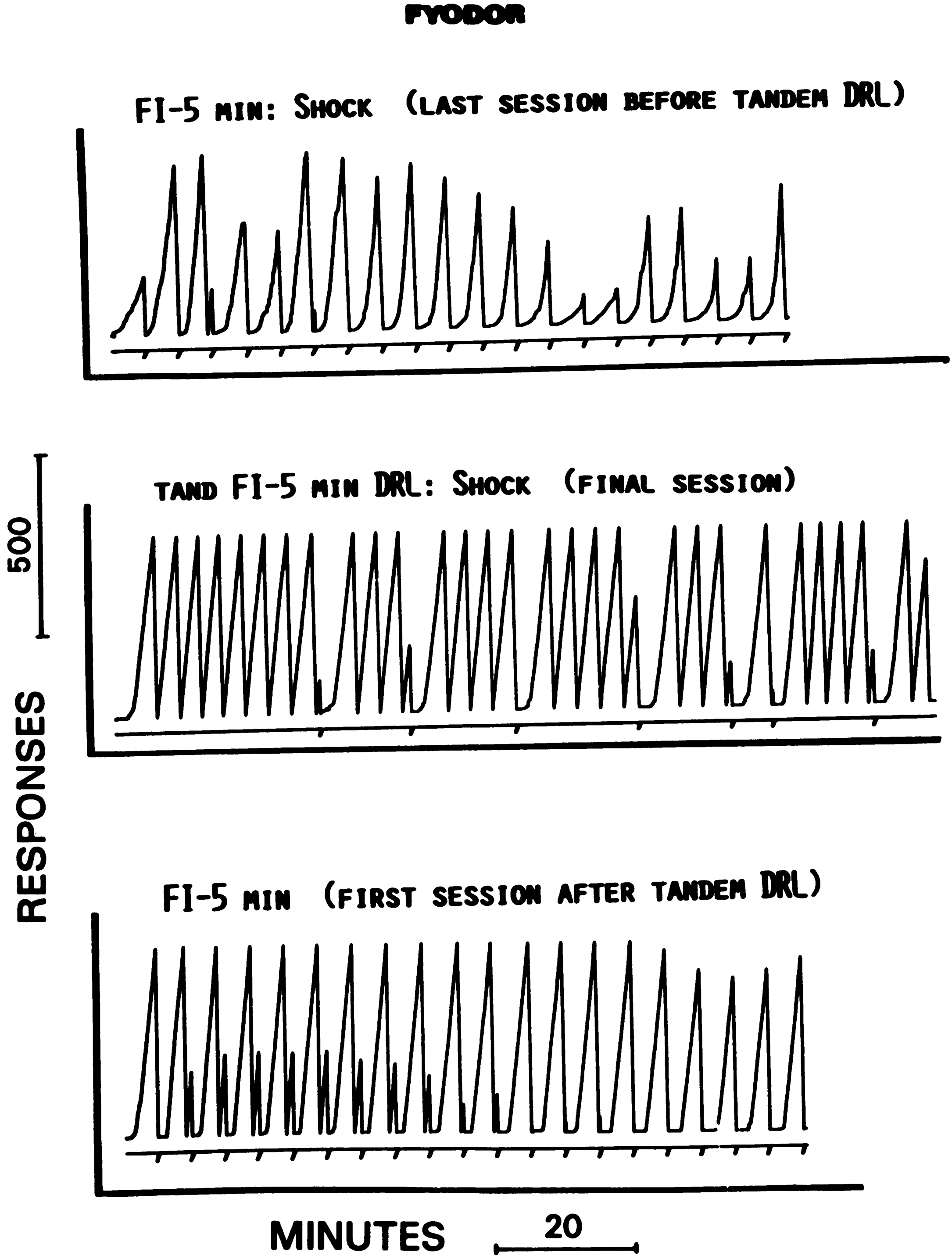


Fig. 2. Cumulative records based on the responding of a squirrel monkey, Fyodor, during three experimental phases. The top panel is taken from Session 102, which was this monkey's last session of exposure to the FI 5-min: shock schedule prior to the addition of a tandem contingency. The middle panel shows Fyodor's patterns during his 35th and final session of exposure to that addition (Session 140), which constituted a tandem FI 5-min DRL:shock schedule. The bottom panel shows the first session of return to the FI 5-min schedule alone (Session 141). The plotting conventions are the same as in Figure 1.

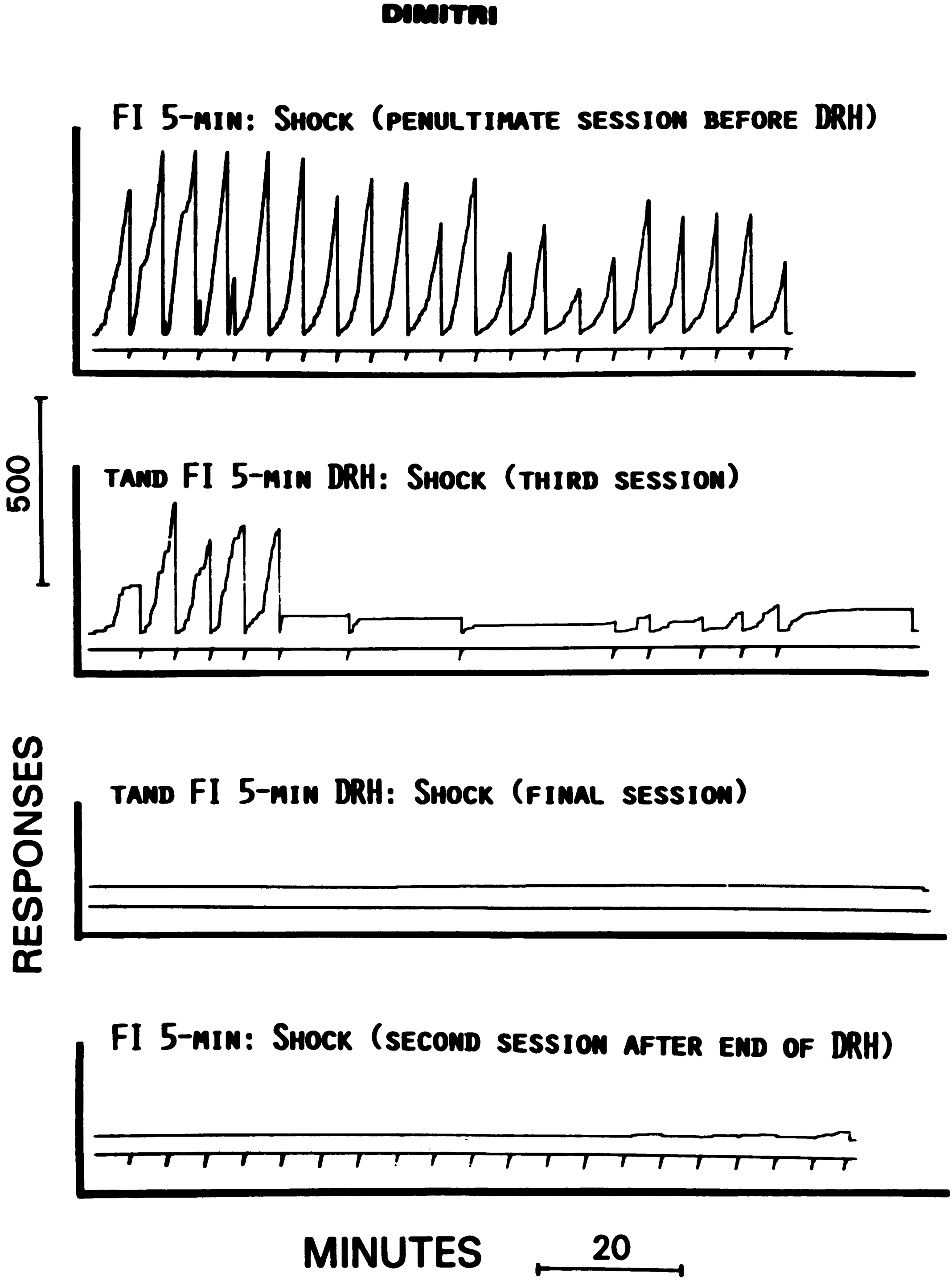


Fig. 3. Cumulative records based on the responding of a squirrel monkey, Dimitri, during three experimental phases. The top panel is taken from Session 93, which was this monkey's next-to-last session of exposure to the FI 5-min:shock schedule prior to the addition of a tandem contingency. (The record from Session 94 could not be included, due to a recorder pen failure.) The next two panels show Dimitri's patterns during his exposure to the tandem FI 5-min DRH:shock schedule. The second panel is from Session 97, which was his third and last session with $t = 0.3$ s. The third panel shows this monkey's final session of exposure to the tandem DRH contingency (Session 104), in which t was equal to 0.5 s. The bottom panel portrays Dimitri's responding during the second session of return to the FI 5-min:shock schedule (Session 106). The plotting conventions are the same as in Figure 1.

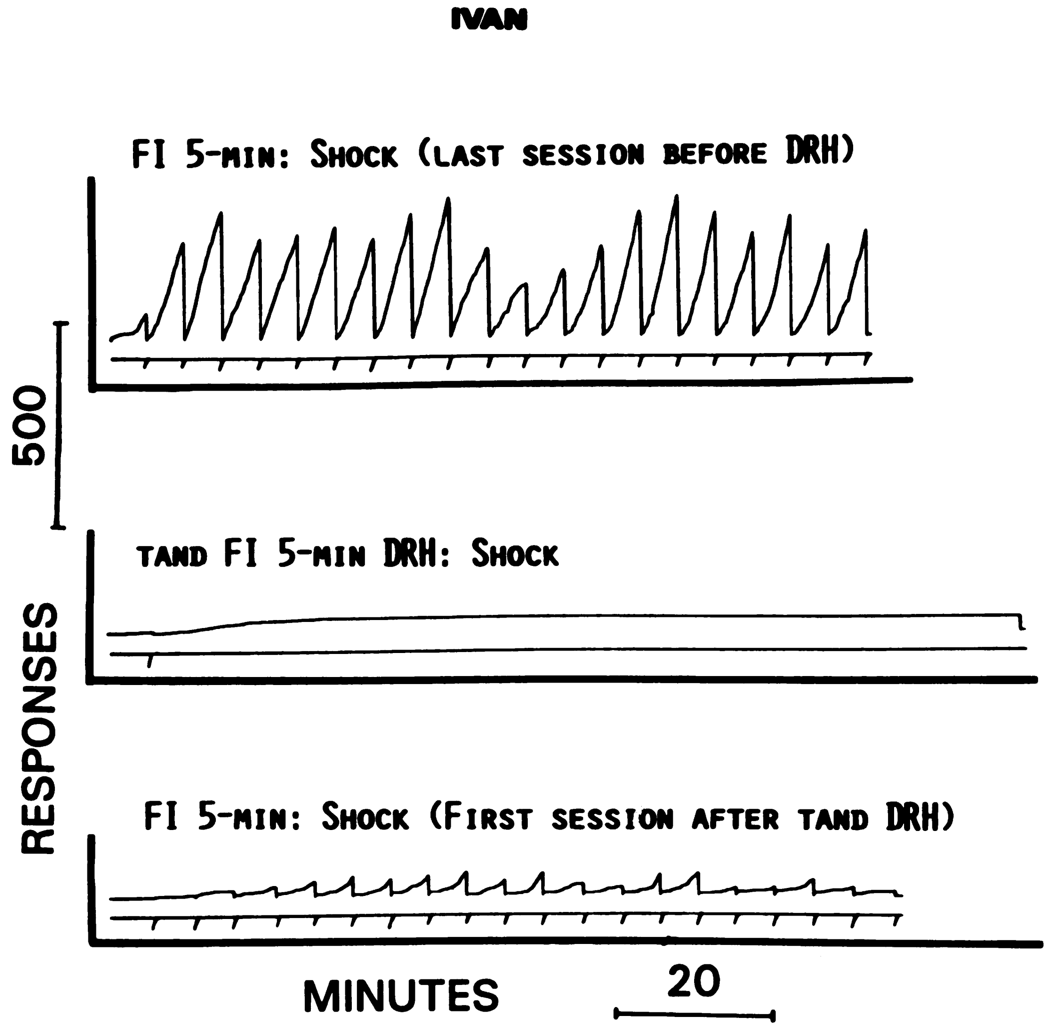


Fig. 4. Cumulative records based on the responding of a squirrel monkey, Ivan, during three experimental phases. The top panel is taken from Session 110, which was this monkey's last session of exposure to the FI 5-min:shock schedule prior to the addition of a tandem contingency. The middle panel shows response patterns during Session 127, which was this monkey's final session on the tandem FI 5-min DRH:shock schedule; the value of t was 0.8 s throughout his 17 sessions of exposure to the tandem DRH schedule. The third panel shows this monkey's first session after returning to the FI 5-min:shock schedule (Session 128). The plotting conventions are the same as in Figure 1.

5-min DRH:shock) made shock presentations selectively contingent upon high rates of responding; it resulted in marked decreases in response rates, with corresponding reductions in the numbers of response-produced shocks. The second panel of Figure 3 shows Dimitri's third session on the tandem DRH schedule (with t = 0.3 s and n = 2); overall response rate had decreased from the 1.25 responses per second of the FI-5 min schedule to 0.24 responses per second. As can be seen from the cumulative record, responding was irregular and included extended periods during which no responses were emitted. By the 10th session of this procedure (third panel of Figure 3), Dimitri's response rate had decreased virtually to zero.

The middle panel of Figure 4 presents the record of Ivan's 17th and last session on this procedure (with t = 0.8 s and n = 4). The overall response rate had decreased from 0.84 responses per second (on the FI) to 0.01 responses per second, and only one shock was produced.

When Dimitri was returned to the FI 5-min schedule without the tandem DRH contingency, there was little evidence of renewed responding (bottom panel of Figure 3). Ivan's response rates did recover slightly, as shown in the corresponding panel of Figure 4, with 17 of the 20 shocks shown being response produced, and with a distinctly scalloped pattern in the cumulative record, which indicates control by the FI schedule.

Second Exposures to the Tandem Contingencies

Ivan and Fyodor were exposed to both principal experimental schedules, tandem FI 5-min DRL:shock and tandem FI 5-min DRH:shock, with the order of exposure counterbalanced between the two. Like the initial exposures, each second imposition of the tandem schedules was preceded and followed by training under the FI 5-min:shock schedule. Thus, performance on this schedule again served as the baseline against which the effects of the tandem contingencies were assessed.

Ivan's responding on the FI-alone baseline procedure recovered after the tandem DRH procedure had been discontinued, but remedial elements of the initial training procedure (avoidance alone, conjoint avoidance and FI 5 min, and then FI 5 min alone) were required for the initial baseline pattern to be fully restored. This restored pattern is shown in the top panel of Figure 5, which portrays data from the final session before a tandem DRL procedure was superimposed. The second panel of that figure shows that the tandem DRL procedure accelerated the responding for this monkey, just as it had for the 2 monkeys that had encountered this as their initial tandem contingency added to the FI schedule. Response rate increased from 0.69 responses per second, which had been maintained by the FI alone, to 2.09 responses per second, and this more-than-doubling of the response rate obliterated the FI-scallop pattern and resulted in a decrease in shock rate to less than half. The bottom panel of Figure 5 was produced by Ivan's responding during the first session of return to the FI 5-min schedule alone. Shocks were again evenly spaced, response rates began to decrease systematically, and there was a distinct reappearance of the FI-scallop pattern by the second half of the session.

Fyodor was the only subject whose responding persisted during exposure to the tandem DRH procedure. After discontinuation of the tandem DRL, which had been this monkey's first tandem schedule, his FI baseline response rates recovered robustly without the aid of special training procedures (see Table 1), and pronounced scallop patterns were evident in his cumulative records (top panel of Figure 6). In this last session before exposure to the DRH schedule, his overall response rate was 1.49 responses per second, and the session's 20 possible shocks all were reliably produced at 5-min intervals. The successively lower panels of Figure 6 show Fyodor's performance during the last session on each IRT condition as that IRT contingency was systematically increased; the value of n (the number of successive response pairs entering into the IRT contingency) was constant at six, having been increased systematically to that value (see Table 3). As the value of t was lengthened from 0.1 to 0.3 to 0.5 s, the monkey's overall response rate decreased to 1.20, 0.56, and 0.59 responses per second, respectively. Throughout these successive conditions, responses were emitted at a steady rate, which tended to decline as the sessions progressed, that was below that specified by the IRT requirement of the schedule; thus, no shocks occurred. Upon the reimposition of the FI 5-min:shock schedule (bottom panel), the overall response rate increased to 0.82 per second, and all 20 shocks were reliably produced at regular 5-min intervals. During this session, responses were emitted at a steady but decreasing rate. Except after the first four response-produced shocks, no postshock pause was evident, nor was the scallop-like pattern present. Not until later sessions under the FI 5-min:shock schedule did the scallop-like pattern reappear.

Transitional Performances After the Change from FI to Tandem FI DRL

During the course of exposure to the tandem FI 5-min DRL:shock schedule, all 3 monkeys went through a period during which overall response rates were depressed. These periods can be characterized as transition periods between the earlier sessions in which response-contingent shocks were reliably produced and those later sessions in which the monkeys were clearly in contact with the contingencies of the tandem schedule (i.e., increased response rates

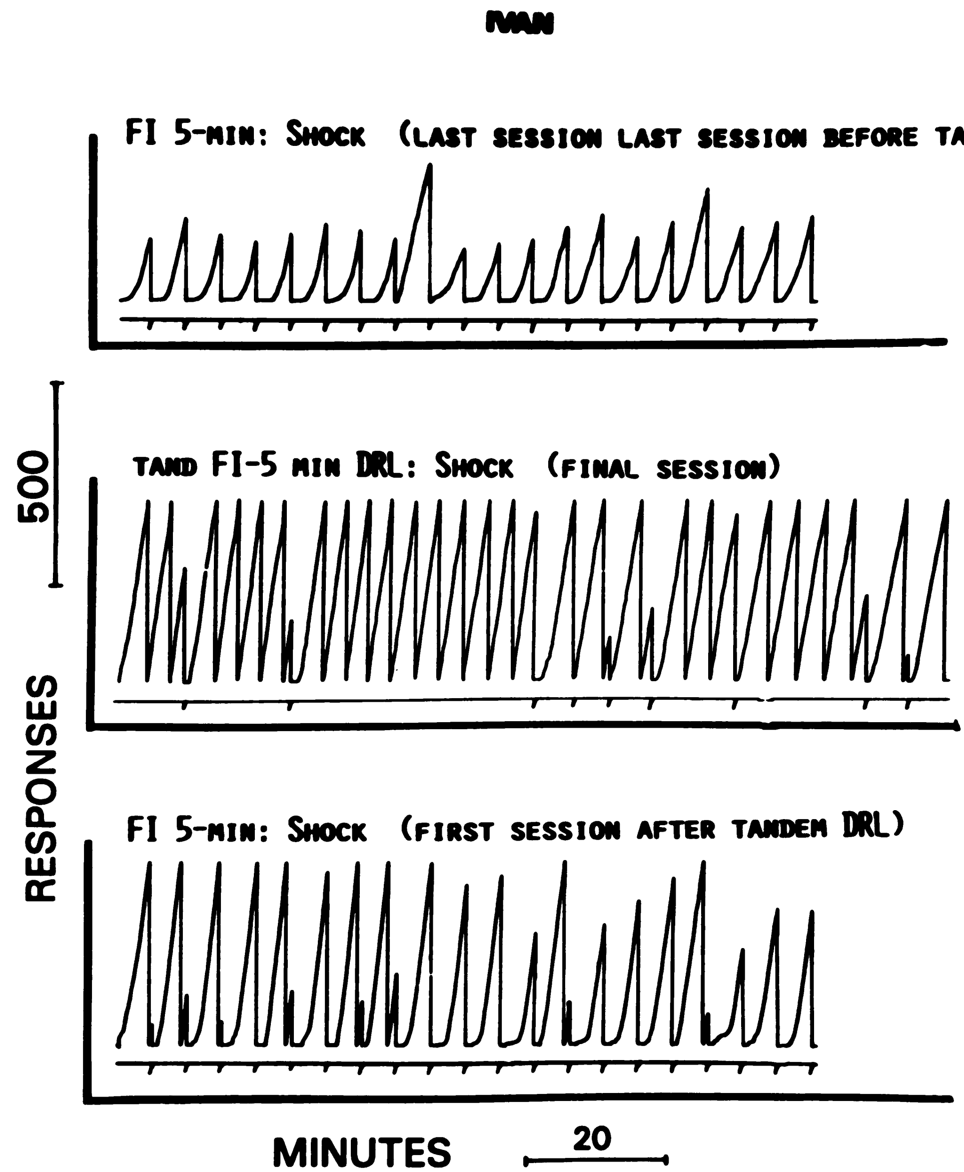
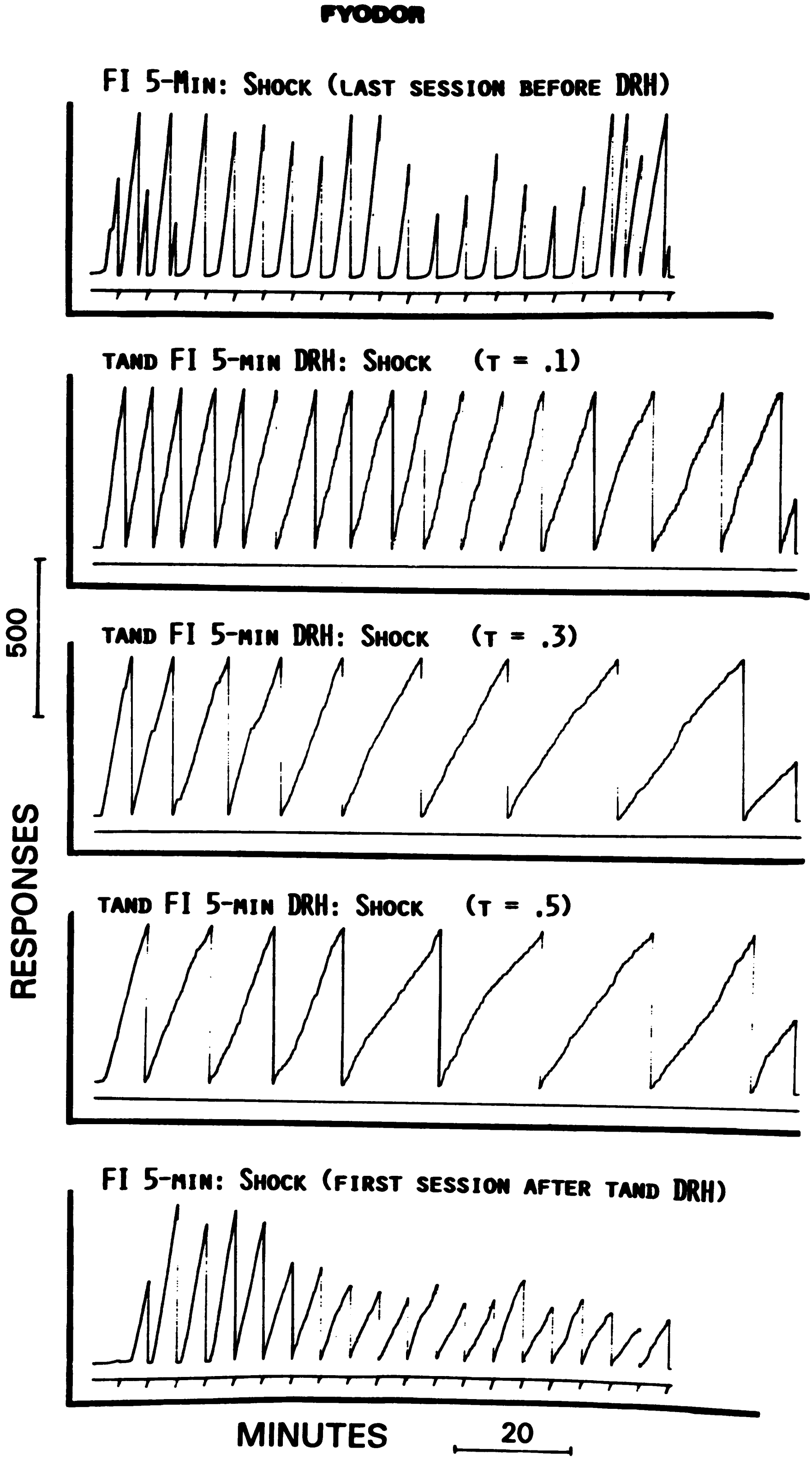


Fig. 5. Cumulative records based on the responding of a squirrel monkey, Ivan, during three phases that bracketed his second exposure to a tandem contingency of response-produced shock. The top panel shows performance during his last session on the FI 5-min:shock schedule prior to his introduction to the tandem DRL contingency (Session 173). This performance constitutes recovery from the disruption shown in the lower panels of Figure 4. The second panel shows performance during the 45th and last session of exposure to the tandem FI 5-min DRL:shock schedule (Session 218). The bottom panel is from the first session after the tandem contingency was discontinued. The plotting conventions are the same as in Figure 1.

→

Fig. 6. Cumulative records of the responding of a squirrel monkey, Fyodor, showing a progression of performances before, during, and after his second exposure to a tandem contingency of response-produced shock. The top panel shows performance during Session 170, his last session on the FI 5-min:shock schedule prior to introduction of the tandem DRH contingency. The second, third, and fourth panels show this monkey's response patterns during the last session in each subphase (Sessions 200, 205, and 210, respectively) of the tandem FI 5-min DRH:shock procedure, in which the value of t (the IRT criterion) was increased from 0.1 to 0.3 to 0.5 s. Throughout these phases, six successive IRTs had to satisfy this contingency for shock to be delivered. The bottom panel is from the first session after the tandem contingency was discontinued. The plotting conventions are the same as in Figure 1.


FYODOR
FI 5-MIN: SHOCK (LAST SESSION BEFORE DRH)
TAND FI 5-MIN DRH: SHOCK (T = .1)
TAND FI 5-MIN DRH: SHOCK (T = .3)
TAND FI 5-MIN DRH: SHOCK (T = .5)
FI 5-MIN: SHOCK (FIRST SESSION AFTER TAND DRH)
RESPONSES
500
MINUTES
20

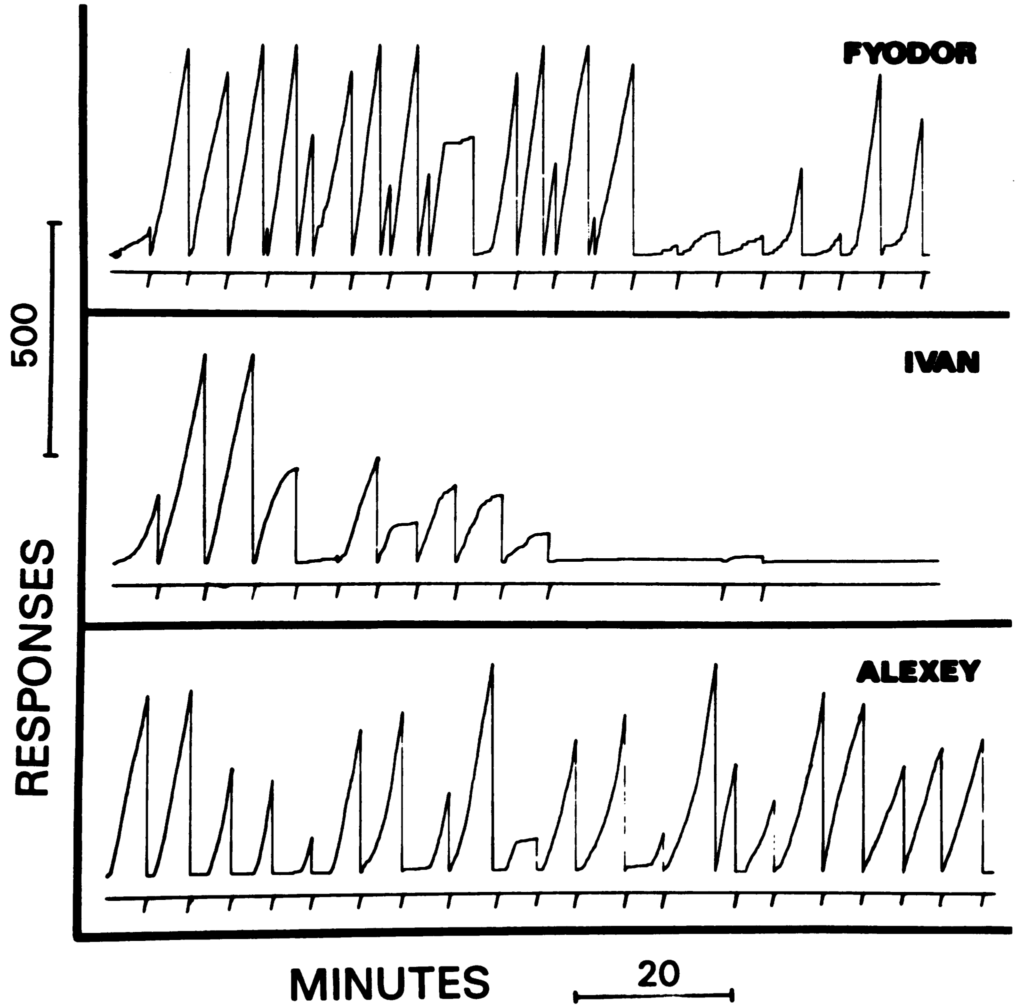


Fig. 7. Representative cumulative records of the responding Fyodor, Ivan, and Alexey during the transition period under the tandem FI 5-min DRL:shock schedule. Fyodor's record is from his 15th session under this tandem schedule (Session 117); Ivan's record is from his 28th session under this tandem schedule (Session 201); and Alexey's record is from his 25th session under the schedule (Session 172). The plotting conventions are the same as in Figure 1.

postponed shock). Response rates varied widely within these transition sessions, resulting in varying intershock intervals. Figure 7 presents cumulative records that are representative of this transition period. Periods of sustained high-rate responding, sustained low-rate responding, pausing, and even fixed-interval scalloped patterns occurred at varying points within the experimental sessions.

Interresponse Time Analyses

The effect of the tandem DRL contingency on interresponse time distributions is illustrated in Figure 8 for all 3 monkeys. The plot at the left in each panel shows stable performance on the baseline fixed-interval schedule of response-produced shock. The plot at the right is based on data from the last session of the tandem DRL schedule, with the t value indicated. Data for this figure were gathered from periods beginning 4.5 min into the fixed interval and ending with the delivery of the response-produced shock. The bars of the histograms represent the percentage of total IRTs that fell into each class interval. The filled circles represent the conditional probability of a response in each class interval (the number of responses falling within each class interval divided by the total number of responses having IRTs greater than the lower limit of the class interval).

These data indicate that the tandem contingency produced a shift in the IRT distributions, with a greater percentage of the total IRTs falling into the lower class intervals, and an elevation in the conditional probability of an IRT in the higher class intervals. Put simply, under the tandem FI 5-min DRL:shock schedule, the monkeys shortened their IRTs and thus postponed shocks, rather than increasing the time between successive responses and thus producing shocks. This result is most apparent from the decrease in height of the bars at the extreme right of the histograms that include all IRTs of 1 s or more. For Fyodor, the proportion of IRTs greater than 1 s declined from .05 under the FI 5-min:shock schedule session to .04 under the tandem FI 5-min DRL:shock schedule session. For Ivan, the comparable decrease was from .19 to .06, and for Alexey, the decrease was from .28 to .06. Further, as IRTs shortened under the tandem schedule, the conditional probability of a response increased. For Fyodor, the probability of a response with an IRT between 0.9 and 1.0 s increased from .15 under the FI 5-min: shock schedule session to .49 under the tandem FI 5-min DRL:shock schedule session. For Ivan and Alexey, the comparable increases were from .19 to .26 and from .28 to .37, respectively.

The tandem DRH contingency specified that two or more pairs of responses be emitted *t* or fewer seconds apart. To produce the shocks, the monkeys were therefore required to decrease the spacing of their responses. The IRT analyses presented in Figure 9 illustrate that they all did quite the opposite. These analyses show the area under the histogram shifting to the right toward longer IRTs and decreasing conditional probabilities of a response in the higher class intervals.

For Fyodor, the proportion of responses greater than 1 s increased from .02 under the FI 5-min:shock schedule to .43 under the tandem FI 5-min DRH:shock schedule. The conditional probability of an IRT between 0.9 and 1.0 s decreased from .35 to .14 for these sessions. For Ivan, the proportion of responses greater than 2 s increased from .07 under the FI 5-min:shock schedule to .55 under the tandem schedule, and the conditional probability

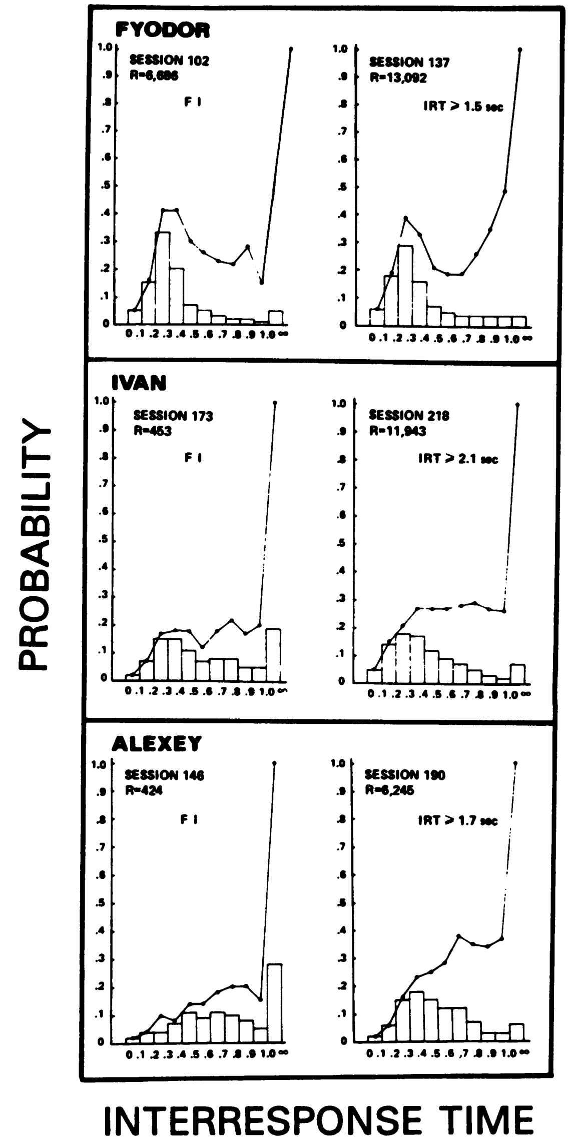


Fig. 8. Interresponse time (IRT) analyses for the last session under the FI 5-min:shock schedule (penultimate session for Alexey), before imposition of the tandem schedule, and the last session under the tandem FI 5-min DRL: shock schedule for Fyodor, Ivan, and Alexey. These analyses include all those responses (the number identified as R in each figure) that were emitted in those periods of the sessions beginning 4.5 min into the fixed intervals and ending with the delivery of the response-produced shock. The area under each bar of a histogram represents the proportion of the total responses that fell within that class interval. Each data point indicates the conditional probability (measured as the number of responses in a category divided by the number of opportunities for responses in that category) of a response falling within a given class interval.

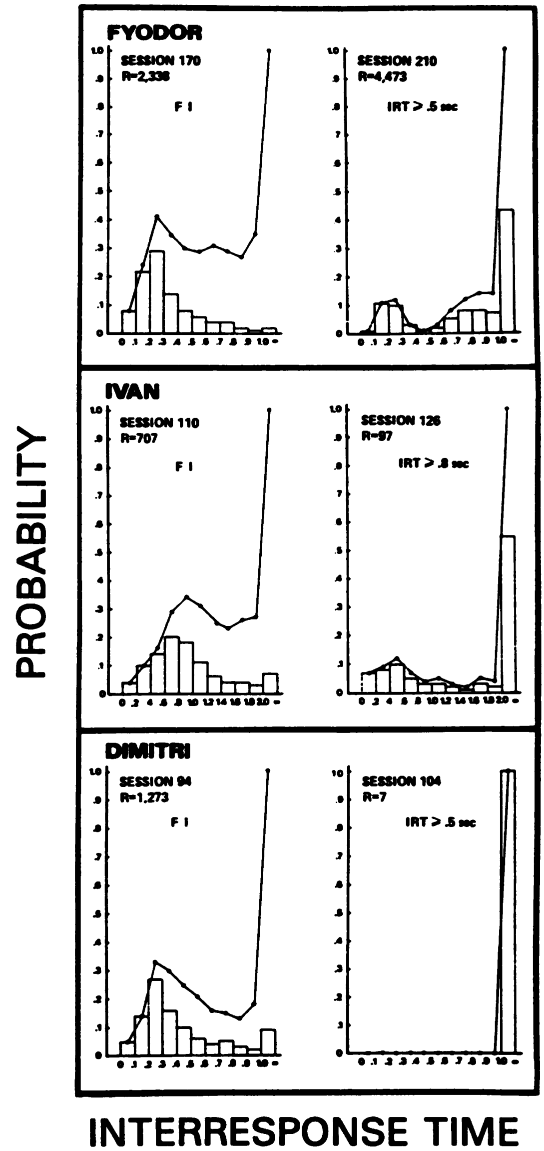


Fig. 9. Interresponse time (IRT) analyses for the last session under the FI 5-min:shock schedule before imposition of the tandem DRH schedule, and the last (second from last for Ivan) session under the tandem FI 5-min DRH:shock schedule for Fyodor, Ivan, and Dimitri. The details of the IRT analyses are the same as in Figure 8.

of an IRT between 1.8 and 2.0 s decreased from .27 to .04. For Alexey, the proportion of IRTs greater than 1 s increased from .09 under the FI 5-min:shock schedule to 1.0 under the tandem FI 5-min DRH:shock schedule. The conditional probability of an IRT between 0.9 and 1.0 s decreased from .18 to 0 for the same sessions.

DISCUSSION

The results of the present research provide further support for invoking concepts of aversive control to account for response maintenance by contingent shock. When the monkeys were exposed to a tandem DRL schedule of response-contingent shock, their lever-press rates increased; when exposed to a tandem DRH schedule, their lever-press rates decreased or responding ceased. If shock were functioning as a positive reinforcer, response rates should have decreased under the tandem DRL schedule and increased under the tandem DRH schedule. This is especially the case given the procedures of the present study. Responding was well maintained by contingent shock on the FI schedule. The choice of the median IRT value as the criterion for the DRL and DRH components of the subsequent tandem schedule ensured that, initially, about half the responses previously leading to shock would continue to produce shock. If shock were functioning as a positive reinforcer, that should certainly have been sufficient to maintain the rate of occurrence of those IRTs which met the criterion. As indicated, however, in the case of both DRL and DRH, the frequency of such IRTs decreased, and when responding continued, the frequency of noncriterion IRTs increased. These effects on responding may have been due either to differential punishment of IRTs or to differential negative reinforcement of IRTs by shock-frequency reduction. Galbicka and Platt (1984) controlled for shock-frequency reduction, and, therefore, attributed the increase in rates they observed to the explicit punishment of long IRTs. In the absence of such a control, no choice can be made between these aversive control functions.

It has been suggested by Galbicka and Branch (1981) that an increase in response rate occurs when shock is contingent upon long IRTs, because the punishment of such IRTs overcomes the suppressive effect of response-produced shock. Indeed, they chose to punish long IRTs rather than short IRTs, because any decrease in rate in the latter case could have reflected response suppression by shock. However, if the IRT is a functional unit of behavior (Galbicka & Branch, 1981; Galbicka & Platt, 1984), short IRTs should be as subject to a punishment contingency as long IRTs are. Furthermore, lower rates of responding were well maintained for 1 of our monkeys (see Figure 6) under the FI 5-min DRH:shock schedule. Thus, in all conditions examined here, only responses that met the IRT criterion were suppressed.

Differential punishment is inherently incomplete as an account of shock-maintained behavior, however. Although punishment can eliminate a class of responses and thus modulate an overall pattern of behavior, this does not directly account for the *maintenance* of the overall pattern. For example, consider the distinction we have just noted and that Galbicka and his colleagues have drawn between suppression of particular IRTs and suppression of the response topography, irrespective of its temporal spacing. The account remains silent as to why either of these response classes has a tendency to occur, without which suppression would be irrelevant. Furthermore, punishment does not readily account for all features of the observed modulation of behavior in the procedures we have described. Specifically, if an FI schedule of contingent shock differentially punishes long IRTs, why should the response pattern show scalloping? Such a pattern indicates that responses with relatively short IRTs produce shocks. Accordingly, short IRTs, rather than longer IRTs, should be suppressed, leading to decelerating response rate as time for shock approached, instead of the accelerating rates that were observed. This suggests that negative reinforcement of short IRTs by shock-frequency reduction, rather than punishment of long IRTs, may play a substantial role in increasing response rates on such a schedule. The findings of Galbicka and Platt (1984) demonstrate, however, that explicit punishment of long IRTs is sufficient to increase response rates (i.e., in the absence of shock-frequency reduction).

The scalloped response pattern on an FI shock schedule was considered by Morse and Kelleher (1977) to constitute prima facie evidence for the powerful effect of schedules as overriding conventional functions of particular stimuli. Note, however, that when a tandem IRT component is added to an interval schedule involving contingent appetitive stimuli, response rate increases if the IRT criterion is shorter than the average spacing of responses on the schedule and decreases if the IRT criterion is longer than the average spacing of responses (Reynolds, 1975, p. 74). This contrasts with the rate changes that occur on an interval schedule of contingent shock. Again, the evidence is against shock as a positive reinforcer in the response-maintenance phenomenon, and we are left with the suggestion of elicitation or some variant of negative reinforcement as a maintaining principle to supplement punishment in accounting for this behavior.

Initial introduction of the contingent shock procedure entails a pattern of shock deliveries, by virtue of the fact that, to engender responding, response-contingent shock procedures must be introduced in the face of an ongoing, relatively stable response rate. It is in the dynamic stream of events that constitute such a pattern that the maintained responding emerges. If that pattern should be construed in terms of shock frequencies, it must be frequencies defined at some intermediate level between micro contingency (e.g., an IRT punishment account) and an account in terms of molar shock-frequency reduction (e.g., Herrnstein & Hineline, 1966). The pattern of frequencies at an intermediate scale is difficult to characterize, but is also difficult to eliminate as a likely scale of process at which the behavior might best be understood.

Descriptively, the scalloped pattern of responding on the FI shock schedule also exists at such an intermediate scale. It is quite possible that the pattern develops as a result of prior or conjoint exposure to the schedule responsible for the initial emergence of the response, or its maintenance by contingent shock alone. In particular, when Sidman's (1953) shock-postponement schedule is involved, such response maintenance may reflect a discriminative function of shocks. In the Sidman procedure, shock follows the lapse of the response-shock interval and reinstates responding. When the Sidman schedule is eliminated, shocks may continue to set the occasion for responding, as a generalization between the presence and the absence of the negative reinforcement contingency of the Sidman schedule. Continued exposure to the Sidman procedure leads to temporal discrimination (Anger, 1963), and the scalloped pattern may represent the continuation of timing, with a shock providing the reference event for such timing. This is not to conclude that temporal discrimination on the Sidman procedure is the necessary basis for negative reinforcement. More likely, the temporal discrimination is *based upon* negative reinforcement (Hineline & Herrnstein, 1970). Of course, such an argument for a discriminative function of shock in maintaining responding does not apply when the prior or conjoint schedule involves positive reinforcement. In this context, it is worth noting that contingent shock alone appears not to maintain responding as well following exposure to a prior or conjoint positive reinforcement procedure (e.g., Galbicka & Branch, 1981). This, too, may suggest a discriminative role for shock in the maintenance phenomenon.

It is also possible that shock elicitation contributes to the response maintenance phenomenon, particularly if elicitation was involved in the initial emergence of the response. However, in the present experiment, the data for Fyodor on the tandem FI 5-min DRH:shock schedule clearly indicates that responding was maintained, but at rates sufficiently low to avoid all shocks (see Figure 6). Nevertheless, it would be informative to use the tandem contingencies of the present experiment with animals whose acquisition of responding maintained by contingent shock does not include histories of explicitly arranged negative reinforcement.

REFERENCES

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

Baum, W. M. (1973). Time allocation and negative reinforcement. *Journal of the Experimental Analysis of Behavior, 20,* 313–322.

Branch, M. N., & Dworkin, S. I. (1981). Effects of ratio contingencies on responding maintained by schedules of electric-shock presentation (response-produced shock). *Journal of the Experimental Analysis of Behavior, 36,* 191–205.

Byrd, L. D. (1972). Responding in the squirrel monkey under second-order schedules of shock delivery. *Journal of the Experimental Analysis of Behavior, 18,* 155–167.

Galbicka, G., & Branch, M. N. (1981). Selective punishment of interresponse times. *Journal of the Experimental Analysis of Behavior, 35,* 311–322.

Galbicka, G., & Platt, J. R. (1984). Interresponse-time punishment: A basis for shock-maintained behavior. *Journal of the Experimental Analysis of Behavior, 41,* 291–308.

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

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

Hineline, P. N., & Herrnstein, R. J. (1970). Timing in free-operant and discrete-trial avoidance. *Journal of the Experimental Analysis of Behavior, 13,* 113–126.

Hutchinson, R. R. (1977). By-products of aversive control. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 415–431). Englewood Cliffs, NJ: Prentice-Hall.

Hutchinson, R. R., Renfrew, J. W., & Young, G. A. (1971). Effects of long-term shock and associated stimuli on aggressive and manual responses. *Journal of the Experimental Analysis of Behavior, 15,* 141–166.

Laurence, M. T. (1980). *Discriminative processes in the maintenance of responding on a fixed-interval schedule of response-produced shock.* Unpublished doctoral dissertation, Temple University.

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

McKearney, J. W. (1969). 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, 12,* 301–313.

Morse, W. H., & Kelleher, R. T. (1977). Determinants of reinforcement and punishment. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 174-200). Englewood Cliffs, NJ: Prentice-Hall.

Pitts, R. C., & Malagodi, E. F. (1991). Preference for less frequent shock under fixed-interval schedules of electric-shock presentation. *Journal of the Experimental Analysis of Behavior, 56,* 21–32.

Reynolds, G. S. (1975). *A primer of operant conditioning (rev. ed.).* Glenview, IL: Scott Foresman.

Sidman, M. (1953). Two temporal parameters of the maintenance of avoidance behavior by the white rat. *Journal of Comparative & Physiological Psychology, 46,* 253-261.

APPENDIX

Summary of experimental procedures (number of sessions).

Procedure	Sessions			
	Fyodor	Ivan	Alexey	Dimitri
Adaptation	1–5	1–5	1–5	1–4
Avoidance	6–37	6–35	6–35	5–34
Conjoint AV FI 5-min:shock	38–72	36–53[a]	36–52[a,b]	35–64
Avoidance	—	54–59	53–82	—
Conjoint AV FI 5-min:shock	—	60–80	83–117[a]	—
FI 5-min:shock	73–102	81–110	118–147[a]	65–94
Tandem FI 5-min DRL:shock	103–140	—	148–190	—
Tandem FI 5-min DRH:shock	—	111–127	—	95–104
FI 5-min:shock	141–170	128–138[a]	191–205	105–112[a]
Conjoint AV FI 5-min:shock	—	139–143[a]	—	113–131[a,b]
FI 5-min:shock	—	144–173[a]	—	132–146[a]
Tandem FI 5-min DRL:shock	—	174–218	—	—
Tandem FI 5-min DRH:shock	171–210	—	—	—
FI 5-min:shock	211–225	219–230	—	—

[a] Response-independent shock contingency in effect for some or all sessions.
[b] Shock intensity increased to 7.75 mA at Session 46 for Alexey and Session 113 for Dimitri.