*AN INTERRESPONSE-TIME ANALYSIS OF
RESPONDING MAINTAINED BY SCHEDULES OF
RESPONSE-PRODUCED ELECTRIC SHOCK*

L. L. HOWELL, L. D. BYRD, AND M. J. MARR

YERKES REGIONAL PRIMATE RESEARCH CENTER, EMORY UNIVERSITY,
AND GEORGIA INSTITUTE OF TECHNOLOGY

The present study investigated ratio contingencies to evaluate factors that may determine the maintenance of responding when electric shock is the consequent event. Initially, squirrel monkeys (*Saimiri sciureus*) were exposed to a continuous-avoidance schedule to initiate bar pressing. Subsequently, a multiple random-interval variable-ratio yoked schedule of response-produced shock was used to maintain and to compare interval and ratio performance. A microcomputer recorded and stored the number of responses and interresponse times occurring between successive shock presentations during a given random-interval component, and these numbers determined the ratio requirements during the subsequent ratio component. Responding was maintained for more than 80 sessions in two of three monkeys under the multiple schedule with the ratio yoked to the interval component. Responding during the ratio component persisted in only one monkey, however, when the components were no longer yoked. An analysis of the interresponse times immediately preceding shock under the multiple yoked schedule revealed that the terminal interresponse times were longer under the interval schedule than under the ratio contingency. The interresponse-time analysis indicated that differential interresponse-time relationships may be major determinants of the maintenance of behavior controlled by schedules of electric-shock presentation.

Key words: response-dependent shock, yoked schedules, multiple schedules, interresponse-time analysis, squirrel monkeys

The presentation of a noxious stimulus is equated frequently with the process of punishment. However, an increasing number of studies have described conditions under which schedules of intermittent electric-shock presentation can serve to maintain responding. Squirrel monkeys (*Saimiri sciureus*) that previously have acquired an avoidance or escape response to electric shock will, under certain circumstances, continue to emit the response when shocks are made response-dependent, that is, when a shock is presented only upon the occurrence of a response (Kelleher & Morse, 1968; McKearney, 1968). Subsequent research has demonstrated similarities in functional relations between responding using shock or food as reinforcers (Byrd, 1972; Gardner &

Malagodi, 1981; Kelleher & Morse, 1968; McKearney, 1969).

Characteristic rates and patterns of responding have been maintained under a variety of schedules of electric-shock presentation, including fixed-interval (Byrd, 1969; Malagodi, Gardner, & Palermo, 1978; McKearney, 1969), variable-interval (Barrett & Speelman, 1978; McKearney, 1974), concurrent variable-interval variable-interval (Webbe, 1974), two-component chained (Malagodi, Gardner, Ward, & Magyar, 1981), and second-order (Byrd, 1972; Gardner & Malagodi, 1981) schedules. These studies illustrate the range of conditions under which schedules of electric-shock presentation can maintain behavior. With few exceptions, however, reports have described only responding maintained by interval schedules of shock presentation. The result usually obtained when ratio schedules of shock presentation are studied is decreased responding or suppression, rather than maintenance, of responding (Branch & Dworkin, 1981; Kelleher & Morse, 1969; McKearney, 1972).

In the only paper reporting the maintenance

This research was supported by U. S. Public Health Service Grants DA-01161 and RR-00165 (Division of Research Resources, National Institutes of Health). We gratefully acknowledge the technical assistance of R. Penrod, M. Arthur, P. Plant, R. Mapou, and J. Richards. Send reprint requests to Leonard L. Howell, Yerkes Regional Primate Center, Emory University, Atlanta, Georgia 30322.

of responding under a fixed-ratio (FR) schedule of shock presentation, McKearney (1970) described responding in squirrel monkeys initially trained under a schedule of electric-shock postponement and then under fixed-interval (FI) schedules of electric-shock presentation. Responding under a multiple FI 10-min FR 30 schedule was maintained for 20 daily sessions with characteristic patterns of responding. When one animal was exposed to an FR 30 schedule of response-produced shock for eight consecutive sessions, however, responding gradually decreased. Branch and Dworkin (1981) studied squirrel monkeys following a history of avoidance responding and reported a similar gradual decline in responding when an FI schedule of response-produced shock was replaced by a variable-ratio (VR) schedule, even though the number of responses per shock under the ratio schedule was yoked to values obtained during previous sessions under the interval schedule. Although these studies report limited success in maintaining responding under ratio contingencies, they do not reveal the basis for the ease in maintaining responding under interval contingencies and the difficulty typically experienced with ratio contingencies.

The present study (1) investigated mechanisms that could be functioning to prevent the maintenance of responding when ratio schedules of response-produced shock are employed, and (2) examined the boundary conditions under which responding can be maintained when electric shock is the consequent event. Procedures were chosen that we felt might increase the likelihood that responding would be maintained under ratio contingencies. A multiple random-interval (RI) VR-yoked schedule of response-produced shock was used with squirrel monkeys as subjects in order to compare performance under ratio and interval contingencies within the same subject and the same experimental session. A microcomputer enabled the VR component to be yoked to performance during the previous RI component so that the number and sequence of ratio requirements for the VR component matched those obtained during the RI component. This ensured that the number of responses per shock was the same for both the interval schedule and the ratio schedule, provided response rates during the VR were equal to or greater than rates during the RI component.

METHOD

Subjects

Three adult male squirrel monkeys (*Saimiri sciureus*) were housed individually and were maintained at free-feeding body weights. All were experimentally naive at the beginning of the experiment.

Apparatus

Daily experimental sessions were conducted within a ventilated, sound-attenuating chamber with each monkey seated in a Plexiglas chair similar to the type described by Hake and Azrin (1963) with modifications (Byrd, 1979). A response lever (Coulbourn Instruments, No. E21-03) mounted on the wall facing the monkey registered a response and operated a feed-back relay following a downward lever press with a force greater than .20 N. Illumination was provided by three pairs of 7-W ac colored lights mounted on the front wall just above eye level. The subject's tail was held motionless in a small stock, and two brass electrodes rested on a shaved portion near the end of the appendage. A 650-V ac source was used to deliver a 6 mA electric shock of 200 msec duration, and electrode paste minimized changes in resistance between the tail and the electrodes. A TRS-80 Model I microcomputer controlled experimental events on line and recorded data. Sessions were conducted 5 days per week, lasting 40 min per session initially and 80 min per session during later procedures.

Procedure

A continuous shock-avoidance procedure (Sidman, 1953) was used to establish lever pressing. In the presence of a red houselight, a response postponed shock for 20 sec (response-shock interval = 20 sec) and, in the absence of responding, shock was delivered every 20 sec (shock-shock interval = 20 sec). After responding stabilized and fewer than three shocks were delivered per session (26 sessions), the procedure was changed to an RI 150-sec schedule of response-produced shock (Table 1). The first response emitted after an interval had elapsed resulted in the delivery of a shock. Interval values, determined by a random probability generator that produced values ranging from 1 sec to infinity, provided for the probability of shock to be constant with the mean interval value equal to 150 sec. A red house-

Table 1
Summary of Experimental Procedures

Schedule	Sessions		
	Monkey S-74	Monkey S-75	Monkey S-77
Continuous Avoidance	26	26	26
Random Interval (RI)	29	20	29
Continuous Avoidance	—	5	—
Random Interval	—	4	—
Multiple RI RI	55	57	55
Multiple RI VR Yoked	81	54	82
Random Interval	—	3	—
Continuous Avoidance	—	20	—
Multiple RI RI	—	9	—
Continuous Avoidance	—	20	—
Random Interval	—	10	—
Multiple RI RR	6	15	44
Random Interval	3	—	—
Continuous Avoidance	12	—	—
Random Interval	10	—	—
Multiple RI RR	6	—	—
Multiple RI VR Yoked	15	6	3
Random Interval	6	8	5

light illuminated the chamber continuously during the RI 150 schedule. (Monkey S-75's response rate declined when he was initially exposed to this procedure and the avoidance schedule was reinstated to increase responding. After five additional sessions under the avoidance procedure, he was returned to the RI 150 schedule of response-produced shock, as indicated in Table 1.)

When schedule-appropriate patterns of responding developed and rates of responding stabilized, the RI 150 schedule was changed to a multiple RI 150 RI 150 schedule of response-produced shock. Each RI component was in effect for 10 min and a different colored houselight (red or blue) illuminated the chamber during each RI component. The red houselight was paired with odd-numbered RI components and the blue with even-numbered components for Monkeys S-74 and S-75; the colors were reversed for Monkey S-77. A 10-sec timeout (white houselight) was scheduled between components. The two RI components alternated until each was presented twice per session. If the 10-min limit on component duration expired before a scheduled shock occurred, the component was terminated, a timeout began, and the shock was not delivered. Subjects were exposed to this procedure until no systematic change in response rate could be detected in either RI component for at least five consecutive sessions (Table 1).

After 55 to 57 sessions, the procedure was changed to a multiple RI 150-sec VR-yoked schedule. Each session began with an RI 150-sec component, which was in effect for 10 min. The computer was programmed to record and to store in sequence the responses and shock presentations occurring during the RI component and to use these data as the ratio contingency during the subsequent VR-yoked component. The ratio requirement and ratio sequences for a VR-yoked component were determined entirely by performance during the immediately preceding RI component. When the 10-min limit expired, the RI component was terminated and a timeout began, independent of responding. If the 10-min limit expired before a scheduled shock occurred, the component was terminated, a timeout began, and the shock was not delivered. Upon completion of the timeout, the VR-yoked component began and it remained in effect until (1) an identical number of responses was emitted as was recorded during the previous RI component, or (2) 10 min had elapsed, whichever occurred first. The response requirement for the VR component mirrored the monkey's response-shock sequences during the RI component and included any responses emitted between the last shock in the RI component and the end of that component.

When response rate during the VR-yoked component was equal to or greater than response rate during the previous RI component, the numbers of responses per shock were equivalent for the interval and ratio schedules because an identical number of responses was emitted and an identical number of shocks was delivered in identical sequences during the two components. When response rate during the VR-yoked component was less than response rate during the preceding RI component, the VR component was terminated at the end of 10 min. When the 10-min clock terminated the VR component, the number of responses did not equal the number that had occurred during the RI component, and it was even possible that all scheduled shocks were not delivered. Whether this condition occurred was dependent upon the monkey's response rate during the two components. Indeed, whether shock was scheduled for delivery at any time during the VR-yoked component was determined entirely by the response-shock sequences generated by performance during the preceding RI

component. There was no automatic delivery of shock at any time during the VR component, even upon termination by the 10-min limitation.

The RI and VR-yoked components alternated during each session, and a 10-sec timeout (white houselight) separated the components. A blue houselight illuminated the chamber during the VR component and a red houselight was present during the RI component for Monkeys S-74 and S-75; the stimulus conditions were reversed for Monkey S-77. Initially, each component was scheduled twice per session; later, each component was scheduled four times per session. The interval values generated by the computer during each 10-min RI component were independent of values generated during previous RI components. If the 10-min limit expired prior to the occurrence of a scheduled shock, that shock was never carried over from one RI component to the next or from one VR component to the next. The monkeys were exposed to the multiple RI 150 VR-yoked procedure until no systematic change in response rate or pattern could be detected for at least 10 consecutive sessions (Table 1).

Subsequently, the procedure was changed to a multiple RI random-ratio (RR) schedule in order to investigate the effect of removing the yoked requirement on responding during the ratio component. The RI component remained at 150 sec and the RR component was derived by averaging the mean number of responses per shock during the VR component for the last five sessions of the yoked procedure. The RR component was 190 for Monkey S-74 and 60 for Monkey S-77. (Monkey S-75's rate declined during the multiple RI VR-yoked procedure and this necessitated procedural changes that were different from those used for the other two subjects, as indicated in Table 1.) Each component was in effect for 10 min, and a 10-sec timeout was scheduled between components. The RI and RR components alternated until each was presented four times during a session. The difference between this procedure and the previous yoked procedure involved the distribution of ratio requirements. During the VR condition, ratio requirements depended on the performance of the subjects during the previous RI component. In contrast, ratio requirements during the RR

condition were determined by a random probability generator and were independent of performance during other components. However, the total number of shocks delivered and the mean number of responses per shock were the same for the VR and RR conditions.

Response rates decreased under the multiple RI RR procedure after six sessions (Monkey S-74) or 44 sessions (Monkey S-77). Because rate decreased so abruptly for Monkey S-74, this animal was exposed to procedures to recover responding that were not necessary for Monkey S-77 (Table 1). Subsequently, the yoked requirement was reinstated for both animals. Finally, when it became evident that responding would not be maintained, the RI 150 schedule was reinstated to determine whether removal of the ratio contingencies would have an enhancing effect on response rate. Response rates, the number of shocks delivered, component durations, and interresponse times (IRTs) were recorded separately for each component.

RESULTS

Performance under the continuous avoidance schedule was characterized by relatively constant responding at moderate rates (1.12, .20, and .28 responses per second for Monkeys S-74, S-75, and S-77, respectively). When the schedule was changed to RI 150 and shock was response-dependent, response rates increased for Monkeys S-74 and S-77 (2.62 and .58 responses per sec, respectively), although performance continued to be characterized by relatively constant responding within sessions (Figure 1). Monkey S-75 began to decrease responding after 15 sessions under the RI schedule. Apparently, the preliminary avoidance training was not adequate for maintaining responding under the RI schedule of response-produced shock for this animal. Following five additional sessions of training under the avoidance procedure, Monkey S-75 again was exposed to the RI schedule and responding stabilized. Subsequently, the RI schedule was replaced by the multiple RI 150 RI 150 schedule of response-produced shock for all three subjects to determine that equivalent performances would be maintained during the two components. For Monkeys S-74 and S-75, response rates during the two components were similar. However, response rate for Monkey

Fig. 1. Cumulative records typical of performance engendered under the continuous-avoidance schedule (top panels) and the RI 150-sec schedule of response-produced shock (bottom panels) for the animal with the highest (Monkey S-74) and the lowest (Monkey S-75) response rates. Records are from the last session of each procedure. During both schedules, the response pen reset after 500 responses, and the response pen deflected upon presentation of electric shock. During the RI procedure, the response pen also reset and the event pen deflected every 10 min.

S-77 was higher in the presence of the light that was used during the avoidance training procedure, even after extensive exposure to the multiple schedule (55 sessions). Mean overall response rates for the two RI components during the last 10 sessions were 1.65, .28, and .65 responses per sec for Monkeys S-74, S-75, and S-77, respectively.

Monkeys S-74 and S-77 persisted in responding under the multiple RI VR-yoked schedule of response-produced shock for more than 80 sessions. A linear-regression analysis of response rates was used to quantify the amount of change in mean daily response rates during the 80 sessions of exposure to this procedure. For Monkey S-74, the slope of the regression line was $-.005$, and for Monkey S-77, the slope was $-.004$. The small negative slopes indicated that there was little change in response rate across sessions for either animal. In addition, there was little difference in ratio and interval response rates under the multiple schedule for Monkey S-74 (Figure 2). Initially, Monkey S-77

continued to respond at a higher rate during the component (VR) paired with the light that was present during the avoidance training procedures, but by the 50th session, responding had decreased and rates during the two components were similar.

Monkey S-75 maintained stable responding under the multiple RI VR-yoked schedule for 50 sessions; a linear-regression analysis of rates during the first 50 sessions (slope = $-.0006$) indicated little change in responding across sessions. However, response rates decreased rapidly during the last four sessions of the yoked procedure (Sessions 51 to 54), and during the last (54th) session, response rates were sufficiently low for both components that the yoked procedure was terminated for this animal. Figure 3 (top) shows a cumulative record typical of performance under the multiple RI RI procedure when responding in Monkey S-75 was well maintained. The middle panel shows how responding decreased during the ratio components of the multiple RI VR-yoked procedure

Fig. 2. Cumulative records typical of performance engendered under the multiple RI RI schedule of response-produced shock (top panels) and the multiple RI VR-yoked schedule of response-produced shock (bottom panels) for the two subjects that maintained responding under the yoked procedure. Records are from the last session of the multiple RI RI procedure and from the 35th session of the multiple RI VR-yoked procedure. The VR component is indicated by parallel, horizontal event lines. Event pen deflection indicates a 10-sec timeout; response pen deflection indicates delivery of shock. The response pen reset after 500 responses and during a timeout.

prior to a decrease in responding during the interval component, and performance during the 54th session is shown at the bottom.

In order to quantify differences between interval and ratio performances when responding was well maintained, IRT distributions were plotted and analyzed. Every IRT was recorded in sequence for each experimental session, and the IRTs were grouped into 61 bins according to duration. Because of the wide range of response rates for the three subjects, different bin widths were chosen to provide comparable spread of the IRT distributions. The bin widths were .05 sec, .10-sec, and .20 sec for Monkeys S-74, S-77, and S-75, respectively. The 61st bin included all IRTs that exceeded the upper limit of the 60th bin. Due to warm-up effects at the beginning of each session, the

first RI and VR components were omitted from the analysis, and IRTs that were followed by shock were also excluded. There were no pronounced differences between the RI and VR distributions for individual animals, but there were slight differences in the shapes of the distributions among the three subjects (Figure 4). The latter can be attributed partly to the different bin widths used.

In the absence of differences in the total IRT distributions, terminal IRTs (i.e., IRTs that were followed by shock presentation) during the interval and ratio components were compared. Data for each animal were derived from the last 10 sessions during which responding was maintained under the multiple RI VR-yoked procedure. The first RI and VR components of each session were omitted from

MRIRI (57th SESSION)

MRIVRY (50th SESSION)

MRIVRY (54th SESSION)

Fig. 3. Cumulative records for Monkey S-75. Top panel shows typical performance engendered under the multiple RI RI schedule of response-produced shock. Middle panel illustrates the decrease in response rate during the ratio components (parallel, horizontal event lines) relative to response rate during the interval components. Bottom panel shows a cumulative record for the last (54th) session under the yoked procedure. Otherwise, recording is as in Figure 2.

the analysis because of warm-up effects. The results showed that the terminal IRTs were of longer duration during the RI component for each subject, indicating that shock was more likely to follow long IRTs under the interval contingency (Table 2). To determine whether similar differences characterized IRTs prior to the terminal one, IRTs as far removed as the tenth preceding shock delivery were compared (Figure 5). For each subject, the first data point (position -1) in Figure 5 represents the mean terminal IRT, that is, the IRT that terminated with shock presentation. Data points for position -10 represent the IRTs that occurred 10 responses prior to shock presentation. These data show that the terminal IRT did not differ in duration from the preceding IRTs under the ratio schedule but that the terminal IRT

Table 2

Comparison of mean terminal IRTs during interval and ratio components of the multiple RI VR yoked schedule.

Monkey	Interval IRTs (sec)	Ratio IRTs (sec)	t Test*
S-74	X = 4.430 SD = 4.862 SE = .565	X = 1.029 SD = 2.134 SE = .248	$t = 5.52$ $df = 73$ ($p < .01$)
S-75	X = 6.721 SD = 4.778 SE = .515	X = 5.847 SD = 6.796 SE = .942	$t = .894$ $df = 68$ ($p > .10$)
S-77	X = 4.289 SD = 3.658 SE = .349	X = 2.181 SD = 2.310 SE = .221	$t = 5.13$ $df = 109$ ($p < .01$)

*two-tailed *t* test.

Note: Data for individuals derived from last 10 sessions of procedure.

was longer than preceding IRTs under the interval schedule. Moreover, the data for Monkeys S-74 and S-77 indicate quite similar IRTs and response rates during the two components when the terminal IRTs are excluded (Figure 5).

Response rates eventually decreased when the yoke requirement was removed and the resulting schedule was multiple RI RR. After five sessions of exposure to the multiple RI RR procedure, Monkey S-74's rate decreased rapidly and this precluded a comparative analysis of the data. However, Monkey S-77 maintained responding for a number of sessions (44) sufficient to warrant an analysis. A linear-regression analysis of daily session rates when responding was well maintained (Sessions 1 to 35) indicated little change in response rates across sessions (slope = $-.005$). In addition, the IRT distributions for Monkey S-77 after 35 sessions under multiple RI RR were similar to those shown in Figure 4 and indicated similar performances during the interval and ratio components. Also, an analysis of the last ten IRTs preceding shock presentation showed that shock was more likely to follow long IRTs under the interval contingency, a phenomenon illustrated in Figure 5, and that during the ratio component, the terminal IRT did not differ from the preceding IRTs.

The top panels of Figure 6 illustrate the nature of the rate decrease for Monkeys S-74 and S-77 under the multiple RI RR procedure. Initially, rate decrements were restricted to the later components (both interval and ratio) of the daily session, whereas rates during the ear-

Fig. 4. Relative frequency IRT distributions during the yoked procedure for Monkeys S-74, S-75, and S-77. The left graphs are for the interval schedule and the right graphs are for the ratio schedule. Data for each were derived from the last five sessions of this procedure. Different bin sizes were used for each monkey, as described in the text.

lier components were relatively unchanged. With continued exposure to the multiple RI RR schedule, however, rates during earlier components of the schedule began to decrease. Reinstatement of the yoked requirement did not prevent further decreases in response rates (Figure 6, middle). Finally, the multiple RI

VR-yoked schedule was discontinued and the RI procedure alone was reinstated to determine the effect of removing the ratio contingency. The bottom panels of Figure 6 show that Monkey S-74's rate changed little, but Monkey S-77's rate continued to decrease. Response rates did not return to levels previously

observed for the RI procedure, ostensibly because the animals' performance was so badly disrupted and behavior was so poorly maintained at the time of reinstatement of this procedure.

DISCUSSION

The present study shows that responding can be maintained in the squirrel monkey under a ratio schedule of response-produced shock. Responding was maintained in two squirrel monkeys for more than 80 sessions under a multiple RI VR-yoked schedule in which performance during each RI component determined the response requirements during the immediately subsequent VR component. A linear-regression analysis of daily response rates during the 80 sessions of exposure to the yoked procedure indicated stable performance and little change in response rates across sessions. An IRT analysis demonstrated differences between interval and ratio performance indicating that electric shock was more likely to follow longer IRTs under the interval schedule. In addition, the IRT that immediately preceded the delivery of shock (terminal IRT) was much longer than the nine preceding IRTs under the RI schedule. In contrast, there was no difference between the terminal IRT and the nine preceding IRTs during the VR or the RR schedule.

Branch and Dworkin (1981) reported the only other study that incorporated a yoking procedure to investigate ratio performance under a schedule of response-produced shock. In that study, a squirrel monkey was trained to press a lever under an FI 5-min schedule of electric-shock presentation, and the number of responses per interval during 10 successive sessions under the FI schedule was used to construct 10 sessions of VR contingencies. The VR schedule during each session had 12 values corresponding to the 12 values obtained in a single session under the FI 5-min schedule. Under this procedure, there was a gradual decline in response rate for the animal that was exposed to the VR schedule. Branch and Dworkin (1981) concluded that some aspect of ratio contingencies acted to prevent the maintenance of responding under the VR schedule of electric-shock presentation.

There are important differences between the Branch and Dworkin (1981) method and the

Fig. 5. Mean ($\pm$ SEM) IRTs that preceded shock presentation during the interval (X) and ratio (●) components. The first data point (at -1) for each subject represents the terminal IRT, that is, the IRT that terminated with shock presentation. Data points for IRT position -10 represent the IRTs that occurred 10 positions prior to shock presentation. Units along the y-axis represent seconds.

yoking procedure used in the present study that may explain why responding was maintained under the VR-yoked schedule of response-produced shock reported here. In the present experiment, the yoking procedure allowed for a direct and immediate interaction between response rate and ratio requirement. If responding changed during an RI component, there

Fig. 6. Cumulative records illustrating the nature of the rate decrease for Monkeys S-74 and S-77 under the multiple RI RI procedure (top panel), the reinstatement of the yoke requirement (middle panel), and the effect of reinstating the RI schedule of response-produced shock (bottom panel). Each record is from the last session of the procedure indicated. Otherwise, recording is as in Figure 2.

was a corresponding change in the number of responses per shock scheduled during the VR component. If responding decreased during the RI component, for example, shock frequency was affected little during the RI component, but the number of responses per shock decreased during the RI and VR components. Therefore, the subjects continued to receive an equivalent number of shocks during the RI and VR components, even if response rate during the RI component decreased. If responding decreased during a VR component and fewer shocks were presented, the following RI component could serve to renew and regenerate responding. In the Branch and Dworkin (1981) study, there was no multiple schedule and no opportunity for interaction among component schedules. When response rate decreased, the animal received fewer shocks, and the decreased shock frequency may have served to

decrease response rate further. Second, the present study yoked the VR schedule to performance during an RI schedule, whereas Branch and Dworkin (1981) yoked their VR schedule to an FI schedule. When the number of responses per FI component was relatively constant from one FI to the next, a very narrow range of ratio values was generated for the yoked VR schedule. Ratio values in the Branch and Dworkin study ranged from 101 to 155 responses when the VR schedule was yoked to an FI 5-min schedule, and from 61 to 74 responses when the VR schedule was yoked to an FI 2-min schedule, very narrow ranges indeed. If regularity in the number of responses per shock contributes to a decline in responding under ratio contingencies, the narrow range of ratio values studied by Branch and Dworkin (1981) may have contributed to the rate decrease they observed under the VR schedule.

Since the RI schedule used in the present experiment could generate interval values ranging from 1 sec to infinity, a relatively constant rate of responding engendered under the interval schedule produced a wide range of ratio values (1 to 720) for the VR-yoked schedule. Thus, the yoking procedure reported here may have increased the probability that responding would be maintained under the ratio contingency because the ratio values varied so widely in contrast to a relatively fixed number of responses.

Evidence consistent with these explanations can be found in earlier studies. McKearney (1970) reported the maintenance of responding for 20 sessions under an FR schedule of shock presentation when the FR schedule was one component of a multiple FI FR schedule, but responding decreased steadily over eight sessions when the FR schedule was studied alone. Ostensibly, schedule interactions contributed to the maintenance of responding under the multiple schedule, as suggested above. This possibility becomes more tenable when one recognizes that Kelleher and Morse (1969) also reported that responding was not maintained under an alternative FR avoidance schedule that resulted in the presentation of shock after a fixed number of responses. Therefore, the multiple RI VR-yoked procedure studied in the present experiment may have increased the probability that responding would be maintained because (1) the RI component could serve to regenerate responding, (2) there was a direct and immediate interaction between response rate and ratio requirement, and (3) the ratio values varied widely.

One conceptualization of behavior maintained by schedules of response-produced shock suggests that the delivery of electric shock following a response results in the suppression of the IRT that is terminated by that response. Galbicka and Branch (1981) showed that IRTs can be suppressed differentially by electric shock when responding in the squirrel monkey is maintained by intermittent food presentation. When shock was presented only after comparatively long IRTs, there was a decrease in the relative frequency of long IRTs and overall response rate increased. When shock was presented regardless of the duration of the IRT, response rate decreased. In a related experiment, Byrd (1977) maintained responding in the squirrel monkey under an FR schedule

of stimulus termination. Completion of the ratio requirement resulted in the termination of a stimulus in the presence of which response-independent shock was occasionally presented. When shock was presented prior to the initiation of responding, for example, .5 sec after onset of the discriminative stimulus, characteristic FR performance was maintained. When shock was presented during a "run" of ratio responses at a high rate, responding was occasionally disrupted, ostensibly because the shock followed relatively brief IRTs. Galbicka and Branch (1981) postulated that interval contingencies of shock presentation have a different effect and result in differential suppression of relatively long IRTs, which leads to an increase in the frequency of shorter IRTs and, thus, increased response rate. Branch and Dworkin (1981) suggested that substitution of a VR schedule for an FI schedule in their experiment decreased the probability that shock would follow long IRTs and, consequently, responding decreased.

The present study confirmed that long IRTs are more likely to be followed by shock under interval contingencies, but not under ratio contingencies, when electric shock is the consequent event. The IRT that was terminated by the delivery of shock (terminal IRT) under the RI schedule was much longer than the nine preceding IRTs. This did not occur with the VR or the RR schedules. There was no difference between the terminal IRT and the nine preceding IRTs under the ratio schedules, but the terminal IRTs recorded under the ratio schedules were shorter than the terminal IRTs under the interval schedule. These results are consistent with the suggestion made by Branch and Dworkin (1981) that substitution of a VR schedule decreased the probability that shock would follow long IRTs.

Although the present study demonstrated that longer IRTs are more likely to be followed by electric shock under interval contingencies of response-dependent shock, there is no evidence that longer IRTs were, in fact, preferentially suppressed by shock under these conditions. One way to demonstrate this relationship is to manipulate directly the IRT durations and shock presentation. The use of a paced-VI schedule, similar to that described by Shimp (1967, 1968), could determine whether shock selectively suppresses IRTs of a specific class under a schedule of response-

produced shock. A paced-VI schedule arranges an event following the first response to occur after some variable time has elapsed if, and only if, the response terminates an IRT of a specified class. If delivery of shock followed only IRTs of a given class, inspection of the IRT frequency distributions would reveal whether that class of IRTs was differentially suppressed. A tandem (VR IRT $> t$) schedule of response-produced shock would also address this issue in that long IRTs would be followed differentially by shock under a ratio schedule. Shock could be scheduled following the first response after some variable number of responses had been completed if, and only if, the response terminated an IRT $> t$ seconds. If the presentation of shock following long IRTs is the necessary condition for the maintenance of behavior under schedules of response-dependent shock, responding should be maintained with little difficulty. Experiments similar to these must be performed in order to increase our understanding of variables controlling the maintenance of behavior under these schedules.

The present study extends the range of conditions under which response-dependent shock maintains responding. Ratio contingencies can support responding when electric shock is the consequent event and the ratio contingency is yoked to an immediately preceding interval performance in the manner described in this report. The empirical relationship between shock presentation and IRT duration suggests a mechanism that may be involved in the maintenance of responding under schedules of response-produced shock. Although this relationship was not directly manipulated, results suggest that there was an opportunity for the occurrence of this type of interaction.

REFERENCES

- Barrett, J. E., & Spealman, R. D. Behavior simultaneously maintained by both presentation and termination of noxious stimuli. *Journal of the Experimental Analysis of Behavior*, 1978, **29**, 375-383.
- Branch, M. N., & Dworkin, S. I. Effects of ratio contingencies on responding maintained by schedules of electric-shock presentation (response-produced shock). *Journal of the Experimental Analysis of Behavior*, 1981, **36**, 191-205.
- 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.
- Byrd, L. D. Responding in the squirrel monkey under second-order schedules of shock delivery. *Journal of the Experimental Analysis of Behavior*, 1972, **18**, 155-167.
- Byrd, L. D. Responding in the squirrel monkey under fixed-ratio schedules of stimulus termination. *Journal of the Experimental Analysis of Behavior*, 1977, **27**, 495-506.
- Byrd, L. D. The behavioral effects of cocaine: Rate dependency or rate constancy. *European Journal of Pharmacology*, 1979, **56**, 355-362.
- Galbicka, G., & Branch, M. N. Selective punishment of interresponse times. *Journal of the Experimental Analysis of Behavior*, 1981, **35**, 311-322.
- Gardner, M. L., & Malagodi, E. F. Responding under sequence schedules of electric shock presentation. *Journal of the Experimental Analysis of Behavior*, 1981, **35**, 323-334.
- Hake, D. F., & Azrin, N. H. An apparatus for delivering pain shock to monkeys. *Journal of the Experimental Analysis of Behavior*, 1963, **6**, 297-298.
- Kelleher, R. T., & 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., & Morse, W. H. Schedules using noxious stimuli: IV. An interlocking shock-postponement schedule in the squirrel monkey. *Journal of the Experimental Analysis of Behavior*, 1969, **12**, 1063-1079.
- Malagodi, E. F., Gardner, M. L., & Palermo, G. Responding maintained under fixed-interval and fixed-time schedules of electric shock presentation. *Journal of the Experimental Analysis of Behavior*, 1978, **30**, 271-279.
- Malagodi, E. F., Gardner, M. L., Ward, S. E., & Magyar, R. L. Responding maintained under intermittent schedules of electric-shock presentation: "Safety" or schedule effects? *Journal of the Experimental Analysis of Behavior*, 1981, **36**, 171-190.
- 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.
- McKearney, J. W. Responding under fixed-ratio and multiple fixed-interval fixed-ratio schedules of electric shock presentation. *Journal of the Experimental Analysis of Behavior*, 1970, **14**, 1-6.
- McKearney, J. W. Maintenance and suppression of responding under schedules of electric shock presentation. *Journal of the Experimental Analysis of Behavior*, 1972, **17**, 425-432.
- McKearney, J. W. Responding under a constant-probability schedule of electric shock presentation. *Psychological Reports*, 1974, **35**, 907-914.
- Shimp, C. P. The reinforcement of short interresponse times. *Journal of the Experimental Analysis of Behavior*, 1967, **10**, 425-434.
- Shimp, C. P. Magnitude and frequency of reinforcement and frequencies of interresponse times. *Journal of the Experimental Analysis of Behavior*, 1968, **11**, 525-535.

- Sidman, M. Avoidance conditioning with brief shock and no exteroceptive warning signal. *Science*, 1953, 118, 157-158.
- Webbe, F. M. *Maintenance and suppression of responding under concurrent schedules of electric shock presentation*. Unpublished doctoral dissertation, University of Florida, Gainesville, 1974.
- Received November 16, 1982
Final acceptance April 21, 1983