*RATIO RESPONDING AS A FUNCTION OF
CONCURRENT AVOIDANCE SCHEDULES,
YOKED SHOCKS, AND RATIO VALUE*

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Fixed-ratio food-reinforced responding in rats was studied alone and with concurrent shock avoidance or with concurrent response-independent shocks matched to those that occurred in the avoidance condition. Under each condition, fixed-ratio size was increased over successive daily sessions. Fixed-ratio response rate generally passed through a maximum as a function of fixed-ratio size. Decreased fixed-ratio responding at values beyond the maximum occurred when (1) the time to complete a fixed ratio approximated the response-shock interval of the avoidance schedule, (2) the shock rate increased, and/or (3) the ratio requirements were so high that ratio strain occurred. Avoidance rates decreased slightly as fixed-ratio size increased.

Key words: decreased responding, fixed ratio, avoidance, yoked shocks, concurrent schedules, lever press, rats

Previous studies examining the effects of one operant on others have usually used the same reinforcer, food, in the different individual schedules. Further investigations are needed to assess the effects of one operant maintained by a specific reinforcer on another operant maintained by a different reinforcer. For example, with a single reinforcer, when the overall rate of reinforcement is relatively constant, the rate of occurrence for one response decreases as a function of reinforcement from another source such as a concurrent schedule (see Catania, 1973, for discussion). Such a relationship may hold only when all the reinforcers are the same. In concurrent-schedule studies using food and water as reinforcers, changing the reinforcement schedule for one response resulted in systematic changes in the corresponding response rate but had little effect on responding maintained by the other reinforcer (Wood, Martinez, & Willis, 1975; Wood & Wil-

lis, 1974). Resolution of this issue with food and water is difficult because of the problems involved in determining the nature of the interactions of these complex and sensitive reinforcers (see Willis, Van Hartesveldt, Loken, & Hall, 1974). Concurrent schedules using different reinforcers that are less likely to interact strongly, such as food delivery and shock postponement, would be preferable in initial studies.

Three experiments have been reported that examined concurrent-schedule responding maintained by food-reinforcement and shock-postponement schedules. The first one was an attempt to maintain behavior appropriate to each schedule. Sidman (1958) studied responding on a concurrent variable-interval (VI) food shock-postponement (AV) schedule. Pulling a chain produced food according to a VI 4-min schedule. Pressing a lever was maintained by an AV schedule with the response-shock (RS) and shock-shock (SS) intervals both equal to 20 sec. Because of the high rate of switching between operants, preventing independence in responding to each schedule, Sidman changed the VI to a fixed-ratio (FR) schedule. Under concurrent FR AV contingencies, switching decreased and responding was maintained appropriate to the requirements of each schedule.

Catania, Deegan, and Cook (1966) compared the effects of responding on a concurrent FR AV schedule in relation to responding on each

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schedule alone. Pressing one lever produced food according to an FR 100 schedule. Pressing a second lever was maintained by a shock-postponement schedule, with the RS and SS intervals both equal at 30 sec. The removal of either lever did not affect the rate or pattern of the other response. This independence of appetitive and aversive schedule effects is similar to that observed by Kelleher and Cook (1959) in which the FR and AV contingencies were simultaneously programmed for responses on one lever (a conjoint contingency). Under these conditions, responses attributable to postponement of shock delivery were made during the preburst pause of FR responding.

Sidman (1958), Catania et al. (1966), and Kelleher and Cook (1959) used only one FR and one AV value. In the present experiment, a procedure was used that allowed for a wide range of reinforcement rates on one schedule while keeping the value constant on the other schedule. This procedure was introduced by Wood and Willis (1974). Using concurrent fixed-ratio fixed-interval (concurrent FR FI) schedules, Wood and Willis increased the FR value daily by a constant multiple of the preceding day while keeping the FI value constant. Cumulative records and response rates under these daily FR increases did not differ from those under procedures where repeated presentations of the same FR values were employed (LaBounty & Reynolds, 1973; Wood et al., 1975). Such a procedure allows a comparison of rates and patterns of responding on schedules maintained by the same or by different reinforcers (food and water) as a function of a wide range of FR values.

The present experiment extends the generality of the previous findings in which different reinforcers were scheduled concurrently. The Wood and Willis (1974) procedure (increasing the FR value daily while keeping the other schedule constant) was used with concurrent FR AV schedules and compared both to FR alone and FR yoked-shock conditions.

METHOD

Subjects

The subjects were three male hooded rats of Long Evans descent. Each subject was deprived to approximately 70% of its ad libitum weight. Two rats (21a and 35) were experimentally naive and the other (33) had been

previously run on the Wood and Willis (1974) procedure with concurrent FR VI schedules of food and water reinforcement.

Apparatus

Experimental sessions were conducted in two operant chambers, each containing two retractable levers, 3 cm above the grid floor and 14 cm apart. The force required to operate each lever was approximately .20 N. A food magazine was 4 cm to the left of the right lever. A 2.5-sec tone accompanied delivery of .045 g Noyes standard pellets. A constant-current shock generator delivered .5-sec, .8 ma ac scrambled shocks through the grid floor. Masking noise was continuously present except for 30 msec following each response; the resulting "pop" served as response feedback. Dim illumination was provided by a 7.5-W lamp. Each chamber was located in a sound- and light-attenuating box. Standard electromechanical scheduling and recording equipment was located in an adjacent room.

Procedure

Table 1 shows the order of exposure of each procedure for each rat. During pretraining, responding on the right lever was established with positive reinforcement and then maintained under the FR-10 schedule, all this with the left lever retracted. Rats 21a and 33 were then trained to respond on the left lever under the AV schedule with the right lever retracted. The RS interval was 30 sec; the SS interval was 20 sec. These sessions were followed by sessions in which the levers were available alternately within each session until the right lever controlled responding appropriate to the FR schedule and the left lever controlled responding appropriate to the AV schedule (a multiple FR AV schedule). Responding was then allowed to develop on a concurrent FR 10-sec RS 30-sec AV schedule with both levers present. The intervals separating shock delivery under this and other baseline concurrent FR 10 AV conditions for Rat 33 were recorded from the cumulative records to be used subsequently with baseline concurrent FR 10 yoked-shock schedules. After a series of baseline and experimental procedures under concurrent FR AV, FR alone, and an intervening procedure, a concurrent FR 10 yoked-shock schedule was used with Rats 21a and 35 (Rat 33 died from old age

Table 1
Order of Exposure of Each Procedure for Each Rat

<i>Concurrent FR AV</i>	<i>Rat 21a</i>	<i>Rat 33</i>
Pretraining		
	FR 1-10 (alone) RS 30" AV (alone) Multiple FR 10 RS 30" AV Concurrent FR 10 RS 30" AV	FR 1-10 (alone) RS 30" AV (alone) Multiple FR 10 RS 30" AV Concurrent FR 10 RS 30" AV
Baseline		
1. Ascending Series	Concurrent FR 10 RS 30" AV Concurrent FR 10-258 RS 30" AV	Concurrent FR 10 RS 30" AV Concurrent FR 10-124 RS 30" AV
Baseline		
2. Ascending Series	Concurrent FR 10 RS 15" AV Concurrent FR 10-179 RS 15" AV	Concurrent FR 10 RS 15" AV Concurrent FR 10-42 RS 15" AV
Baseline		
3. Ascending Series	Concurrent FR 10 RS 60" AV Concurrent FR 10-372 RS 60" AV	Concurrent FR 10 RS 7.5" AV Concurrent FR 10-20 RS 7.5" AV
Baseline		
4. Ascending Series	FR 10 (alone) FR 10-535	FR 10 (alone) FR 10-446
<i>Concurrent FR yoked SH</i>	<i>Rat 21a</i>	<i>Rat 33</i>
Pretraining		
	NA	FR 1-10
Baseline		
1. Ascending Series	Concurrent FR 10 YOK 7.5" SH Concurrent FR 10-20 YOK 7.5" SH	FR 10 (alone) FR 10-372
Baseline		
2. Ascending Series	Concurrent FR 10 YOK 15" SH Concurrent FR 10-42 YOK 15" SH	Concurrent FR 10 YOK 15" SH Concurrent FR 10 YOK 15" SH
Baseline		
3. Ascending Series	Concurrent FR 10 YOK 30" SH Concurrent FR 10-124 YOK 30" SH	Concurrent FR 10 YOK 30" SH Concurrent FR 10-124 YOK 30" SH
Baseline		
4. Ascending Series	FR 10 (alone) FR 10-535	Concurrent FR 10 YOK 7.5" SH Concurrent FR 10-20 YOK 7.5" SH

during the intervening procedure) with only the right lever present. Under these conditions response-independent shock presentations occurred at the same temporal point in a session as they had under baseline concurrent FR 10 AV conditions for Rat 33.

Several baseline procedures, separated by various ascending series, were used: three concurrent FR 10 AV schedules with RS intervals of 30, 15, and 7.5 or 60 sec with both levers present for Rats 21a and 33; three concurrent FR 10 yoked-shock schedules with different patterns and rate of response-independent shock presentations based on Rat 33's baseline performance under concurrent FR 10 AV schedules with only the right lever present for Rats 21a and 33; and FR alone with only the right lever present for all three rats. Baseline

conditions of stable weight (each subject was weighed prior to each session) and responding were defined as less than a 3-g difference in body weight and less than 2 responses-per-min difference in responding over a period of 5 or more days. These conditions were established for each baseline schedule prior to a corresponding series of changing FR values. Daily sessions ended when the subject received its daily food allotment within a session or when 90 min had elapsed, whichever came first. To maintain stable body weights, supplemental food was given after the session whenever the daily allotment was not received during the session.

Following each of the baseline procedures, the ratio requirement was increased from FR 10 by a factor of 1.2 (rounded to the nearest

whole number) each session (10, 12, 14, 17, ...) until the subject's FR response rate clearly approached zero (concurrent FR AV and FR alone conditions) or once the ratio requirement reached the ratio at which Rat 33's FR response rate was below 10 per min (concurrent FR yoked-shock conditions). Baseline responding was then developed under another concurrent or FR alone schedule. Under concurrent FR yoked conditions, response independent shocks were delivered at the same temporal points in each session as they had been received at each FR for Rat 33 in that specific FR ascending series under concurrent FR AV conditions. The only exceptions were when food allotment was earned in a session prior to the completion of the matched session with Rat 33.

Table 1 shows the order of presentation of the different RS and/or yoked-shock intervals and FR alone conditions for each series of changing FR values. Rat 21a had eight series; Rats 33 and 35 had four. For Rats 21a and 33 the first three series were under concurrent FR AV conditions with FR alone conditions in the fourth. For Rat 35 the FR alone condition was first followed by three series under concurrent FR yoked conditions. Rat 21a was under concurrent FR yoked conditions for the fifth through the seventh series (the first through the third under concurrent FR yoked-shock conditions) and FR alone conditions in the eighth.

RESULTS

Figure 1 shows the overall response rate functions for the different ascending series under FR alone and concurrent FR AV conditions (top panels), and FR alone and concurrent FR yoked conditions (bottom panels). Response rates were computed by dividing the total responses on one lever by the total minutes (including reinforcement duration) in a session. The FR response rate first increased over sessions (and, thus over FR values) to some peak, then decreased as the ratio requirement was increased further. The FR value resulting in the peak FR response rate (the highest rate of FR responding followed by consistent decreases in FR responding) depended upon the ratio value, the length of the RS interval, and the temporal pattern and rate of received shocks. The overall response rates

Fig. 1. Rates of responding for Rats 21a, 33, and 35 as a function of the FR requirement. Fixed-ratio response rates are shown directly above AV response rates for concurrent FR AV conditions (Rats 21a and 33). Fixed-ratio response rates for concurrent FR yoked conditions (Rats 21a and 35) are shown in the bottom panels. Filled squares represent FR alone conditions, filled triangles represent concurrent FR RS 60-sec AV conditions, unfilled squares represent concurrent FR RS 30-sec AV or concurrent FR yoked 30-sec SH conditions, filled circles represent concurrent FR RS 15-sec AV or concurrent FR yoked 15-sec SH conditions, and unfilled circles represent concurrent FR RS 7.5-sec AV or concurrent FR yoked 7.5-sec SH conditions.

on the avoidance lever declined slightly with the concurrent ratio increases even though a burst of AV responses frequently occurred after shock delivery and shock frequency often increased (see Meyer, 1975). Avoidance response rates were highest with the shortest RS interval and the lowest with the longest RS interval.

Figure 2 shows the mean time to complete a ratio under FR alone and under concurrent FR AV contingencies (left side) and the mean number of shocks per minute under concurrent FR AV contingencies (right side). The mean

Fig. 2. Mean time to complete a ratio (left panels) and rate of shock delivery (right panels) for Rats 21a and 33 under concurrent FR AV conditions as a function of the FR requirement. Each pair of panels shows data for a single AV condition while the FR value was varied. Unfilled circles represent Rat 21a. Broken horizontal lines (left panels) represent number of seconds of the RS interval in the AV component of the schedule.

time to complete a ratio was determined by dividing the total number of FR reinforcers into the cumulative seconds spent from the first press on the FR lever after an avoidance response to the next press on the avoidance lever. Shock rates were computed by dividing the total number of delivered shocks by the total minutes in a session. In general the mean times to complete a ratio decreased slightly with increases in the fixed-ratio requirement. Once the mean time to complete a ratio approximated the time for avoidance permitted by the RS interval (the broken horizontal lines), the FR response rate began to consistently decrease (resulting in increased ratio completion times); shock rates tended to increase at this point for Rat 33 but not for Rat 21a.

Figure 3 compares the mean changeover rates (filled circles and filled squares) and completed ratio rates (unfilled circles) under concurrent FR AV conditions for Rat 33 (top panels) and Rat 21a (bottom panels). With smaller ratios and shorter RS intervals (RS 7.5-sec and RS 15-sec), the subjects would typically complete a ratio with a burst of responding until food was delivered, eat and make a

Fig. 3. Rates of changeovers and completed ratios for Rat 33 (top panels) and Rat 21a (bottom panels) under concurrent FR AV conditions as a function of the FR requirement. Unfilled circles represent completed ratios and filled circles represent changeovers; filled squares represent changeovers under concurrent FR RS 60-sec AV conditions (the rate of completed ratios was omitted).

few avoidance responses during the FR pause, then complete another burst of FR responding. Note the similarity of rate and pattern between completed ratios and changeovers at these values. This pattern was very similar to that described by Kelleher and Cook, 1959. With smaller ratios and longer RS intervals (RS 30-sec and RS 60-sec), the rats typically completed two or three ratios prior to making an avoidance response (the rate of completed ratios under concurrent FR RS 60-sec AV conditions was omitted; the rates were similar to those when the RS interval was 30 sec). Note that the completed ratio rate is higher than the changeover rate. With higher ratios, subjects could not continue the chain-like pattern of an FR burst and AV responses during the FR pause. Ratios could no longer be completed within the time constraints of the avoidance contingency. At these ratio values, changeovers occurred prior to the completion of the ratio, affecting the FR responding. This break in the chain-like pattern had less effect on AV responding but did result in in-

creased shock rates with the shorter RS intervals (see Figure 2).

Figure 4 shows cumulative response records of the first 50 minutes of sessions under various concurrent FR AV conditions and one FR alone condition for Rat 21a. Fixed-ratio responding is shown above the concurrent AV responding. Changeover records are just below those for avoidance responding. These response patterns were typical of the entire session for Rats 21a and 33. The top left set of cumulative records shows baseline responding (FR 10) for the concurrent FR RS 15-sec ascending series. At baseline conditions, responding was similar to responding under each schedule's contingencies alone. At an intermediate ratio requirement (FR 72), the subject's pattern of FR responding remained similar to that of the baseline conditions, while the AV rate of responding dropped slightly. The pattern of FR and AV responding showed a little disruption in the beginning of the session (what looked like a warm-up effect typically seen in AV responding). At a higher ratio requirement (FR 149), the subject's pattern of AV responding again remained similar to that of baseline conditions while the rate of FR responding dropped further. The pattern of FR responding showed disruption throughout the session.

The effects of the concurrent avoidance RS interval on FR responding can be seen by comparing FR cumulative records at the same ratio (149) with a concurrent RS 15-sec AV schedule, a concurrent RS 30-sec AV schedule, or no concurrent schedule at all (right side of Figure 4). Depending on the concurrent avoidance requirement, the pattern of FR responding on a specific ratio requirement showed marked disruption throughout the session, slight disruption throughout the session, or no disruption in responding. Cumulative records of sessions under concurrent FR yoked conditions were quite similar to the ratio responding presented.

DISCUSSION

The data presented here indicate that behavior maintained by an FR schedule can be affected either by concurrently programmed shock postponement or by yoked-shock (response independent) contingencies. The extent of that effect is primarily determined by as-

pects of the shock delivery schedule: The shorter the interval by which a response postpones a shock (concurrent FR AV and concurrent FR yoked) or the higher the density of received shocks (concurrent FR AV and concurrent FR yoked), the greater the effect. Under small to intermediate requirements on a concurrent FR AV schedule, responding is similar to that of each contingency alone. Increases in the requirements for food result in disrupted ratio responding with minimal changes in AV responding. Increases in the requirement for shock postponement result in higher rates of schedule-appropriate AV responding with disrupted food responding at smaller ratios than with less stringent AV requirements.

In this study three factors seemed to interact, resulting in major effects on ratio responding and minimal effects on shock-postponement responding: (1) delivered shocks, (2) disrupted chain-like responding, and (3) ratio strain. A comparison of concurrent FR AV and concurrent FR-yoked results demonstrates that the rate and pattern of shock contributed to decreased FR responding. In general the higher the rate of shock, the greater the decrease in FR responding. With longer RS intervals, shock rates failed to show any increase with ratio requirement increases, but FR response rate decreased. Under these values it appeared the chain-like pattern of a completed ratio-shock postponement/completed ratio was disrupted, resulting in changes in ratio-response patterns and rates but maintained avoidance responding. Under conditions of FR alone, ratio responding decreased at high ratio requirements, but schedule-appropriate patterns were consistently maintained.

Although the procedures and subjects of the present experiment differed from those of the Sidman (1958), Kelleher and Cook (1959), and Catania et al. (1966) studies, the results are comparable. That is, FR and AV responding appear independent under certain conditions with little or no effect on subjects' concurrent-schedule response rate or pattern. These data are also similar to concurrent FR FI studies using food and water as reinforcers (Wood et al., 1975). As in this latter study, FR response rates were an inverted U-shaped function of the size of the ratio requirement; FI response rates either showed no systematic effect as a function of ratio size or showed

RAT 21a

Fig. 4. Cumulative records of rates and patterns of responding by Rat 21a under concurrent FR AV and FR alone schedules. The records numbered 1, 2, and 3 are from three sessions in which the same RS interval was used (15-sec) with three different FR requirements (10, 72, and 149). The records numbered 4 and 5 are from two sessions in which the FR requirement was the same as that used in record number 3 (FR 149) with either a longer RS interval (30-sec) or no concurrent avoidance schedule. Paper drive motors ran throughout sessions. Fixed-ratio records are above concurrent AV records; changeovers are below the response records. Pips on the FR response records indicate food delivery; pips on the AV response records indicate shock delivery. Arrows above the FR response records indicate shock delivery.

slight increases as the ratio requirement was increased. These similarities suggest that behavior maintained by different reinforcers differs from behavior maintained by the same reinforcer. Such results may have serious implications for previous generalizations based on concurrent-schedule responding maintained by food in each component. It appears there is a direct relationship between responding and the component requirements in concurrent schedules when both responses are reinforced with food, essentially no relationship when the reinforcers are food and water, and some relationship, depending on the scheduled values, when the reinforcers are food and shock postponement. Further research should investigate behavior on various schedules maintained by different reinforcers.

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