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TWO TEMPORAL PARAMETERS OF FOOD POSTPONEMENT[1]

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Rats were trained to press a lever under schedules of food postponement. In the absence of lever presses, food was delivered periodically (food-food interval). Responses initiated a second interval (response-food interval) that was reset by each additional response. Performance was first studied at different response-food intervals with the food-food interval fixed at 30 or 60 sec, or 10 min. Response-food intervals were examined in ascending order and then recovery was studied at shorter intervals. Finally, the food-food interval was manipulated with response-food interval fixed at 30 sec. At food-food intervals of 30 and 60 sec, responding first increased and then decreased as the response-food interval increased. At the 10-min food-food interval, responding decreased with increasing response-food interval. In general, very low rates of responding occurred when the response-food interval was 60 sec or more and when it equalled or exceeded the food-food interval. However, responding was maintained in one animal when the food-food interval was decreased from 120 to 15 sec with the response-food interval at 30 sec. Results, in terms of several dependent variables, are compared with data on shock avoidance. Effects of response-independent and response-produced food and shock are discussed.

Recent research indicates that the nature and history of interactions between ongoing behavior and reinforcement schedules can be more powerful than traditional variables such as the type of reinforcer (Morse and Kelleher, 1970). The history of schedule contact has been studied in experiments on response-independent food (*e.g.,* Herrnstein and Morse, 1957; Zeiler, 1968), response-independent electric shock (Herrnstein and Sidman, 1958; Kelleher, Riddle, and Cook, 1963) and response-produced shock (Morse and Kelleher, 1970). Kelleher and Morse (1968*a*, 1968*b*) and McKearney (1968, 1969, 1970) have shown that similar patterns of behavior can be generated and maintained under similar schedules for the production of either food or shock. These experiments suggest additional comparisons in which formally similar schedules are studied using different reinforcers.

The present experiment examined the effects of schedules of food postponement. These schedules are formally similar to free operant avoidance schedules (Sidman, 1953*a*, 1953*b*) but use food rather than shock as the postponed event. With some restrictions on the order of presentation, the two parameters of Sidman's procedure were manipulated over a range comparable to that employed in parametric experiments on avoidance of electric shock (Sidman, 1953*b;* Clark and Hull, 1966).

METHOD

Subjects

Four male Sprague-Dawley rats (R3, R5, R6, and R7) were maintained at 80 to 85% of free-feeding weights. Free-feeding weights varied from 600 to 640 g. Animals were about four months old at the start of the experiment and had no prior experimental history.

Apparatus

Experiments were conducted in cages mounted in ventilated, sound isolated chambers. Each inner cage contained a Gerbrands rat lever mounted 2 in. (5 cm) above the grid floor and requiring a force of at least 15 g (0.15 N) for activation. Experimental cages were 9 in. (23 cm) long, 8 in. (20 cm) wide and 7.8 in. (19 cm) deep. Reinforcers were 0.045-g

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Noyes food pellets delivered by solenoid-operated feeders. Water was continuously available from a bottle mounted on the wall opposite the lever and food cup. Two 3-w incandescent lamps indirectly illuminated each cage, and white noise was continuously presented. Scheduling and recording equipment was located in an adjoining room.

Procedure

Under free-operant avoidance procedures, two temporal parameters determine the delivery of shocks. Except for the use of food instead of shock as the postponed event, the schedules in this experiment were formally the same as those developed by Sidman (1953*b*). In the absence of lever presses, food was delivered periodically (the food-food or FF interval). Responses during the food-food interval terminated that interval and postponed food by a second interval (the response-food or RF interval). Additional responses during the RF interval reset the interval. Thus, RF intervals were initiated by responses and terminated by food delivery. Food-food intervals were initiated by food delivery and terminated by responses. Except for the additional FF interval, the procedure is like a delay-of-reinforcement schedule with reset of the delay (Dews, 1960).

Preliminary training consisted of food deprivation and feeder training. Rats were then trained at successive RF intervals with the FF interval fixed. At each interval, training was begun at RF = 0 sec and longer RF intervals were employed in ascending order after performance stabilized under the preceding schedule. Two subjects (R3 and R5) were first exbegun at RF = 0 sec and longer RF intervals with the FF interval fixed at 30 sec. Two other rats (R6 and R7) were trained at successive RF intervals with FF = 10 min. In each case, training began at RF = 0 and continued until there was no trend in response rates between daily sessions. The RF interval was then increased. This treatment was repeated until the RF interval equalled the FF interval, or until very low rates of responding occurred. Performance at one of the shorter RF intervals was then recovered. Following these two series of treatments, a third series was obtained with the FF interval fixed at 60 sec. Two rats were used in the third series (R3, previously exposed to the series with FF = 30 sec, and R6, previously trained with FF = 10 min). In all treatments, the daily session duration was adjusted according to the RF and FF intervals to prevent satiation effects within sessions. The order of occurrence, number of sessions and session duration for each rat under each combination of RF and FF intervals are given in Table 1.

Table 1

Session duration, and order and number of sessions for each RF interval at each fixed FF interval.

	Session Duration	*Number of Sessions*	
FF 30-sec			
		Rat 3	*Rat 5*
RF 0-sec	20 min	5	5
RF 3-sec	30 min	14	14
RF 6-sec	45 min	18	18
RF 15-sec	60 min	25	25
RF 30-sec	60 min	30	30
RF 6-sec	45 min	26	26
FF 10-min			
		Rat 6	*Rat 7*
RF 0-sec	20 min	7	7
RF 3-sec	30 min	16	16
RF 6-sec	45 min	13	13
RF 15-sec	60 min	19	20
RF 30-sec	90 min	25	25
RF 60-sec	120 min	46	46
RF 90-sec	120 min	31	31
RF 60-sec	120 min	10	10
RF 60-sec	60 min	11	11
FF 60-sec			
		Rat 3	*Rat 6*
RF 0-sec	20 min	9	3
RF 3-sec	30 min	17	17
RF 6-sec	45 min	7	7
RF 15-sec	60 min	9	9
RF 30-sec	60 min	9	9
RF 60-sec	90 min	15	15
RF 3-sec	30 min	31	31

After varying the RF interval at different fixed values of the FF interval, one series of treatments was conducted with the RF interval fixed and the FF interval varied. Rats R3 and R6 were trained at RF = 30 sec, FF = 120 sec. A descending series of FF intervals was then studied with the RF interval fixed at 30 sec. The FF interval was decreased successively after performance stabilized at each value until responding was virtually eliminated in both subjects (at FF = 5 sec). One of the earlier schedules (RF = 30 sec, FF = 60 sec) was then repeated. The schedule order, number of sessions, and the session durations for each subject in this series appear in Table 2.

Table 2

Session duration, and order and number of sessions for each FF interval at fixed FR 30-sec.

	Session Duration	*Number of Sessions*	
RF 30-sec			
		Rat 3	*Rat 6*
FF 120-sec	90 min	32	32
FF 60-sec	60 min	13	13
FF 45-sec	60 min	8	8
FF 30-sec	60 min	6	6
FF 15-sec	60 min	5	5
FF 5-sec	30 min	12	12
FF 60-sec	60 min	25	25

RESULTS

Figure 1 presents five dependent variables as functions of the Response-Food interval with the Food-Food interval as a parameter. Individual data are presented for each subject at each of the three fixed FF intervals used in the first part of the experiment. Each frame shows one dependent variable (rows) as a function of the RF interval at one value of the FF parameter (columns). Each point represents the mean value of the dependent variable for one session. In each case the last three sessions are plotted for each subject. Straight lines join the means of the last three sessions.

The top row of Figure 1 shows response rate as a function of the RF interval at each FF interval. At both FF = 30 sec and FF = 60 sec responding first increased and then decreased as the RF interval was increased. At both the shorter FF intervals the highest rate of responding occurred at RF = 3 sec. The peak rate at RF = 3 sec occurred in all four subjects but was more pronounced at FF = 30 sec than at FF = 60 sec. At FF = 30 sec and FF = 60 sec, responding was nearly abolished when the RF interval was increased to equal the FF interval. Under these conditions all responses decreased the overall frequency of food delivery. At FF = 10 min (upper right frame) the increase in rate at short RF intervals that was seen at shorter FF intervals did not occur. Rather, rate of responding decreased monotonically as the RF interval was increased from 0 to 90 sec. Low rates of responding were maintained, however, at RF intervals of 60 and 90 sec. After the ascending series plotted in Figure 1, response rates were redetermined (Tables 1 and 2) at FF = 30 sec RF = 6 sec, FF = 60 sec RF = 3 sec, and FF = 10 min RF = 60 sec. Redetermined rates are not shown in Figure 1 because, with one exception, they were within 10% of the plotted values. The exception was R5. Responding did not recover in this subject when the RF interval was decreased from 30 sec to 6 sec at FF = 30 sec. Beginning at RF = 6 sec, this subject had developed excessive drinking during the ascending series. When the RF interval was decreased the animal continued drinking rather than lever pressing. This was the only subject that developed polydipsia and the only one whose data at short RF intervals were not recoverable after exposure to longer intervals.

The second row in Figure 1 shows reinforcement rate as a function of the RF interval. At all three FF intervals, the rate of reinforcement was a decreasing negatively accelerated function of the RF interval. At longer RF intervals these curves approached asymptotes determined largely by the FF interval.

The third row of Figure 1 shows the proportion of all reinforcements resulting from the FF interval as a function of the RF interval. At FF = 30 sec, this proportion increased rapidly at RF intervals longer than 6 sec. The same kind of increase occurred at FF = 60 sec but at a much lower rate. At FF = 10 min, the larger portion of reinforcements resulted from timing out of the RF interval even at the longest RF intervals.

The ordinate in the fourth row of Figure 1 shows the proportion of total time the FF interval was in effect. This proportion was necessarily 1.0 at RF = 0 where the FF interval was continuously in effect. At all FF intervals, the proportion of FF time first decreased and then increased as the RF interval increased. All the curves are similar in shape, but the point at which the minimum proportion occurred appears to depend on the FF interval. At long RF intervals, the proportion of FF time never reached 1.0, reflecting the occurrence of some responses even at long postponement times.

The fifth row of Figure 1 shows the number of responses emitted per reinforcement at each RF interval. At all FF intervals, the number of responses per reinforcement first increased and then decreased as the RF interval was increased. The responses per reinforcement variable reflects in part the development of post-pellet response bursts. This pattern of

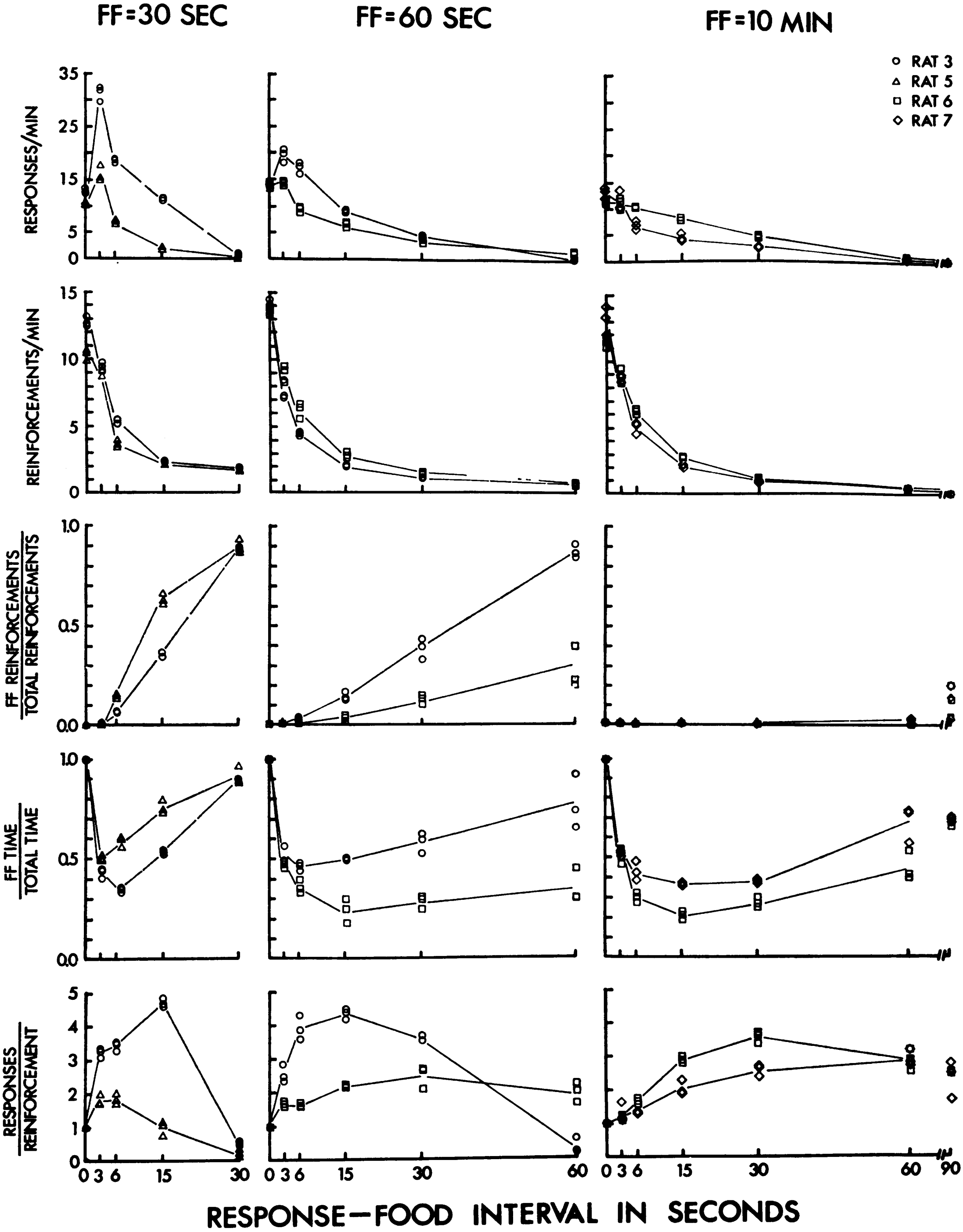

Fig. 1. Five dependent variables (rows) as functions of the response-food interval with the food-food interval as a parameter (columns). Mean values for each of the last three sessions are plotted for each subject under each condition. By rows, the dependent variables are rate of responding, rate of reinforcement, proportion of all reinforcements that resulted from the FF interval, proportion of total time during which the FF interval was timing, and number of responses emitted per reinforcement.

responding occurred to some degree at all RF and FF intervals, but appeared to be stronger at intermediate values of both parameters. (Again, with the exception of Rat 5 under FF = 30 sec where polydipsia had been induced.) The length of post-pellet bursts increased at moderate RF intervals even where average rates were lowered. And under FF = 10 min several responses per reinforcement continued to be emitted even at RF = 90 sec, where average rates were very low.

Figures 2, 3, and 4 show cumulative records of final performance of one rat under each schedule. Figure 2 shows performance at all RF intervals with FF = 30 sec. Figures 3 and 4 present similar data with FF = 60 sec and FF = 10 min, respectively. Each record shows a complete session with the event pen indicating when RF or FF intervals were in effect. The pattern of post-pellet response bursts that developed at intermediate RF intervals can be seen in each figure.

After the data in Figure 1 were obtained, Rats R3 and R6 were returned to FR = 30 sec and the FF interval was manipulated while RF was held constant. The FF interval was initially 120 sec and, after performance stabilized at each value, was decreased in steps until, at FF = 5 sec, responding nearly ceased in both subjects.

Figure 5 shows the results of manipulating the Food-Food interval with the Response-Food interval fixed at 30 sec. Data are plotted as in Figure 1, except that the independent variable on the abcissa is the FF interval. The five ordinates give the same variables as in Figure 1. The top frame of Figure 5 shows that response rate decreased with decreasing FF intervals. However, the form of this relation differed between the two subjects. Responding of Rat 3 was nearly abolished when the RF and FF intervals were equal at 30 sec. This is in agreement with data from the same subject at RF = FF = 30 sec in Figure 1. Rat 6, however, responded at about the same rate at all FF intervals from 120 sec down to 15 sec. The reinforcement rate as a function of the FF interval (second frame, Figure 5) was little affected by the difference in performance of the two subject at shorter FF intervals. The lower three frames of Figure 5, however, show differences between animals that are correlated with the rate differences in the upper frame. In the data of Rat 6, the proportion of FF reinforcements (third frame) and of FF time (fourth frame) remained low at all values down to FF = 15 sec. These data indicate that food pellets, resulting from the RF interval, were so reliably followed by lever presses that the FF contingency was without effect until its value was decreased to 5 sec. In the data of Rat 3, however, both proportion of FF reinforcements and of FF time, as well as response rate, were sensitive to changes in the value of the FF interval above RF = FF = 30 sec. A similar difference between subjects can be seen in the responses per reinforcement functions in the fifth frame of Figure 5. For each rat, these functions have the same shape as those for average rate in the top frame. In particular, Rat 6 emitted about two responses per reinforcement at all values of the FF interval from 15 to 120 sec.

Figure 6 shows final performance of Rat 6 under each schedule in the descending series of FF intervals with RF = 30 sec. The records are arranged and labelled as in Figures 2 through 4.

DISCUSSION

Rate of responding first increased and then decreased as the response-food interval was increased at intermediate food-food intervals (FF = 30 sec and FF = 60 sec). At longer food-food intervals (10 min), responding decreased monotonically as the response-food interval increased. At all three FF intervals, the number of responses emitted per reinforcement increased at intermediate RF intervals and decreased again at longer RF intervals. At all FF intervals, the reinforcement rate decreased monotonically with increasing RF values and the proportion of reinforcements resulting from the FF interval increased. Low response rates occurred when the RF and FF intervals were equal (at RF = FF = 30 sec and RF = FF = 60 sec). With the longest FF interval (10 min), low rates occurred at RF = 60 sec and RF = 90 sec, although several responses were emitted for each reinforcement even at RF = 90 sec.

When the RF interval was fixed at 30 sec and the FF interval was decreased in steps from 120 sec to 5 sec, responding was maintained in one subject (Rat 3) down to RF = FF = 30 sec. In the other subject (Rat 6), responding continued at about the same rate from FF = 120

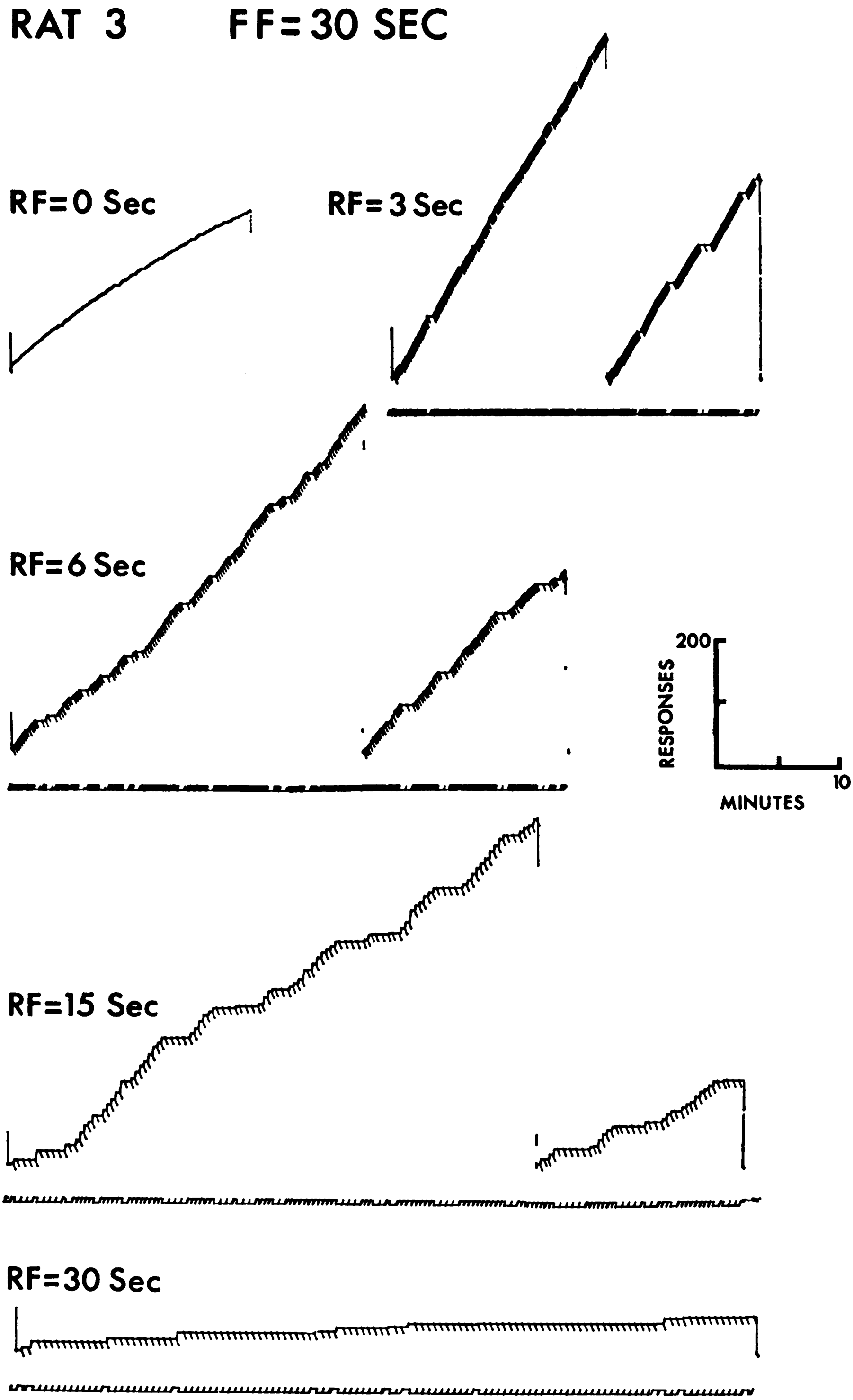

Fig. 2. Cumulative records of final performance of Rat 3 at each RF interval with FF = 30 sec. Each record shows the complete final session under each schedule. The event pen was displaced during the FF interval and released either momentarily to mark FF reinforcements or upon the occurrence of a response to indicate timing of the RF interval. The recorder reset after 550 responses and at the end of each session.

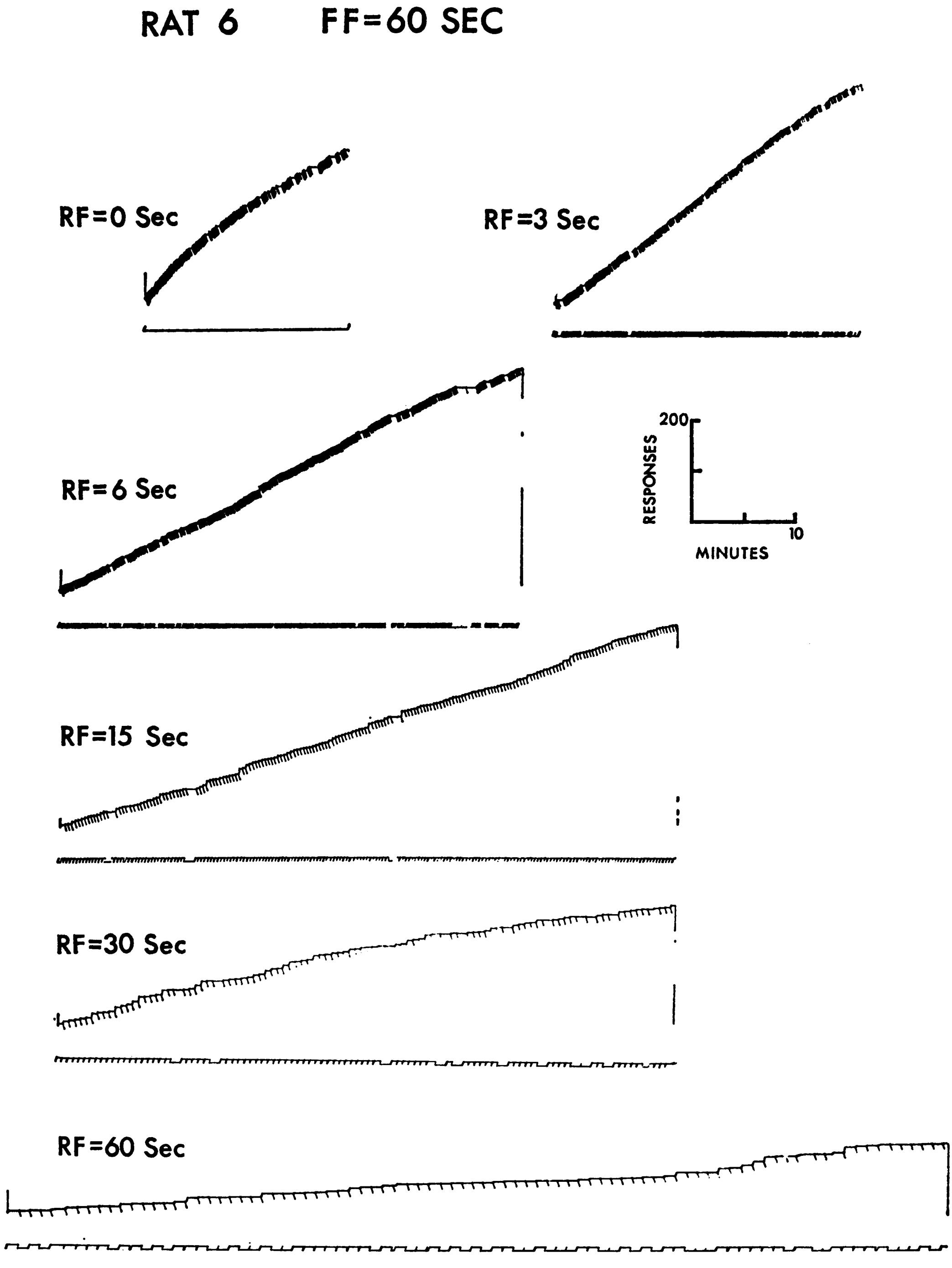

Fig. 3. Final performance of Rat 6 at each RF interval with FF = 60 sec. Each record shows the entire final session under each schedule. The recorder operated as in Figure 2.

sec down to FF = 15 sec. Rat 6 ceased responding only when the FF interval was decreased to 5 sec.

In the first part of the experiment, where RF intervals were increased at different fixed FF intervals, the functions relating independent and dependent variables for individual subjects were all of the same shape for any given

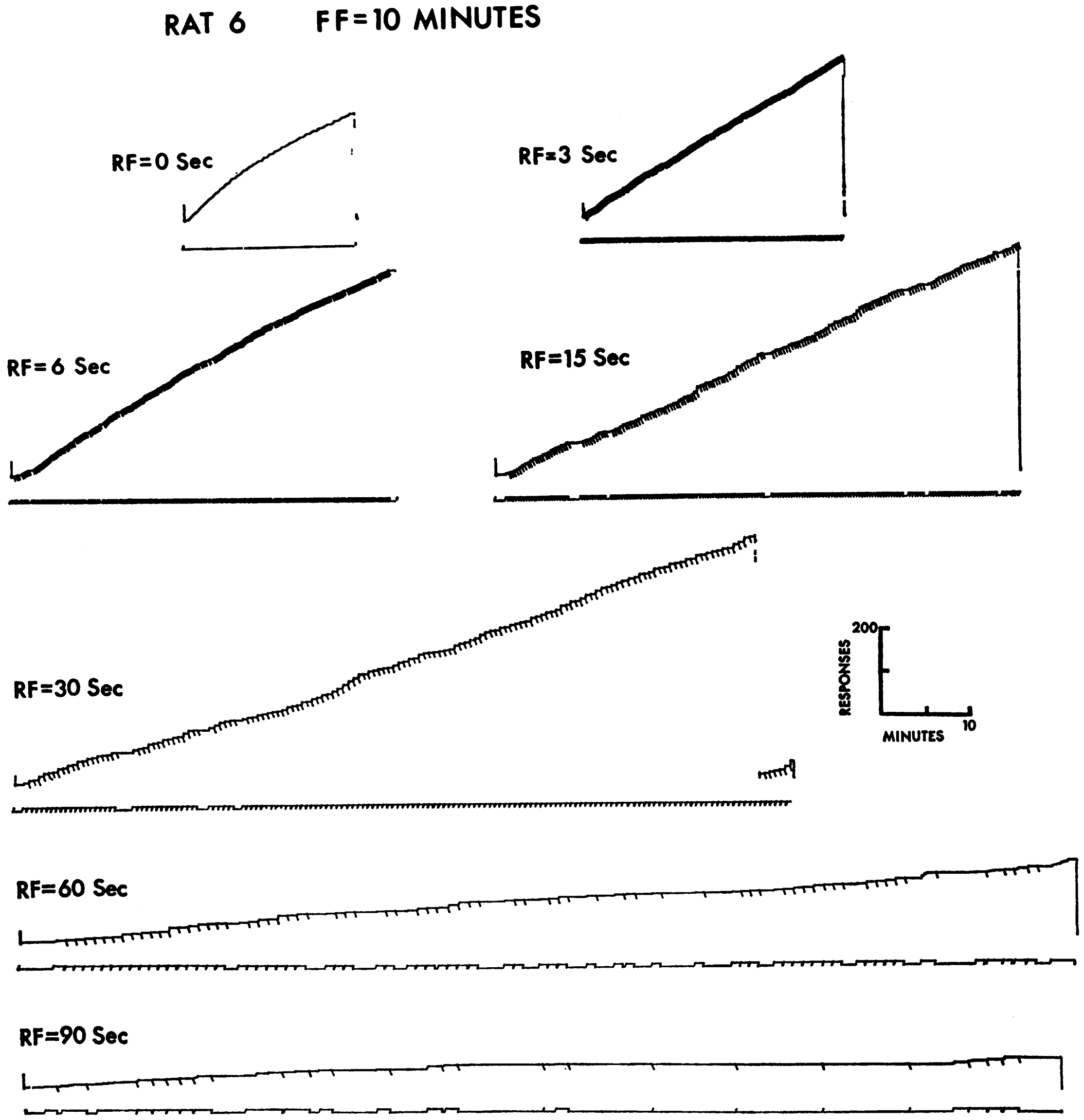

Fig. 4. Final performance of Rat 6 at each RF interval with FF = 10 min. Each record shows the last session under each schedule. The recorder operated as in Figure 2.

dependent variable and FF interval. That is, there were no individual differences in the general shape of curves within frames of Figure 1. This was even true for the animal (Rat 5) that developed polydipsia in the initial series at FF = 30 sec. However, this was the only subject in which data at short RF intervals were not recoverable after exposure to longer intervals. Individual functions obtained at FF = 60 sec in Figure 1 were also of the same shape, although one subject had been previously exposed to the RF series at FF = 30 sec and the other subject had been exposed to the RF series at FF = 10 min.

Although functions obtained with the RF interval as independent variable were of the same shape for each dependent variable and FF interval, this was not the case when the FF interval was manipulated at RF = 30 sec (Figure 5). Here, curves of the same general shape were obtained from both subjects only for reinforcement rate as a function of the FF interval. On all four other dependent variables the form of the relation differed for the two sub-

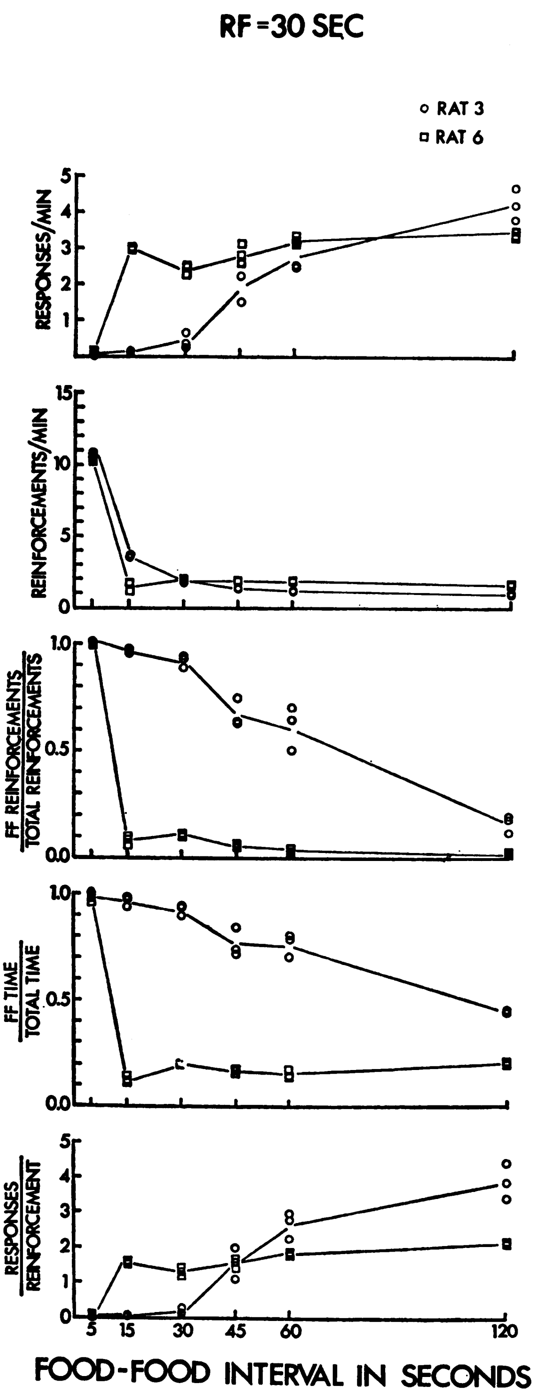

Fig. 5. Five dependent variables as functions of the food-food interval with the response-food interval fixed at 30 sec. Mean values for each of the last three sessions are plotted for each subject under each condition. The FF intervals were run in descending order from 120 to 5 sec. The dependent variables occur in the same vertical order as in Figure 1.

jects. Further, there was some redundancy in the dependent variables of Figure 5, which was absent in Figure 1. In Figure 5, with the FF interval as independent variable, the plots for response rate and responses per reinforcement, and those for proportion of FF reinforcements and proportion of FF time, respectively, have the same shape for each subject, although they differ between subjects in each case. The converse was the case in Figure 1 where each dependent variable gave a relation different in form from the others.

Obviously, the data obtained in the first part of this experiment with the RF interval as independent variable depended on early training at RF = 0 and at short RF intervals. RF = 0 with any finite value of the FF interval is, of course, a schedule of continuous reinforcement with an added free-food contingency. It would be premature to conclude, however, that original training at RF = 0 is necessary to maintain behavior at other values. That responses be emitted at some substantial rate, for whatever reason, and that their occurrence influence the temporal distribution of reinforcements, may be sufficient (*cf.*, Schoenfeld and Farmer, 1970).

The behavior of Rat 6, particularly with the FF interval as independent variable, requires special comment. This subject was initially exposed to the ascending series of RF intervals at FF = 10 min, and subsequently to the series with FF = 60 sec. In both of these treatments, Rat 6 generated functions similar in shape to those obtained from the other subject. In the series with FF = 60 sec, however, Rat 6 continued to emit about two responses per reinforcement at RF = FF = 60 sec, although both response and reinforcement rates were low. About 75% of reinforcements resulted from the RF interval on this schedule, whereas in the other subject, nearly all reinforcements resulted from the FF interval. Finally, when Rat 6 was exposed to the decreasing series of FF intervals with RF = 30 sec, rate of responding remained about the same from FF = 120 sec down to FF = 15 sec. A rate of about three responses per minute (or two responses per reinforcement) was maintained, not only at RF = FF = 30 sec, but also at RF = 30 sec FF = 15 sec. On both of these schedules, all responses decreased the frequency of food delivery, and at RF = 30 sec FF = 15 sec, the least effect of a response following food de-

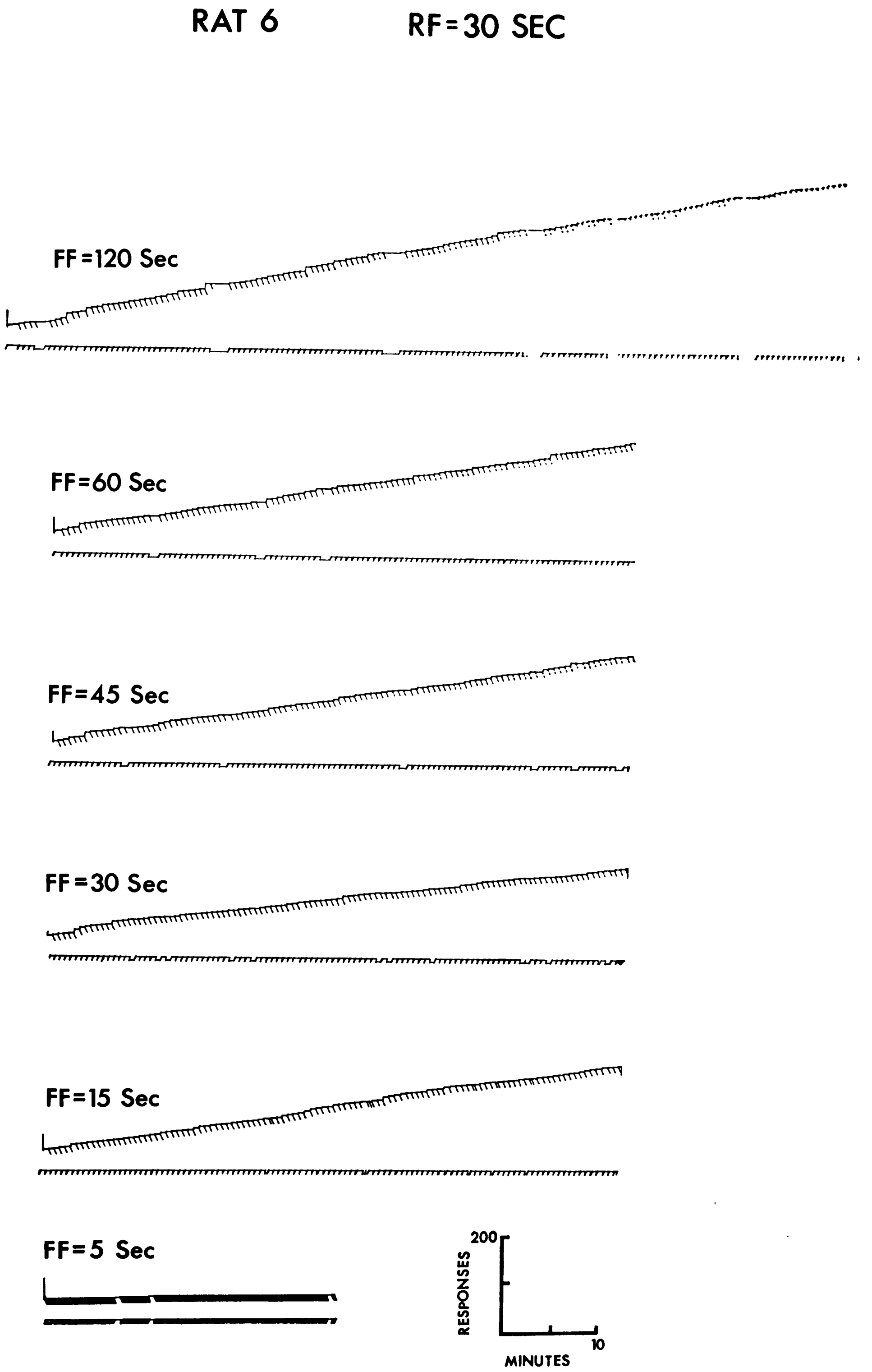

Fig. 6. Final performance of Rat 6 at each FF interval with RF = 30 sec. The recorder operated as in Figure 2. The entire last session is shown for each schedule.

livery was to double the time until the next reinforcement was due. These were the only cases in this experiment in which behavior was maintained in substantial strength under conditions where all responses decreased the frequency of food delivery. Further research will be required to uncover the conditions responsible for this phenomenon. The pattern of responding seen in Rat 6 during manipulation of the FF interval (Figure 6) has already been noted. Except at FF = 5 sec, the animal responded on the lever shortly after nearly every food pellet. Hence, the FF contingency, regardless of its value, seldom made contact with the behavior. Although similar patterns of responding were generated in the other subjects, they did not persist when the FF interval was equal to or less than the RF interval.

In this experiment, there was a high incidence of behavior directed at the food tray just before reinforcement. It is possible to view the schedules studied here as involving differential reinforcement of response chains whose terminal member is unspecified but whose duration and initial members are specified. For example, regardless of the values of the RF and FF intervals, any chain of duration FF is reinforced and any chain of duration RF that is initiated by a lever press is reinforced. Similar observations have been made in connection with free operant shock avoidance, where the schedules are formally identical to those studied here. Thus, in free operant avoidance, a sequence initiated by a specified response is not followed by shock for a specified duration (Dinsmoor, 1954; Schoenfeld, 1950; Sidman, 1953). This is tantamount to specification that a response-initiated sequence of a given duration will be followed by shock. In this experiment, schedules in which the RF interval was less than the FF interval generated the highest rates of responding. Yet behavior was sometimes maintained at other values. In shock avoidance, the converse is usually the case.

The relationships obtained between response rates and schedule parameters in this experiment are similar to those obtained in avoidance with shock as the postponed stimulus event. At short shock-shock intervals, rate of responding first increases and then decreases as the response-shock interval is increased. At longer shock-shock intervals (up to 50 sec), the point of maximum responding occurs at longer RS intervals (Sidman, 1953*b*). In the present data, there was a point of maximal responding with lower rates at both longer and shorter RF intervals when the FF interval was either 30 sec or 60 sec. When the FF interval was 10 min, however, rates decreased monotonically with increasing RF intervals. Comparably long shock-shock intervals have not been studied in avoidance.

Under appropriate conditions, behavior can be maintained by shock postponement (Sidman 1953*a*, 1953*b*), by shock frequency reduction (Herrnstein and Hineline, 1966), by response independent shock (Kelleher, *et al.*, 1963), and by production of shock (Kelleher and Morse, 1968*b*). Similarly, signalled response-independent food can either increase or decrease responding (Herrnstein and Morse, 1957). The present experiment was concerned with some of the conditions under which behavior is maintained by food postponement.

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