

EFFECTS OF A DELAY-REINFORCEMENT PROCEDURE ON PERFORMANCE UNDER $IRT > t$ SCHEDULES¹

FERNANDO A. GONZALEZ AND ROBERT J. NEWLIN

YERKES REGIONAL PRIMATE RESEARCH CENTER,
EMORY UNIVERSITY AND HARVARD MEDICAL SCHOOL

Water-deprived rats were studied under a compound schedule that prescribed that responses terminating interresponse times (IRTs) greater than a fixed value t_1 ($IRT > t_1$ component schedule) initiated a delay of reinforcement interval t_2 , at the end of which water was presented if the subject did not respond ($\bar{R} > t_2$ component schedule). If the subject responded before the t_2 interval elapsed, the $IRT > t_1$ component schedule was re-initiated and water was not presented. The $IRT > t_1$ and $\bar{R} > t_2$ component schedules were not differentially correlated with distinctive stimuli. Rate of responding during the $IRT > t_1$ component decreased as a function of the value of t_2 . The magnitude of the decreases in response rate appeared to be proportional to the subject's rate under the $IRT > t$ schedule with no delay of reinforcement ($t_2 = 0$ sec). The effects were independent of the parameter value of the $IRT > t_1$ component schedule and of the rate of reinforcement. The results suggested that "efficiency" of performance under $IRT > t$ schedules can be increased by appropriately arranging brief delays of reinforcement.

Key words: delay of reinforcement, $IRT > t$ schedules, DRL, DRO, efficiency, rats

Delay of reinforcement refers to the temporal separation between a specified response and the subsequent presentation of a reinforcer. Operant procedures for studying effects of delay of reinforcement have often involved compound schedules consisting of two component schedules. By responding during one component schedule, the subject produces a second component schedule, which is temporally defined. The reinforcer is presented when the requirement of the second component schedule is completed. The duration of the second component schedule is the delay of reinforcement. Generally, rate of responding in the initial component decreases as delay of reinforcement is increased (Azzi, Fix, Keller, and Rocha e Silva, 1964; Dews, 1960; Morgan, 1972; Pierce, Hanford, and Zimmerman, 1972; Silver and

Pierce, 1969; Skinner, 1938, pp. 139-150). However, characteristics of the schedule, such as whether a distinctive stimulus is correlated with the delay interval (Azzi *et al.*, 1964; Ferster, 1953; Ferster and Hammer, 1965), and whether responses reset the delay-interval timer (Dews, 1960), can modulate the magnitude of the effects of delay of reinforcement.

A schedule that has been shown to produce substantial decreases in response rate when programmed as a delay of reinforcement component, that is, as the second component of a two-component schedule, consists of presenting the reinforcer only after an interval of time elapses, during which responding does not occur. This schedule can be designated $\bar{R} > t$ (Zeiler, 1976), where t is the time interval at the end of which the reinforcer is presented if the response R does not occur. (This schedule has also been called differential-reinforcement-of-other-behavior, or DRO.) The $\bar{R} > t_2$ component is especially effective in decreasing response rate during the first component schedule if distinctive stimuli are not differentially correlated with the two components (Azzi *et al.*, 1964; Dews, 1960; Skinner, 1938, pp. 139-150).

The present experiment studied the effects of an $\bar{R} > t$ schedule, programmed as a delay-of-reinforcement component, on rats responding under schedules of differential reinforce-

¹This research was supported by N.I.M.H. grants MH12383 and MH15468, and by N.A.S.A. grant NGL34-003-040. Preparation of the manuscript was supported by U.S. Public Health Service Grant NIH07084, with facilities furnished by the New England Regional Primate Research Center, Harvard Medical School, Southborough, Massachusetts (PHS Grant RR00168, Division of Research Resources, N.I.H.) and the Yerkes Regional Primate Research Center (PHS Grant RR-00165, Division of Research Resources, N.I.H.). The authors thank W. H. Morse, R. D. Spealman, L. D. Byrd, and P. B. Dews for critical readings of the manuscript. Reprints may be obtained from F. A. Gonzalez, Yerkes Regional Primate Research Center, Emory University, Atlanta, Georgia 30322.

ment of interresponse times greater than a fixed value t ($IRT > t$). The $IRT > t$ schedule specifies that a response will be followed by the reinforcer only if a time exceeding t has elapsed since the preceding response. (This schedule has also been designated differential-reinforcement-of-low-rate, or DRL.) Characteristically, the frequency distribution of interresponse times (IRT) in the rat under $IRT > t$ schedules is bimodal, with one peak near the class interval that includes the IRT requirement for reinforcement, and a second peak at the shortest class interval. As the value of t is increased, the maximum rate of reinforcement under $IRT > t$ schedules necessarily decreases; however, the obtained reinforcement rate usually decreases faster than the maximum reinforcement rate (Richardson and Loughhead, 1974; Staddon, 1965; Wilson and Keller, 1953). Response rate also decreases as t is increased, but it does not decrease as rapidly as reinforcement rate (Richardson and Loughhead, 1974; Wilson and Keller, 1953).

Schoenfeld and Farmer (1970) studied the performance of rats under tandem $IRT > t_1, \bar{R} > t_2$ schedules of water presentation. Under this procedure, lever-pressing responses that met the requirement of an $IRT > 10$ -sec component schedule produced the $\bar{R} > t_2$ component schedule. Once initiated, the $\bar{R} > t_2$ component remained in effect until the no-response requirement was met and water was presented; thus, sequences of IRT s shorter than 10 sec could occur during the $\bar{R} > t_2$ component immediately before the period of no responding required for reinforcement. Distinctive stimuli were not correlated with the two components. Schoenfeld and Farmer found that response rate during the $IRT > 10$ -sec component was not substantially affected when t_2 was varied between 0 and 10 sec. The schedule used in the present study differed from that used by Schoenfeld and Farmer in that responses during the $\bar{R} > t_2$ component re-instated the $IRT > t_1$ requirement; therefore, the requirements of both component schedules had to be met consecutively to produce the reinforcer. Since, in contrast with Schoenfeld and Farmer's procedure, the reinforcer would be presented at completion of the $\bar{R} > t_2$ requirement only if the preceding IRT was greater than t_1 , it was anticipated that our procedure would decrease response rate as delay of reinforcement (t_2) increased. It was of interest, therefore, to deter-

mine functional relationships between the value of t_2 and summary measures of performance, such as response rate, reinforcement rate, proportion of time under each component schedule, *etc.*, and to explore the possibility of interactions between the parameter value of the $IRT > t_1$ component schedule and the $\bar{R} > t_2$ component.

METHOD

Subjects

Six experimentally naive male albino rats, approximately 100 days old, were deprived of water for 21 to 23 hr before each daily experimental session. Access to water in the home cages was limited to 30 min immediately following each session. Food was always available in the home cages. Two subjects, Rats 5 and 9, died of pneumonia after 125 and 123 sessions, respectively.

Apparatus

Two identical rat chambers, 20 by 23.5 by 19.5 cm, were used. A 7.5- by 5.5-cm opening centered on the front wall, 2 cm above the floor, permitted access to a water dipper (No. 114-02, Lehigh Valley Electronics, Fogelsville, Pa.) that provided 0.02 ml of water per operation. White jewel lamps were located on each side of the dipper opening, 8 cm above the floor and 4 cm from the side walls. A response lever (No. 121-03, Lehigh Valley Electronics, Fogelsville, Pa.) was located directly underneath the right jewel lamp, 3 cm above the floor and 4 cm from the right wall. When a subject pressed the lever with a force of 0.10 N or more, there was an audible click, and a response was recorded. A 3- by 4-cm piece of 2-mm aluminum was attached to the front wall 1 cm left of the lever, between the lever and the dipper opening. This small screen reduced the likelihood that subjects would depress the lever while drinking or moving about. The rat chambers were located in separate small rooms. White noise was provided to mask extraneous sounds. Electromechanical programming and recording equipment were located in adjacent rooms.

Procedure

The subjects were trained to drink from the dipper and to press the lever. They were then exposed to a schedule under which each response resulted in water presentation. When

responding and drinking occurred consistently, the schedule was changed to IRT > t. The value of t was progressively increased to the final value during two to three sessions. Rats 5, 6, 9, and 10 were studied with IRT > 30 sec. Rats 14 and 15 were studied with IRT > 10-sec and IRT > 60-sec schedules, respectively. Sessions were conducted seven days a week at approximately the same time of day. The jewel lamps were illuminated during the sessions but were turned off for approximately 30 msec by each response.

The $\bar{R} > t$ component schedule was introduced when no trends were apparent in the daily response rate and reinforcement rate for at least 10 successive sessions. This criterion of performance stability was used throughout the experiment. A flow diagram (after Mechner, 1959) describing the relevant features of the procedure is shown in Figure 1. Responses terminating IRTs longer than t_1 initiated a $\bar{R} > t_2$ component schedule. Water was presented at the end of the t_2 interval if the subject did not respond during the interval. If, however, the subject responded during the t_2 interval, the IRT > t_1 schedule was immediately re-instated and water was not presented. Therefore, water was presented only after the subject made a response that termi-

nated an IRT longer than t_1 , and did not respond again for a time interval equal to the fixed delay of reinforcement value t_2 . All other temporal distributions of responses re-instated the IRT > t_1 component schedule. The IRT > t_1 schedule was also re-instated when water was presented. The IRT > t_1 and $\bar{R} > t_2$ component schedules were not differentially correlated with distinctive stimuli.

The sequence of experimental conditions, and the number and approximate duration of sessions under each condition, are listed in the left-hand column of Table 1. For Rats 5, 6, 9, 10, and 14, t_2 was progressively increased. For Rat 15, the sequence of experimental conditions was unsystematic. Rats 5 and 9 died while being studied under $t_2 = 6$ sec. For the remaining subjects, t_2 was increased until response rate and reinforcement rate approached zero. After being studied under all values of t_2 , Rats 6, 10, 14, and 15 were again studied under the IRT > t_1 schedules with no delay of reinforcement ($t_2 = 0$ sec). Rats 6 and 10 were also exposed to IRT > 60 sec with $t_2 = 0$ sec and IRT > 180 sec with $t_2 = 0$ sec, respectively. These IRT > t schedules matched the minimum interreinforcement times corresponding to the largest t_2 values under which the subjects were studied. For Rats 14 and 15, the final experimental condition was extinction. Each experimental condition remained in effect for at least 20 sessions, and until performance was judged stable. In an attempt to reduce the likelihood that satiation effects would obscure the effects of the $\bar{R} > t_2$ requirements, session duration was roughly adjusted across subjects, depending on their reinforcement rate under the IRT > t schedules. As t_2 was increased to large values, session durations were increased to compensate for decreases in reinforcement rate.

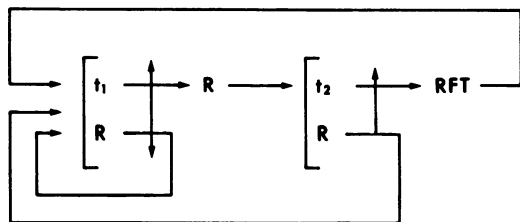


Fig. 1. Schematic diagram of the procedure in accordance with Mechner's (1959) notation system. The diagram is read from left to right. The bracket on the left encompasses conditions representing the IRT > t_1 component schedule: a lever-pressing response R, which occurred before a time interval t_1 had elapsed since the preceding response, prevented succession to the next condition, and re-initiated both the time interval and the response requirement. If R occurred after t_1 had elapsed since the preceding response, the second set of conditions was produced. The conditions encompassed by the bracket on the right of the diagram represent the $\bar{R} > t_2$ component schedule: a lever-pressing response, which occurred before a time interval t_2 had elapsed, prevented presentation of the reinforcer (RFT) and re-initiated the IRT > t_1 component schedule. If R did not occur during the interval t_2 , the reinforcer was presented at the end of t_2 , and the IRT > t_1 schedule was re-initiated. Different stimuli were not differentially correlated with the two component schedules.

RESULTS

Summary statistics for individual subjects are presented in Table 1. Daily overall response rates and reinforcement rates from Rat 10 are shown in Figure 2. (Rat 10 was selected to illustrate details of performance because it was studied under the IRT > t schedule of intermediate value and under all values of t_2 . Except as otherwise specified, the results obtained with Rat 10 were representative.) A relatively large number of sessions under

Table 1
 Details of Procedure and Summary Statistics for the Last 10 Sessions under Each Condition

Subject	IRT > t ₁ (sec)	\bar{R} > t ₂ (sec)	Sessions	Session Duration (min)	Responses per min		Reinforcements per min	
					Mean	SD	Mean	SD
14	10	0	40	30	7.499	0.284	3.669	2.259
	10	1	30	30	6.427	0.656	3.043	0.221
	10	3	26	30	4.874	0.405	2.508	0.211
	10	6	27	30	3.055	0.382	2.213	0.117
	10	12	25	60	1.932	0.266	1.395	0.205
	10	30	25	60	0.959	0.146	0.680	0.072
	10	60	25	120	0.639	0.137	0.258	0.037
	10	150	25	120	0.157	0.056	0.042	0.016
	10	0	20	30	6.621	0.345	3.953	0.214
		extinction		27	120	0.145	0.061	
5	30	0	42	60	2.567	0.265	1.128	0.143
	30	1	30	60	2.466	0.210	1.004	0.128
	30	3	31	60	2.185	0.207	1.125	0.066
	30	6	18	60	1.843	0.201	1.088	0.085
6	30	0	70	60	3.091	0.338	1.000	0.065
	30	1	30	60	2.858	0.257	0.880	0.057
	30	3	39	60	2.259	0.245	0.863	0.064
	30	6	33	60	1.557	0.165	0.823	0.060
	30	12	44	60	1.053	0.208	0.362	0.077
	30	30	35	60	0.365	0.499	0.045	0.039
	60	0	22	60	2.198	0.185	0.288	0.049
	30	0	20	60	3.484	0.587	0.762	0.099
9	30	0	29	60	3.059	0.197	0.527	0.071
	30	1	32	60	2.670	0.211	0.952	0.069
	30	3	31	60	1.850	0.242	1.007	0.067
	30	6	17	60	1.718	0.136	0.960	0.036
10	30	0	68	60	2.855	0.187	0.665	0.069
	30	1	31	60	2.173	0.225	1.007	0.061
	30	3	32	60	2.020	0.220	0.910	0.063
	30	6	35	60	1.534	0.192	1.021	0.064
	30	12	36	60	1.016	0.152	0.745	0.070
	30	30	35	60	0.840	0.103	0.506	0.078
	30	60	37	120	0.452	0.035	0.342	0.030
	30	150	30	120	0.269	0.042	0.103	0.022
	30	0	35	60	2.691	0.295	1.073	0.062
	180	0	29	120	1.210	0.240	0.042	0.012
15	60	0	50	120	2.657	0.435	0.087	0.021
	60	12	38	120	0.982	0.130	0.344	0.035
	60	6	25	120	1.341	0.077	0.395	0.046
	60	60	31	120	0.385	0.064	0.103	0.029
	60	0	20	120	2.392	0.224	0.109	0.045
	60	3	20	120	1.706	0.173	0.220	0.042
	60	1	23	120	2.007	0.144	0.302	0.064
	60	30	20	120	0.578	0.139	0.256	0.036
	60	150	20	120	0.219	0.054	0.075	0.013
		extinction		18	120	0.062	0.061	

IRT > t₁ with t₂ = 0 sec were necessary before response rates stabilized at the beginning of the experiment. However, performance stabilized more rapidly after the \bar{R} > t₂ component schedule was introduced and upon subsequent manipulations. Session-to-session variability of response rate was greater for Rat 10 than for

the other subjects. For Rats 6, 14, and 15, response and reinforcement rates were similar during both determinations with t₂ = 0 sec (Table 1). For Rat 10, reinforcement rates were substantially higher during the second determination. Session-to-session variability was generally negligible for all subjects during the

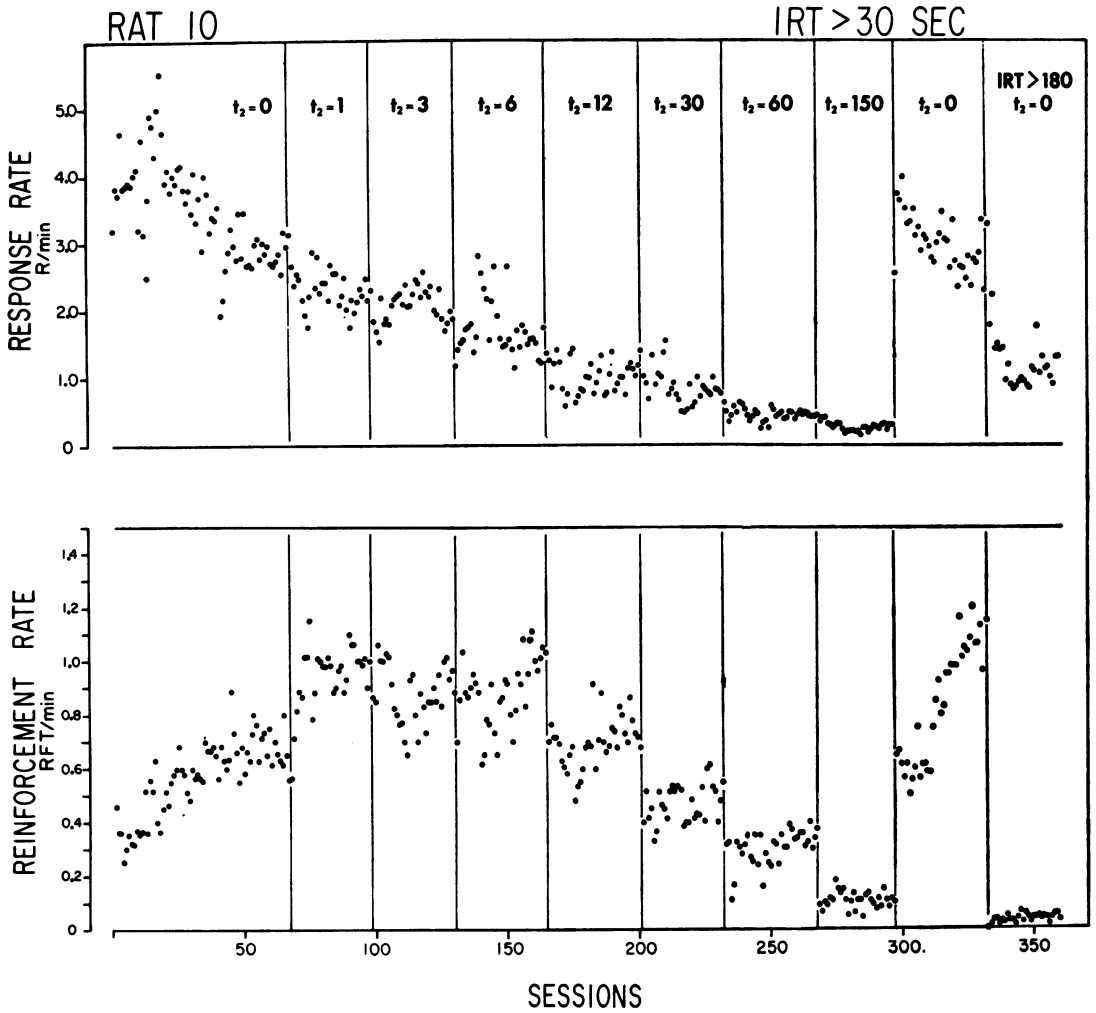
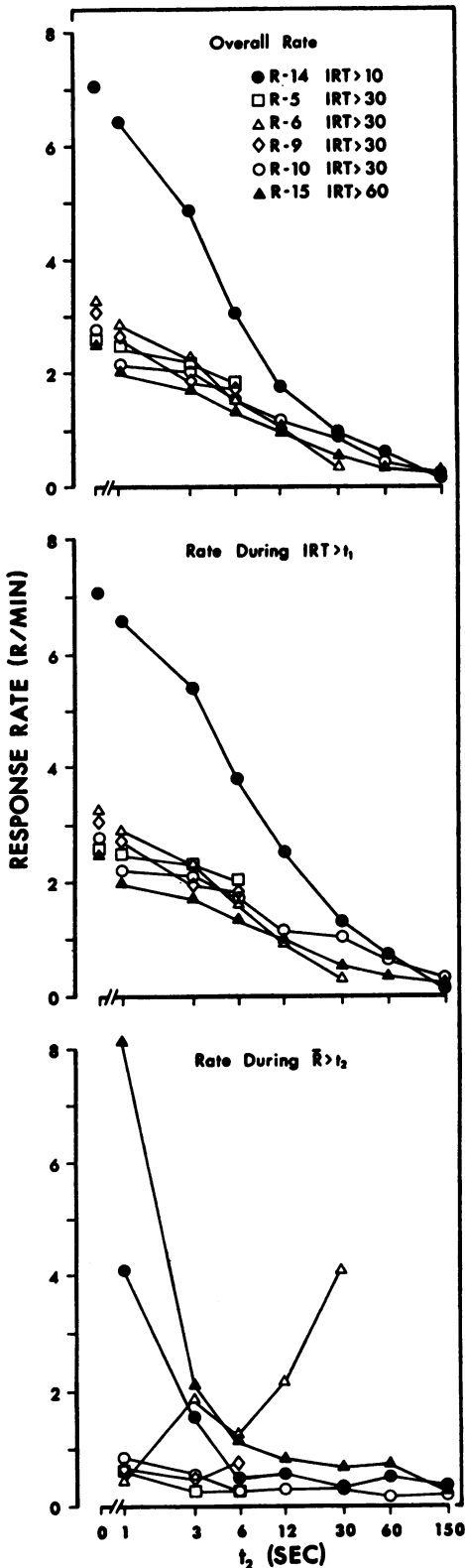


Fig. 2. Daily response rates (upper panel) and reinforcement rates (lower panel) from Rat 10. With the IRT > t₁ schedule parameter (t₁) set at 30 sec, the $\bar{R} > t_2$ schedule parameter (t₂) was progressively increased from 0 to 150 sec. Performance was then redetermined with t₂ = 0 sec. Under the final experimental condition, t₁ = 180 sec and t₂ = 0 sec.

last 10 sessions under each experimental condition (Table 1).

Overall response rate (Figure 3; upper panel) and response rate during the IRT > t₁ component schedule (Figure 3; middle panel) were monotonically decreasing functions of t₂ for all subjects. In contrast, the form of the function relating response rate during the $\bar{R} > t_2$ component to the value of t₂ (Figure 3; lower panel) was more variable among the subjects. Overall response rate is a composite of the rate of responding during each component schedule and of the proportion of session time spent under each component. Since, under most values of t₂, overall response rate was

very similar to response rate during the IRT > t₁ component, but was different from response rate during the $\bar{R} > t_2$ component, it follows that the IRT > t₁ component was in effect for the greater part of the sessions. Under the present procedure, the proportion of session time spent under the IRT > t₁ component schedule could vary between 1.0 and a minimum value t₁/t₁ + t₂. Therefore, the value of the ratio of time spent during the IRT > t₁ component to the total session time, and its complement, the value of the ratio of time spent under the $\bar{R} > t_2$ component to total session time, were not independent from the parameters of the procedure. When t₂ was



small relative to t_1 , the value of the ratio of time under the $IRT > t_1$ component to total session time had to be large, but when t_2 was large relative to t_1 , the value of the ratio of time under the $IRT > t_1$ component to total time *could* be small. The upper panel of Figure 4 shows that, although there were decreases in the value of the ratio of time under the $IRT > t_1$ component to total session time as t_2 was increased, it was never less than about 0.6, which was substantially greater than its possible minimum value at the corresponding values of t_2 .

The proportion of responses that occurred during the $IRT > t_1$ component schedule and its complement, the proportion of responses that occurred during the $\bar{R} > t_2$ component schedule, are measures of the relative contribution of responding during each component schedule to overall response rate. The present procedure prescribed that there be at least one response during the $IRT > t_1$ component in order for the $\bar{R} > t_2$ component to occur, and also that there be no more than one response during each occurrence of the $\bar{R} > t_2$ component. Therefore, the value of the ratio of responses during the $IRT > t_1$ component to all responses could be no greater than 1.0 and no less than 0.5, independently of the parameters of the procedure. The lower panel of Figure 4 shows that initially the value of this ratio was close to 1.0, and that it decreased very little as t_2 increased. At $t_2 = 150$ sec, more than 0.75 of all responses still occurred during the $IRT > t_1$ component schedule.

The above analysis indicates that the major effect of increasing t_2 was to decrease response rate during the $IRT > t_1$ component schedule. As shown in the middle panel of Figure 3,

Fig. 3. Effects of varying the parameter of the $\bar{R} > t_2$ component schedule on response rate. X-axis: t_2 ; log scale. Y-axis, upper panel: overall response rate (responses per minute). Y-axis, middle panel: response rate (responses per minute) during $IRT > t_1$ component schedule. Y-axis, lower panel: response rate (responses per minute) during $\bar{R} > t_2$ component schedule. For Rats 6, 10, 14, and 15, the data points at $t_2 = 0$ sec represent the mean of the last 10 sessions from two determinations. All other points represent the mean of the last 10 sessions under each condition. The standard deviation corresponding to each data point in the upper and middle panels was less than 10% of mean for $t_2 < 30$ sec, and less than 30% of mean for $t_2 \geq 30$ sec. The standard deviation corresponding to each data point in the lower panel was generally greater than 50% of mean.

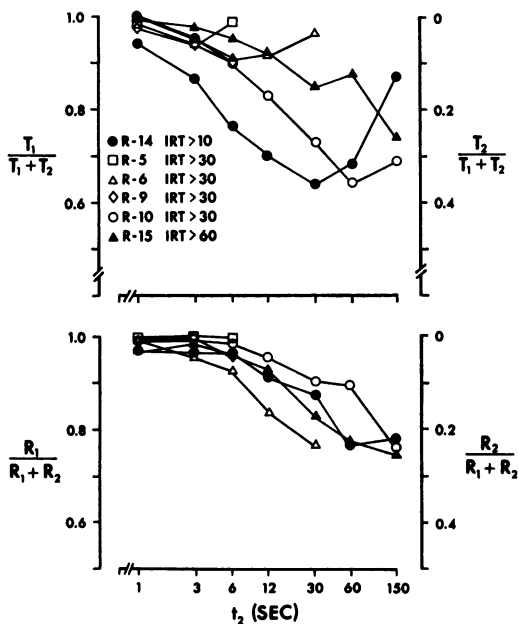


Fig. 4. Effects of varying the parameter of the $\bar{R} > t_2$ component schedule on the proportion of session time spent under each component schedule (upper panel) and the proportion of responses occurring during each component schedule (lower panel). X-axis: t_2 ; log scale. Left Y-axis, upper panel: ratio of time spent under IRT > t_1 component schedule to time spent under both component schedules ($T_1/T_1 + T_2$). Right Y-axis, upper panel: ratio of time spent under $\bar{R} > t_2$ component schedule to time spent under both component schedules ($T_2/T_1 + T_2$). Left Y-axis, lower panel: ratio of responses during the IRT > t_1 component schedule to responses during both component schedules ($R_1/R_1 + R_2$). Right Y-axis, lower panel: ratio of responses during $\bar{R} > t_2$ component schedule to responses during both component schedules ($R_2/R_1 + R_2$). Data points represent the mean of the last 10 sessions under each condition. The standard deviation corresponding to each data point was less than 10% of mean.

response rate during the IRT > t_1 component was a monotonically decreasing function of t_2 . At $t_2 = 0$ sec, Rat 14 (IRT > 10-sec schedule) responded at a substantially higher rate than the other subjects. However, response rate decreased faster for Rat 14 as t_2 was increased. The effects of increasing t_2 were very similar across subjects when response rate was expressed as a proportion of response rate at $t_2 = 0$ sec (Figure 5).

Functions relating reinforcement rate to the parameter value of the $\bar{R} > t_2$ component schedule differed substantially, depending on the parameter value of the IRT > t_1 schedule (Figure 6; upper panel). Reinforcement rate at $t_2 = 0$ sec was inversely related to the param-

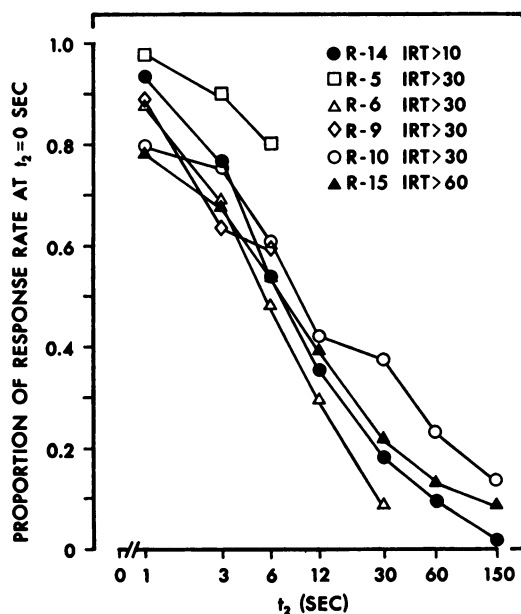


Fig. 5. Effects of varying the parameter of the $\bar{R} > t_2$ component schedule (X-axis, log scale) on response rate during IRT > t_1 component schedule, expressed as proportion of response rate at $t_2 = 0$ sec (Y-axis). Data points represent the mean of the last 10 sessions under each condition. In calculating the proportions for Rats 6, 10, 14, and 15, the rate at $t_2 = 0$ sec was considered to be the mean of the last 10 sessions from two determinations.

eter of the IRT > t_1 schedules. For Rat 14 (IRT > 10 sec), reinforcement rate decreased monotonically as t_2 increased. For Rats 5, 6, 9, and 10 (IRT > 30 sec), reinforcement rate did not decrease until t_2 was 12 sec. For Rat 15 (IRT > 60 sec), the function was biphasic, with the peak at $t_2 = 6$ sec. Although the actual increases in reinforcement rate for Rat 15 were small, they represented large percentage increases over the rate of reinforcement at $t_2 = 0$ sec. (The cumulative records for Rat 15 (Figure 11) clearly show the increases in reinforcement rate.)

To produce the reinforcer, subjects had to make a response to initiate the $\bar{R} > t_2$ component and then abstain from responding for the duration of the t_2 interval. Reinforcement rate, therefore, can be considered the product of two factors, rate of initiation of $\bar{R} > t_2$ components and proportion of initiated $\bar{R} > t_2$ components which actually terminated with reinforcement: $RFT/\min = \bar{R} > t_2$ components / $\min \times RFT/\bar{R} > t_2$ components. The functions for rate of initiation of $\bar{R} > t_2$ components

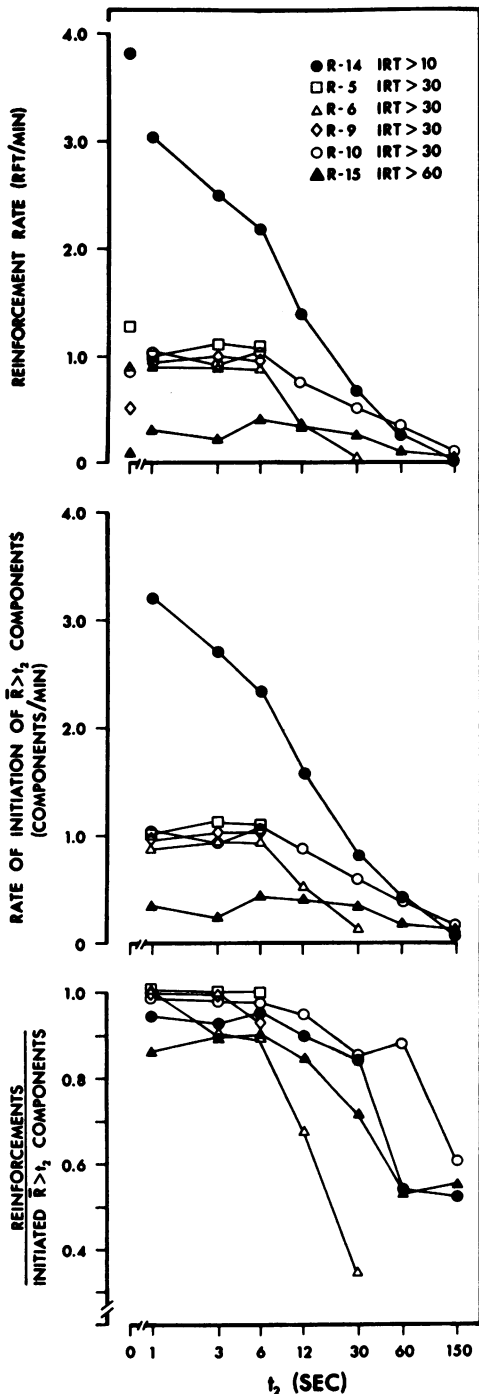


Fig. 6. Effects of varying the parameter of the $\bar{R} > t_2$ component schedule on: reinforcement rate (upper panel); rate of initiation of $\bar{R} > t_2$ components (middle panel); ratio of reinforcements per initiated $\bar{R} > t_2$ components (lower panel). The three measures are related according to the equation: $RFT/min = \bar{R} > t_2$ components/min \times $RFT/\bar{R} > t_2$ components. Each data point represents the mean of the last 10 sessions

(Figure 6; middle panel) closely paralleled the reinforcement-rate functions. The ratio of reinforcements per initiated $\bar{R} > t_2$ components (Figure 6; lower panel) was generally less sensitive to variations in the value of t_2 than rate of initiation of $\bar{R} > t_2$ components, and did not differ systematically depending on the parameter of the IRT $> t$ schedules. Of the two factors, rate of initiation of $\bar{R} > t_2$ components was the more important determinant of reinforcement rate.

Since maximum reinforcement rate was the reciprocal of the sum of the parameter values of the two-component schedules, the reinforcement rate functions (Figure 6; upper panel) not only reflected differences or changes in responding, but also differences or changes in maximum reinforcement rate. Therefore, the contribution of the temporal distribution of responses to the reinforcement-rate functions is best examined by considering the ratio of reinforcement rate to maximum reinforcement rate. This variable describes the same interaction between responding and the parameters of the procedure that reinforcement rate describes, but it *can* vary within a constant range (0 to 1.0) independently of the parameters of the procedure. Empirically, the ratio of reinforcement rate to maximum reinforcement rate was not independent of the parameters of the procedure. At $t_2 = 0$ sec, the value of the ratio was inversely related to the IRT $> t_1$ schedule parameter (Figure 7). In subjects for which the ratio value at $t_2 = 0$ sec was relatively low (Rat 15 and Rat 9), short and intermediate values of t_2 produced substantial increases in the ratio value. As the ratio value at $t_2 = 0$ increased, the magnitude of the increases produced by short and intermediate values of t_2 decreased. The longer $\bar{R} > t_2$ requirements tended to decrease the value of the ratio. For Rat 15, however, the value of the ratio was increased by all values of t_2 greater than 0 sec.

The effects of increasing t_2 on the relative frequency distributions of IRTs were qualitatively similar among subjects. Relative fre-

under each condition. For Rats 6, 10, 14, and 15, the points at $t_2 = 0$ sec represent the mean of the last 10 sessions from two determinations. The standard deviation corresponding to each data point was generally less than 15% of mean (less than 20% of mean for Rat 15) for $t_2 < 30$ sec, and generally less than 30% of mean for $t_2 \geq 30$ sec.

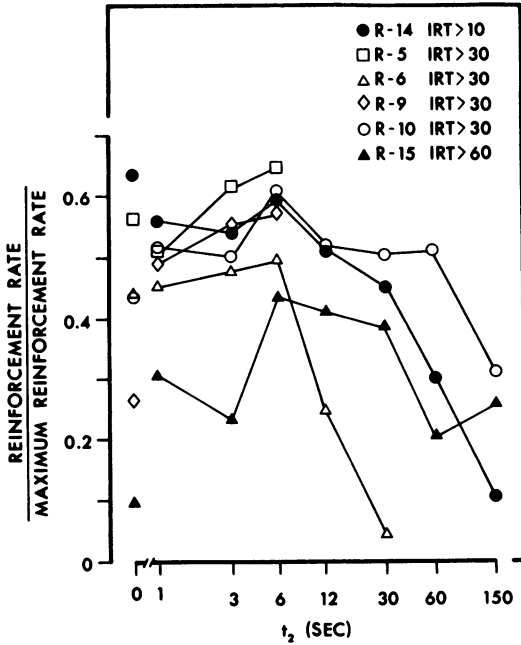


Fig. 7. Effects of varying the parameter of the $\bar{R} > t_2$ component schedule (X-axis, log scale) on the ratio of actual reinforcement rate to maximum reinforcement rate. Each point represents the mean of the last 10 sessions under each condition. For Rats 6, 10, 14, and 15, the points at $t_2 = 0$ sec represent the mean of the last 10 sessions from two determinations. The standard deviation corresponding to each data point was less than 15% of mean (less than 20% of mean for Rat 15) for $t_2 < 30$ sec and generally less than 30% of mean for $t_2 \geq 30$ sec.

quency distributions of IRTs for Rat 10 are displayed in Figure 8. Short and intermediate values of t_2 produced decreases in the relative frequency of very short IRTs, shifted the central peak of the distributions towards longer IRT categories, and produced small increases in the relative frequency of very long IRTs. The longer values of t_2 resulted in progressively more-uniform distributions, and

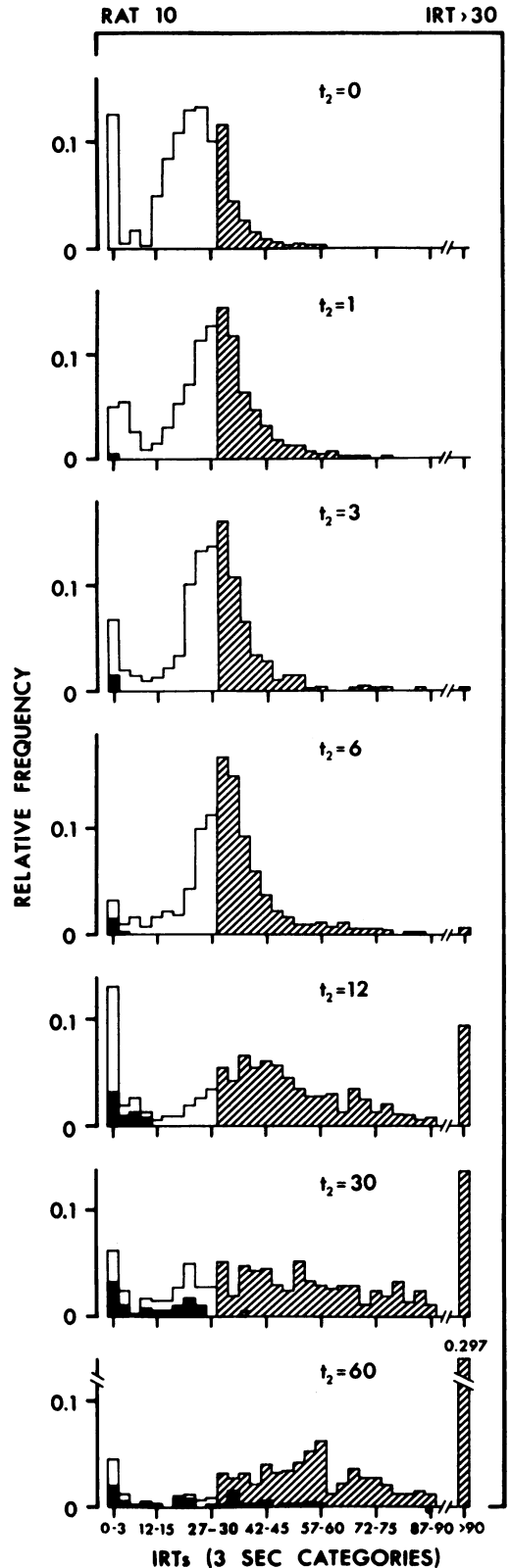


Fig. 8. Effects of varying the parameter of the $\bar{R} > t_2$ component schedule (t_2) on the relative frequency distribution of IRTs. X-axis: IRT in 3-sec categories. Y-axis: relative frequency. The height of each column represents the value of the ratio of the number of IRTs in a given category to the total number of IRTs in all categories. Unshaded columns correspond to IRTs shorter than the parameter of the IRT > t_1 component schedule, *i.e.*, 30 sec. Shaded columns correspond to IRTs greater than 30 sec. Black columns correspond to IRTs during $\bar{R} > t_2$ component schedule. Each complete distribution is based on approximately 500 IRTs.

substantial proportions of very long IRTs. Changes in the distribution of IRTs during the $\bar{R} > t_2$ component paralleled the changes in the distribution of IRTs in the corresponding categories during the $IRT > t_1$ component.

The cumulative response records displayed in Figures 9, 10, and 11 show that decreases in response rate as t_2 was increased reflected a gradual decrease in the absolute frequency of short and intermediate IRTs, and the occurrence of progressively longer IRTs. Very long pauses from responding and brief episodes of responding at a high rate were characteristic of performance with $t_2 = 150$ sec ($t_2 = 30$ sec for Rat 6) and under extinction (Rat 14, Rat 15).

Occasional observation of the subjects during the sessions did not reveal regular patterns of behavior when the subject was not lever pressing. Easily identifiable activities, such as grooming, sniffing around the corners of the chamber, gnawing the metal screen, circling, and remaining still in front of the dipper

opening occurred with different frequencies among the subjects. Within subjects, these activities did not appear to occur reliably during the interresponse times, especially when the $\bar{R} > t_2$ requirement was long.

DISCUSSION

The major effect of the $\bar{R} > t_2$ requirement on responding was to decrease response rate during the $IRT > t_1$ component schedule. Response rate during the $\bar{R} > t_2$ component did not change in a consistent fashion as t_2 was varied, and did not contribute substantially to overall response rate. Even when t_2 was large relative to t_1 , the $IRT > t_1$ component was in effect for the greater part of each session, and responding during the $IRT > t_1$ component accounted for most responses that occurred during the sessions. Response rate during the $IRT > t_1$ component schedule decreased monotonically as t_2 increased. The

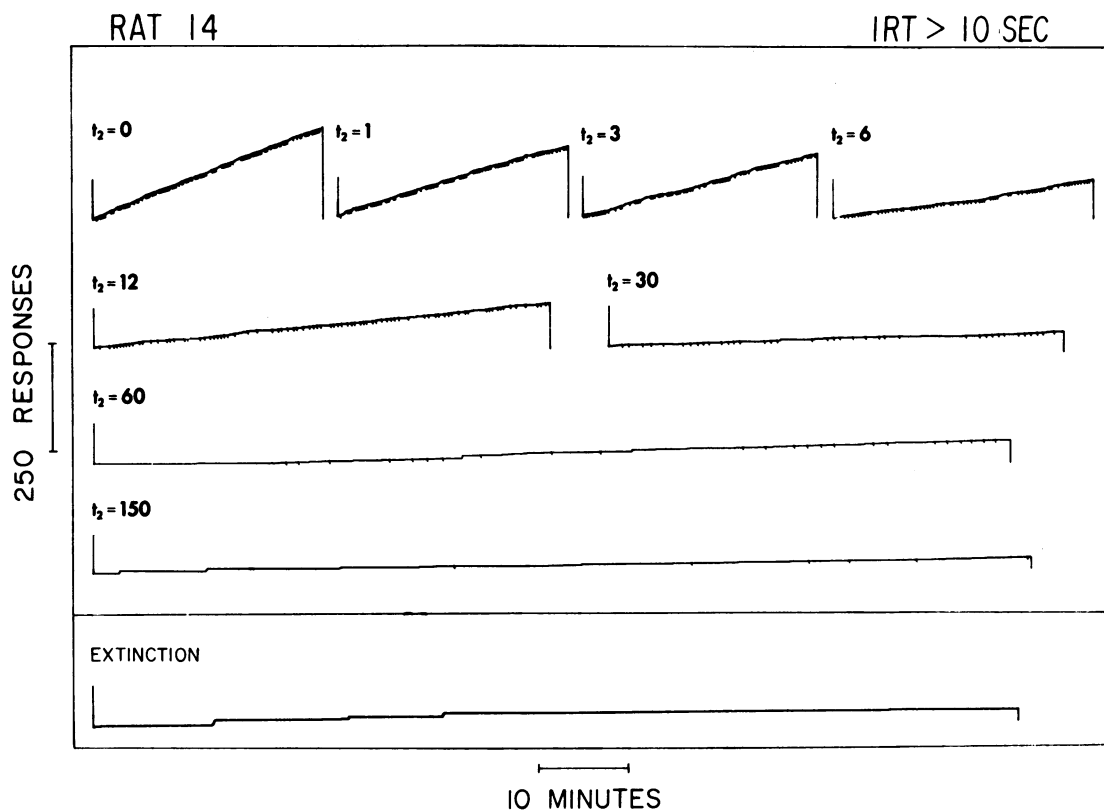


Fig. 9. Performance of Rat 14 under each experimental condition. X-axis: time. Y-axis: cumulative number of responses. Each record shows the complete final session under each condition. Short diagonal strokes indicate water presentations. Responding was stable within sessions under all but the largest values of t_2 , and extinction.

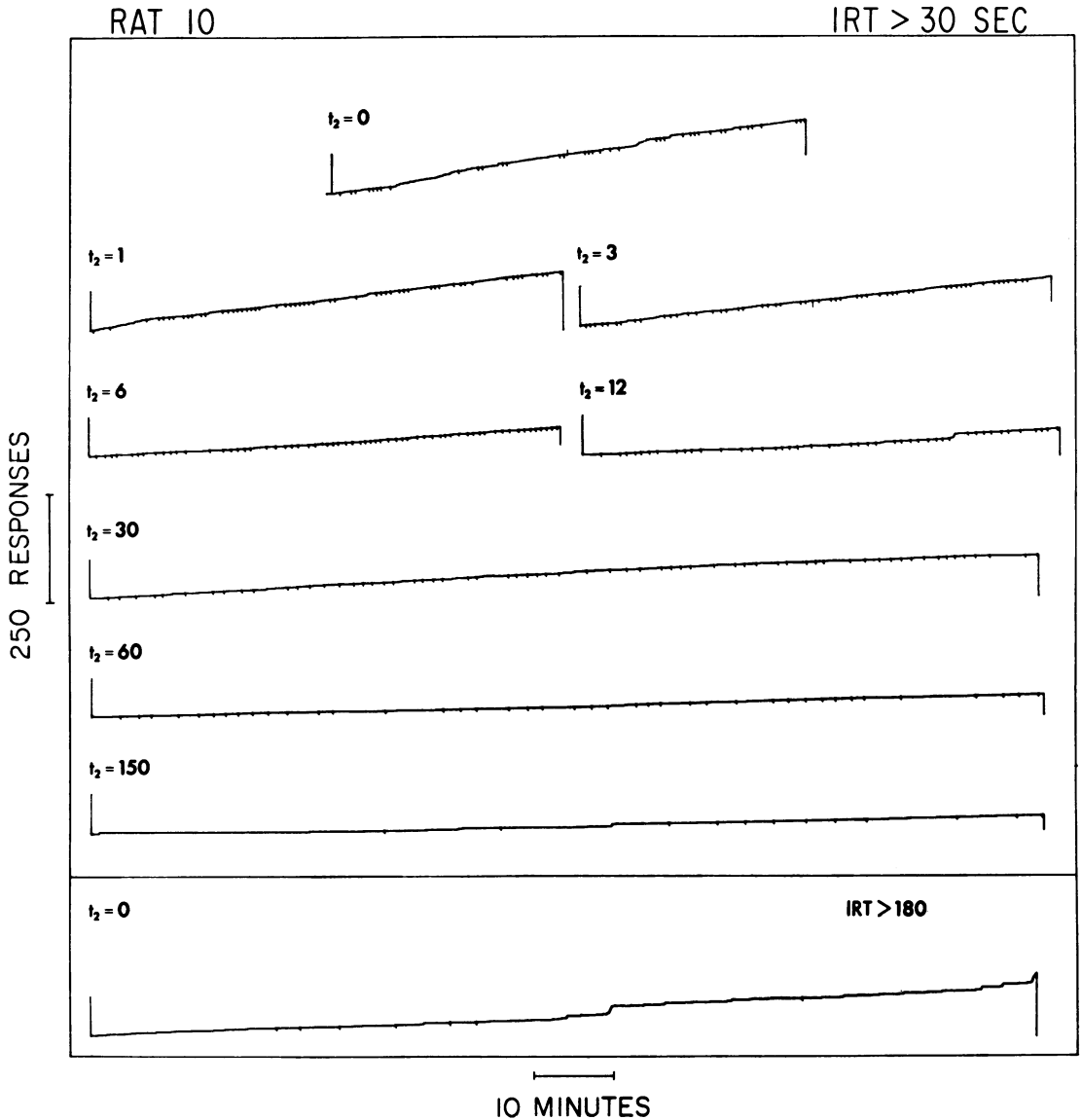


Fig. 10. Performance of Rat 10 under each experimental condition. Recordings as in Figure 9.

magnitude of the rate decrease was approximately proportional to the subject's response rate under the $IRT > t_1$ schedule with $t_2 = 0$ sec. This relationship was true with subjects that responded at similar rates under different $IRT > t_1$ schedules (e.g., Rat 15 and Rat 10), and also with subjects that responded at different rates under different $IRT > t_1$ schedules (e.g., Rat 10 and Rat 14). Therefore, the effect of the $\bar{R} > t_2$ requirement on response rate was independent of the value of t_1 .

Response rate during the $IRT > t_1$ component was also relatively independent of rein-

forcement rate. Whereas response rate always decreased as t_2 increased, the form of the functions relating reinforcement rate to the value of t_2 ranged from monotonically decreasing to inverted U-shaped. In Rats 5, 6, 9, 10, and 15, short and intermediate values of t_2 that either increased or did not affect reinforcement rate, produced substantial decreases in response rate. Furthermore, when actual reinforcement rates and maximum reinforcement rates were matched across two procedures, one that did not involve the $\bar{R} > t_1$ component schedule (Rat 6 under $IRT > 60$ sec with $t_2 = 0$; Rat 10

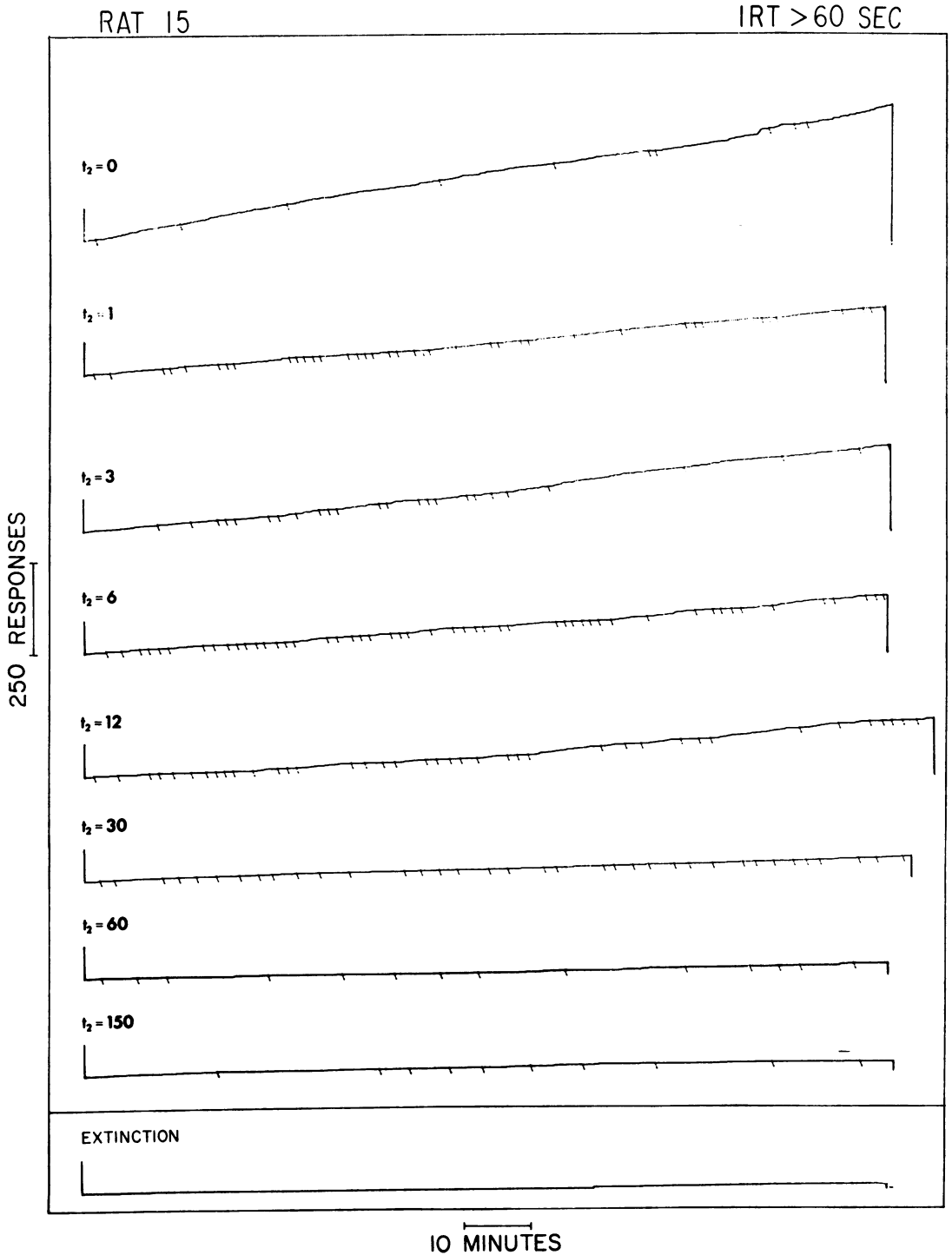


Fig. 11. Performance of Rat 15 under each experimental condition. Recordings as in Figure 9.

under IRT > 180 sec with $t_2 = 0$) and the other one involving the $\bar{R} > t_2$ component schedule (Rat 6 under IRT > 30 sec with $t_2 = 30$ sec;

Rat 10 under IRT > 30 sec with $t_2 = 150$ sec), response rates were much higher under the former (Table 1). Thus, it is clear that neither

actual nor potential rates of reinforcement were as important as the $\bar{R} > t_2$ requirement in determining decreases in response rate.

The proportionality between the magnitude of the rate-decreasing effect of delay of reinforcement and the response rate at $t_2 = 0$ (Figure 5) was previously reported by Skinner (1938, pp. 139-150). This relationship is reminiscent of the Law of Initial Value (Wilder, 1967) and of its counterpart in behavioral pharmacology, the Rate Dependency Hypothesis (Dews, 1958, 1964; Kelleher and Morse, 1968). Since the scale on the X-axis in Figure 5 is logarithmic, it is clear that the functions displayed in that figure are negatively decelerating. Other studies involving the $\bar{R} > t_2$ schedule as a delay-of-reinforcement procedure (Azzi *et al.*, 1964; Dews, 1960; Skinner, 1939, pp. 139-150) have also obtained negatively decelerating functions relating response rate to the value of t_2 . Data from the present study are described moderately well by an exponential equation of the form

$$\frac{R}{R_0} = (1 - k) e^{-ct_2} + k \quad (0 \leq k < 1; c > 0)$$

where R is response rate during $IRT > t_1$, R_0 is response rate at $t_2 = 0$ sec, and k and c are constants. Similar equations were suggested by Hull (1943, pp. 135-164) to describe data from early delay of reinforcement studies (*e.g.*, Perin, 1943*a, b*; Wolfe, 1934). Chung (1965) also found that exponential functions adequately fit his data on the effects of delay of reinforcement on responding under a concurrent schedule. It is not clear how other formulations that have been suggested for the description of the effects of delay of reinforcement (*e.g.*, Chung and Herrnstein, 1967) could be applied to the present results. Much more data on the effects of different delay-of-reinforcement procedures are a prerequisite for the development of accurate mathematical models of sufficient generalizability to render them useful.

Reinforcement rate was the product of the rate of initiation of $\bar{R} > t_2$ components and the proportion of initiated $\bar{R} > t_2$ components that actually terminated with reinforcement. For the most part, changes in reinforcement rate as t_2 was varied reflected changes in rate of initiation of $\bar{R} > t_2$ components. This same relation was obtained with three different $IRT > t_1$ schedules, indicating that the result

was independent of the value of t_1 . Since maximum reinforcement rate was inversely related to the values of t_1 and t_2 , decreases in reinforcement rate as either parameter increased were partly due to decreases in maximum reinforcement rate. Reinforcement rate and maximum reinforcement rate, however, did not covary perfectly. The ratio of reinforcement rate to maximum reinforcement rate would have been a constant fraction, given perfect covariation. Instead, the value of this ratio changed as the parameters of the procedure were varied. The forms of the functions relating the value of t_2 and the value of the ratio of reinforcement rate to maximum reinforcement rate differed, depending on the value of this ratio at $t_2 = 0$ sec. If the ratio of reinforcement rate to maximum reinforcement rate was low at $t_2 = 0$ sec, short and intermediate delays substantially increased its value; but if the value of this ratio was initially high, short and intermediate delays had little effect.

The ratio of reinforcement rate to maximum reinforcement rate can be considered a measure of the "efficiency" of performance, since it represents the proportion of reinforcements produced to the maximum possible number that could have been produced. It is clear that the ratio of reinforcements to responses (obtainable from data presented in Table 1), which is a more common measure of efficiency, was affected in similar fashion as the ratio of reinforcement rate to maximum reinforcement rate by changes in the value of t_2 . Thus, the results indicate that "inefficient" performances under $IRT > t$ schedules can be made more efficient by appropriately scheduling a brief delay of reinforcement.

As is the case with other independent variables (*e.g.*, intermittency of reinforcement, electric shock, drugs), the effects of delay of reinforcement depend on the experimental procedure. Ferster (1953) and Ferster and Hammer (1965) have shown that substantial rates of responding can be maintained under simple schedules with prolonged delays of reinforcement if a distinctive stimulus is correlated with the delay interval. On the other hand, Chung (1965) and Chung and Herrnstein (1967) varied delay of reinforcement for responses occurring on one of two response keys under a concurrent variable-interval variable-interval schedule. Although a distinc-

tive stimulus (blackout) was correlated with the delay interval, the relative frequency of responding on the delay-of-reinforcement key decreased rapidly as delay of reinforcement increased. Dews (1960) showed that response rates tend to be much lower if responses re-initiate the delay interval than if responses during the interval have no scheduled consequences. But, Pierce, Hanford, and Zimmerman (1972) found that delay of reinforcement had similar rate-decreasing effects independently of whether or not responses re-initiated the delay interval if a distinctive stimulus was correlated with the delay interval. Thus, it is clear that different characteristics of the procedure interact to determine the effects of delay of reinforcement. In this experiment, there was no distinctive stimulus correlated with the delay interval (t_2), and responses during the delay interval re-instated the $IRT > t_1$ component schedule. Both features were probably essential for the results. Schoenfeld and Farmer (1970) did not obtain consistent decreases in the response rate of rats under a tandem $IRT > t_1, \bar{R} > t_2$ schedule as t_2 was increased. Under their procedure, however, responses during the $\bar{R} > t_2$ component re-initiated the t_2 interval but not the $IRT > t_1$ requirement; therefore, sequences of short IRTs could and did immediately precede the periods of no responding required for reinforcement. In the present experiment, of course, only IRTs that met the $IRT > t_1$ schedule requirement could be followed by presentation of the reinforcer. The different contingencies under the two procedures probably account for the different results.

The present experiment did not attempt to assess the relative importance of possible underlying determinants of the results, such as: (1) reinforcement of behaviors incompatible with lever pressing, or (2) decreased "response-strengthening" effect of water presentation on lever pressing due to increased temporal separation between the two events. Either of these presumed mechanisms could account for the observed decreases in response rate as t_2 was increased. It should be noted, however, that although easily identifiable collateral behaviors occurred during all phases of the experiment, there was no obvious pattern to their occurrence. Furthermore, the behavior of each subject away from the response lever appeared to become more irregular as t_2 was increased.

Thus, it was not apparent that specific sequences of behaviors other than lever pressing were reinforced. Given the very clear and orderly relation between lever pressing and the parameters of the procedures, the possible occurrence of indistinct sequences of other behaviors is of secondary importance.

In summary, the $\bar{R} > t_2$ requirement substantially decreased response rate. The absolute magnitude of the decreases depended on the value of t_2 , and also appeared to depend on the subject's response rate when $t_2 = 0$ sec. The effects appeared to be independent of the parameter value of the $IRT > t_1$ component schedule and of the rate of reinforcement. It would be of considerable importance if the observed dependence between the magnitude of the effects and the initial response rates was also true for other schedules and delay-of-reinforcement procedures. After all, it is reasonable to assume that quantitative formulations of the effects of an independent variable should take into account the initial baseline level. The generalizability of the present results across species should also be tested. Pigeons, for example, usually respond at much higher rates than rats under $IRT > t$ schedules, and produce far fewer reinforcements. It would be of interest if, given the differences in initial performance between rats and pigeons, the same effects of the $\bar{R} > t_2$ requirement were obtained.

REFERENCES

- Azzi, R., Fix, D. S. R., Keller, F. S., and Rocha e Silva, R. R. Exteroceptive control of response under delayed reinforcement. *Journal of the Experimental Analysis of Behavior*, 1964, 7, 159-162.
- Chung, S. H. Effects of delayed reinforcement in a concurrent situation. *Journal of the Experimental Analysis of Behavior*, 1965, 8, 439-444.
- Chung, S. H. and Herrnstein, R. J. Choice and delay or reinforcement. *Journal of the Experimental Analysis of Behavior*, 1967, 10, 67-74.
- Dews, P. B. Analysis of the effects of pharmacological agents in behavioral terms. *Federation Proceedings*, 1958, 17, 1024-1030.
- Dews, P. B. Free operant behavior under conditions of delayed reinforcement: I. CRF-type schedules. *Journal of the Experimental Analysis of Behavior*, 1960, 3, 221-234.
- Dews, P. B. A behavioral effect of amobarbital. *Naunyn-Schmiedeberg's Arch. Pharmakol.* 1964, 248, 296-307.
- Ferster, C. B. Sustained behavior under delayed reinforcement. *Journal of Experimental Psychology*, 1953, 45, 218-224.
- Ferster, C. B. and Hammer, C. Variables determining

- the effects of delay in reinforcement. *Journal of the Experimental Analysis of Behavior*, 1965, 8, 243-254.
- Hull, C. L. *Principles of behavior: an introduction to behavior theory*. New York: Appleton-Century-Crofts, 1943.
- Kelleher, R. T. and Morse, W. H. Determinants of the specificity of behavioral effects of drugs. *Ergebnisse der Physiologie*, 1968, 60, 1-56.
- Morgan, M. J. Fixed-ratio performance under conditions of delayed reinforcement. *Journal of the Experimental Analysis of Behavior*, 1972, 17, 95-98.
- Perin, C. T. The effect of delayed reinforcement upon differentiation of bar responses in white rats. *Journal of Experimental Psychology*, 1943, 32, 95-109. (a)
- Perin, C. T. A quantitative investigation of the delay of reinforcement gradient. *Journal of Experimental Psychology*, 1943, 32, 37-51. (b)
- Pierce, C. H., Hanford, P. V., and Zimmerman, J. Effects of different delay of reinforcement procedures on variable-interval responding. *Journal of the Experimental Analysis of Behavior*, 1972, 18, 141-146.
- Richardson, W. K. and Loughhead, T. E. Behavior under large values of the differential-reinforcement-of-low-rate schedule. *Journal of the Experimental Analysis of Behavior*, 1974, 22, 121-129.
- Schoenfeld, W. N. and Farmer, J. Reinforcement schedules and the "behavior stream". In W. N. Schoenfeld (Ed.), *The theory of reinforcement schedules*. New York: Appleton-Century-Crofts, 1970.
- Silver, M. P. and Pierce, C. H. Contingent and non-contingent response rates as a function of delay of reinforcement. *Psychonomic Science*, 1969, 14, 231-232.
- Skinner, B. F. *The behavior of organisms*. New York: Appleton-Century-Crofts, 1938.
- Staddon, J. E. R. Some properties of spaced responding in pigeons. *Journal of the Experimental Analysis of Behavior*, 1965, 8, 19-27.
- Wilder, J. *Stimulus and response: The law of initial value*. Bristol: John Wright and Sons, Ltd., 1967.
- Wilson, M. P. and Keller, F. S. On the selective reinforcement of spaced responses. *Journal of Comparative and Physiological Psychology*, 1953, 46, 190-193.
- Wolfe, J. B. The effect of delayed reward upon learning in the white rat. *Journal of Comparative Psychology*, 1934, 17, 1-21.
- Zeiler, M. D. Schedules of reinforcement: the controlling variables. In W. K. Honig and J. E. R. Staddon (Eds.), *Handbook of operant behavior*. New York: Prentice Hall, 1976. (In press).

Received 15 September 1975.

(Final Acceptance 16 April 1976.)