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THE EFFECTS OF DELAYED REINFORCEMENT ON FREE-OPERANT RESPONDING

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In previous studies of delayed reinforcement, response rate has been found to vary inversely with the response-reinforcer interval. However, in all of these studies the independent variable, response-reinforcer time, was confounded with the number of reinforcers presented in a fixed period of time (reinforcer frequency). In the present study, the frequency of available reinforcers was held constant, while temporal separation between response and reinforcer was independently manipulated. A repeating time cycle, T, was divided into two alternating time periods, t^{D} and t^{Δ}. The first response in t^{D} was reinforced at the end of the prevailing T cycle and extinction prevailed in t^{Δ}. Two placements for t^{D} were defined, an early t^{D} placement in which t^{D} precedes t^{Δ} and a late t^{D} placement in which t^{D} follows t^{Δ}. The duration of the early and late t^{D} was systematically decreased from 30 seconds (i.e., $t^{D} = T$) to 0.1 second. Manipulation of t^{D} placement and duration controlled the temporal separation between response and reinforcement, but it did not affect the frequency of programmed reinforcers, which was $1/T$. The results show that early and late t^{D} placements of equal duration have similar overall effects upon response rate, reinforcer frequency, responses per reinforcer, and obtained response-reinforcer temporal separation. A stepwise regression analysis using log response rate as the dependent variable showed that the obtained delay was a significant first-step variable for six of eight subjects, with obtained reinforcer frequency significant for the remaining two subjects.

Key words: variable-delay schedules of reinforcement, reinforcement delay, delay-reduction hypothesis, key peck, pigeons

In immediate reinforcement procedures, a criterion response is followed immediately by a reinforcer. Delayed reinforcement procedures introduce some temporal separation between the reinforced response and the reinforcer. Delayed reinforcement procedures have generally been found to be less effective in maintaining control of behavior than have immediate reinforcement procedures. In addition, the consistent detrimental effect of delay has been the basis for a number of theoretical analyses of behavior. Reports of decreased behavioral control by delayed reinforcement in trial-by-trial research date back to Hunter (1913) and have been reviewed by Renner (1964) and by Tarpy and Sawabini (1974). In trial-by-trial self-control experiments, in which the reinforcer frequency is controlled by trial duration and separation, subjects preferred immediate or short delays preceding short access to reward over longer delays which preceded longer access to reward (e.g., Rachlin & Green, 1972; see also Ainslie, 1975). There is an inverse relationship between response rate and delay in single-key free-operant procedures (e.g., Dews, 1960; Pierce, Hanford, & Zimmerman, 1972; Sizemore & Lattal, 1978; Skinner, 1938), and between response rate on a delay key and delay in concurrent reinforcement schedules (Chung, 1965; Chung & Herrnstein, 1967; Hursh & Fantino, 1973). In choice procedures, switching to a delay condition occurred less often the longer the delay (Shull, Spear, & Bryson, 1981). Delayed punishment has been found less effective than immediate punishment (e.g., Baron, Kaufman, & Fazzini, 1969).

Theoretical systems (e.g., Hull, 1932; Spence, 1947) that were based on delayed-reinforcement research postulated maximal control of

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the responses that were temporally proximal to reinforcement. The goal-gradient hypothesis is one famous example. In fact, in those experiments in which delayed and immediate reinforcement generated equivalent control, the control by delayed reinforcement was attributed to secondary reinforcement that counteracted the detrimental behavioral effects of delaying the reinforcer (e.g., Hull, 1943; Kimble, 1961; Lawrence & Hommel, 1961; Perin, 1943a, 1943b; Perkins, 1947; Wolfe, 1934). As a basis for his theoretical analysis of impulsiveness and impulse control, Ainslie (1975) stated that "delaying rewards from the moment of choice causes them to lose effectiveness according to a highly concave function of that delay" (p. 463).

One might conclude from the delay literature that the temporal separation of the reinforced response from the reinforcer is the primary controlling variable of the conditioned behavior. However, no straightforward analysis of the relationship between response-reinforcer (R-S^{R}) interval with response rate is possible, because in all single-operant delay studies the minimum interreinforcement time, and thus the frequency of reinforcement, has covaried with the R-S^{R} interval. Even in choice procedures, imposing a delay obviously increases the minimum interreinforcement time for the delay condition, but also increased delay decreases the overall reinforcer frequency, provided the subject samples the delay condition. Because reinforcer frequency has been shown to control response rate (Catania & Reynolds, 1968; Clark, 1958; Findley, 1958; Wilson, 1954), interpretation of the delay literature cannot rule out the possibility that the diminished rate of behavior produced by increasing R-S^{R} delay may be the result of a concomitant reduction in reinforcer frequency. Furthermore, the relationship between response rate and delayed reinforcer frequency cannot be assessed because the pertinent delay literature, with one notable exception (Williams, 1976), does not report the reinforcer frequency. In addition, it is impossible to regenerate the reinforcer frequencies from either the independent variables or the data which are reported.

In the present study, a procedure was developed that permitted separate analysis of the effects of reinforcer delay and reinforcer frequency. To maintain compatibility with the delay literature, three procedural elements common to delay procedures were incorporated into the present procedure: (1) a method to select a response for reinforcement, (2) a temporal separation between criterion responses and the reinforcer, and (3) response-contingent reinforcement. Unlike the previous procedures, the present procedure permitted variation in the temporal separation between the response selected for reinforcement and the reinforcer without covariation in the programmed reinforcer frequency.

To meet all these criteria, a modified version of the *t*-system (Schoenfeld & Cole, 1972) was used. In the present version a repeating time cycle, T, was divided into two alternating time periods, t^{D} and t^{Δ}. The original *t*-system provided immediate reinforcement for the first response in t^{D}. In the present modification the first response in t^{D} was selected for response-contingent reinforcement, which occurred at the end of the prevailing T cycle. When t^{D} duration is less than T cycle length, this modification allows t^{D} to be moved to any placement within the T cycle, in turn varying the temporal separation between the response selected in t^{D} for reinforcement and the reinforcer (see Figure 1). This type of reinforcement schedule was named "variable delay" by Schoenfeld, Cole, Lang, and Mankoff (1973) because the last response in a T cycle may occur with any temporal separation between 0.0 and T from reinforcement. Given that the subject places one response in each t^{D}, reinforcement occurred at the same temporal position in all T cycles. The maximum reinforcer frequency was 1/T (i.e., one reinforcer per unit

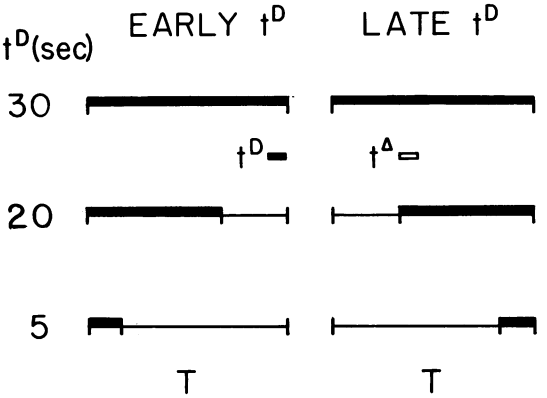

Fig. 1. Schematic representation of the early and late t^{D} placements for three values of t^{D}.

of time as defined by T) and was independent of t^{D} manipulations unless $t^{D} = 0$.

Different R-S^{R} relations are produced by the placements of t^{D} and t^{Δ} within the T cycle. If t^{D} precedes t^{Δ} (i.e., the early t^{D} placement), decreases in t^{D} duration increase the minimum duration between the reinforced response emitted in t^{D} and the reinforcer towards the limit of T seconds. In this operation the minimum temporal separation between the reinforced response and the reinforcer is equal to t^{Δ}. However, the obtained delay between the subject's last response and the reinforcer (i.e., the obtained R-S^{R} interval) could vary from 0 s to T s. This operation, diagrammed in Figure 1, can be described as a delay paradigm with a limited-hold and with no reset consequence for further responses.

If t^{D} follows t^{Δ} (i.e., the late t^{D} placement), decreases in t^{D} duration decrease the maximum response-reinforcer interval toward a limit of 0 s. The maximum temporal separation between the reinforced response occurring in t^{D} and the reinforcer is equal to t^{D}. As late t^{D} duration decreases, the probability increases that the reinforced response will also be the subject's last response. This second operation, also diagrammed in Figure 1, has no precedent in the literature; nevertheless, one may see that as t^{D} is decreased, immediate reinforcement (0-s delay) is approached.

The late t^{D} placement defines a maximum reinforced response-reinforcer delay and is a limited-hold replication of studies conducted by Sizemore and Lattal (1978) and Williams (1976). Williams (1976) introduced a 3-s delay in a variable-interval 2-min schedule and recorded a 75% decrease in response rate between the immediate reinforcement and 3-s delayed-reinforcement schedule. In addition there were slight but nonsignificant decreases in response rate as the programmed delay was increased from 3 s to 15 s. Sizemore and Lattal (1978) compared tandem variable-interval fixed-time against variable-interval and tandem variable-interval fixed-interval schedules with equivalent mean interreinforcement times. They replicated the inverse relationship between response rate and reinforced response-reinforcer delay, but they also showed that "obtained delay" (the dependent variable) was directly related to "nominal delay" (the independent variable). Because reinforcer frequency was equal in the control and delay conditions, the effect of delay on response rate appears to be well documented. In sum, increases in the programmed reinforced response-reinforcer delay produce increases in obtained delay and decreases in response rate.

The early t^{D} placement defines a minimum reinforced response-reinforcer delay, in contrast to Sizemore and Lattal (1978), Williams (1976), and the late t^{D} placement. Given the results reported in the previous two experiments and the delay literature in general, one would predict that the early t^{D} placement should generate effects different from the late t^{D} placement as the duration of t^{D} is decreased (see Figure 1). Specifically, early t^{D} placements should produce lower response rates relative to the late t^{D} placement, because as t^{D} duration decreases in the early placement, longer programmed reinforced response-reinforcer delays are produced. In addition, obtained R-S^{R} intervals should become longer in the early t^{D} placement but shorter in the late t^{D} placement.

The present experiment (1) provides a schedule framework within which one may evaluate the effect of reinforced response-reinforcer temporal separation independently from the effects of changes in the programmed reinforcer frequency, and (2) extends reported relationships between obtained delay, reinforcer frequency, and response rate with variations in either the minimum (i.e., the early t^{D} placement) or the maximum (i.e., the late t^{D} placement) programmed R-S^{R} temporal separation.

METHOD

Subjects

The subjects were eight experimentally naive female White Carneaux pigeons that were approximately four years old at the beginning of the experiment. Water and grit were continuously available throughout the experiment in the home cages. The subjects were maintained at 80% of their free-feeding weights.

Apparatus

One standard Lehigh Valley pigeon chamber (BRS/LVE Panel Model 141-16) was used in this experiment. The houselight and a white keylight were on throughout experimental sessions and off at all other times. Although the chamber had three translucent plastic response keys, only the center key was used. A static mass of 16 g was required to operate the switch behind the key. BRS digital logic devices controlled the experiment, and data were recorded by Sodeco impulse and printout counters.

Procedure

Five days after the subjects reached 80% of their free-feeding weights, the operant level of key pecking was measured in two 30-min sessions. In the third experimental session, hopper approach and key pecking were shaped. Reinforcement was 2.75-s access to mixed grain. The third session terminated after 100 reinforcers had been presented under a continuous schedule.

In all subsequent sessions, food presentations were arranged according to a modified *t*-system schedule (Schoenfeld & Cole, 1972). A repeating time cycle, T, was divided into two alternating time periods, t^{D} and t^{Δ}. t^{D} was that portion of T in which the first response was eligible for reinforcement at the end of the prevailing T cycle. Responses in t^{Δ} had no scheduled consequence. In the fourth session subjects were exposed to a schedule in which $\mathrm{T} = t^{\mathrm{D}} = 5$ s for 60 reinforcer presentations. T and t^{D} were increased by 5-s increments on each subsequent experimental day until $\mathrm{T} = t^{\mathrm{D}} = 30$ s was obtained. Subjects were exposed to this schedule for 30 sessions, the last ten of which were analyzed.

Subjects were then matched in four pairs according to overall rates of responding and visual examination of the temporal distributions of responses obtained under $\mathrm{T} = t^{\mathrm{D}} = 30$ s. One bird from each pair was randomly assigned to either an early t^{D} or late t^{D} placement. In the early t^{D} placement, t^{D} preceded t^{Δ} in the T cycle. In the late t^{D} placement, t^{D} followed t^{Δ} in the T cycle. The early t^{D} durations, in sequence of use, were 30.0, 25.0, 23.0, 20.0, 15.0, 10.0, 5.0, 2.5, 1.5, 0.5, 0.2, and 0.1 s. The late t^{D} durations were 30.0, 20.0, 15.0, 10.0, 5.0, 2.5, 1.5, 0.5, 0.2, and 0.1 s. T was maintained at 30 s throughout the experiment.

Subjects were exposed to each t^{D} (with the exception of the initial 30-s t^{D}) for a block of 15 experimental sessions. The first key peck also initiated the session counter, which terminated the session when 60 T cycles had been accumulated.

RESULTS

Generally, the effects produced by the early t^{D} placement were comparable to those produced by the late t^{D} placement. The overall direction of change on the dependent variables was determined by t^{D} duration regardless of its placement within the T cycle.

The absolute numbers of responses per 30-min session for early and late t^{D} subjects are presented in Table 1. Examination will reveal large absolute differences among subjects within and between groups for the number of responses emitted per session. For this reason a percentage baseline response rate was derived by dividing the average response rate at a given t^{D} by the average response rate maintained in the last ten baseline sessions ($t^{\mathrm{D}} = 30$ s). Figure 2 shows the percent baseline response rate for the four subjects in the early t^{D} and the four subjects in the late t^{D} placements. All subjects

Table 1

Individual subject and group means from the last ten sessions on each t^{D} duration for absolute number of responses per 30-min session for the four early and four late t^{D} subjects.

	Early t^{D} *Placement Subjects*					*Late* t^{D} *Placement Subjects*				
t^{D} *Duration*	*152E*	*153E*	*159E*	*160E*	*Mean*	*151L*	*156L*	*161L*	*455L*	*Mean*
30.0 s	650.7	400.8	359.6	102.7	378.00	238.2	363.5	109.0	568.2	319.73
25.0 s	617.0	287.6	267.2	81.1	313.23					
23.0 s	453.7	238.8	132.9	69.9	223.83					
20.0 s	743.9	351.2	116.1	88.0	324.80	269.8	352.0	122.2	1610.8	588.65
15.0 s	993.9	381.2	130.7	77.1	395.73	167.4	662.4	145.1	1930.3	726.3
10.0 s	787.4	354.4	194.6	83.7	355.03	282.5	866.4	192.4	2518.2	964.88
5.0 s	680.0	376.2	254.4	89.8	350.08	425.1	874.9	203.4	2321.2	956.15
2.5 s	1110.6	568.1	404.8	98.1	545.43	955.2	1539.3	292.1	2104.8	1222.88
1.5 s	1436.7	460.6	1072.9	118.7	772.23	722.3	1753.3	669.3	2349.2	1373.53
0.5 s	1512.7	606.3	1525.7	407.9	1013.15	1333.0	1776.7	1372.5	2276.6	1689.7
0.2 s	1828.8	1180.1	2107.8	875.7	1498.08	2375.3	2284.9	1751.5	2553.8	2241.28
0.1 s	1771.7	1052.7	1577.3	1628.5	1507.55	2567.9	2059.3	1932.9	2563.0	2280.78

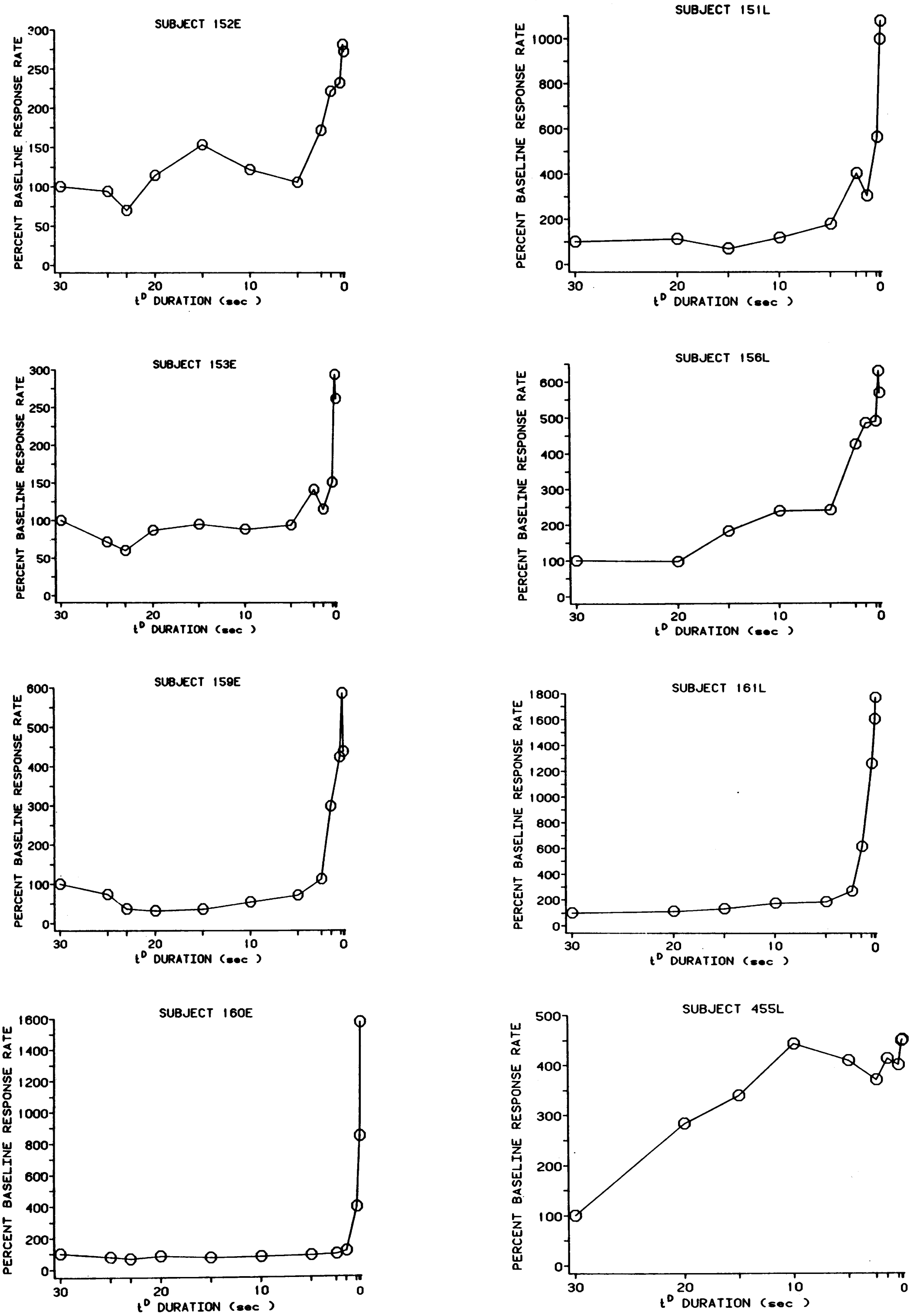

Fig. 2. Mean percent baseline response rate as a function of t^D duration for the four early and four late t^D placement subjects. The points plotted are means computed from the last ten sessions of each t^D placement group. The x-axis is labeled from 30.0 s to 0.1 s (left to right) because this order reflects the systematic decreases in t^D duration to which the subjects were exposed.

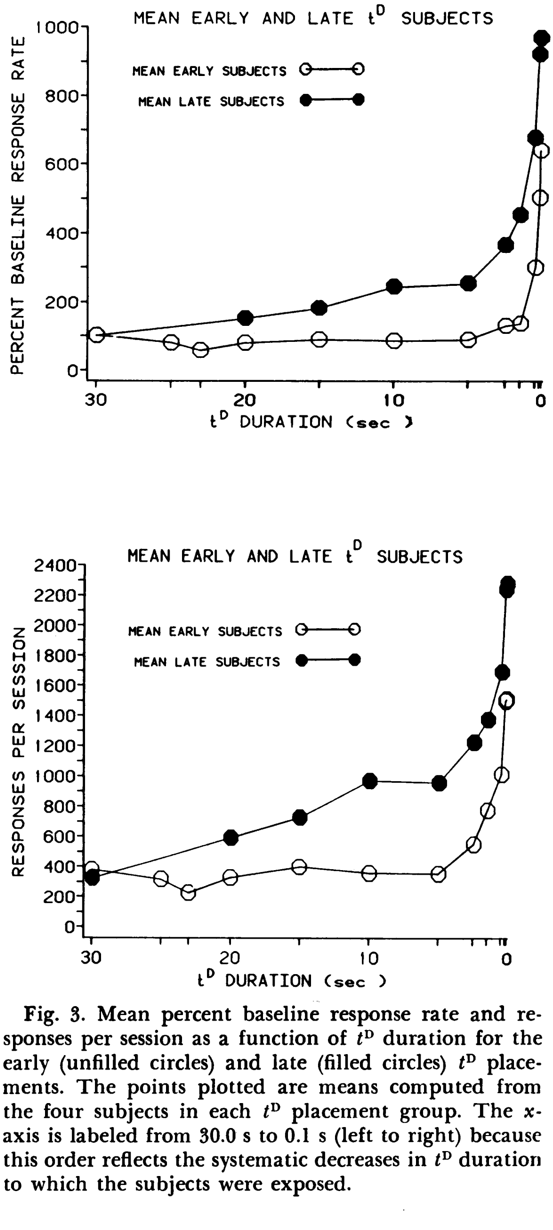

Fig. 3. Mean percent baseline response rate and responses per session as a function of t^D duration for the early (unfilled circles) and late (filled circles) t^D placements. The points plotted are means computed from the four subjects in each t^D placement group. The x-axis is labeled from 30.0 s to 0.1 s (left to right) because this order reflects the systematic decreases in t^D duration to which the subjects were exposed.

except 455L demonstrated positive growth functions in percent baseline response rate between $t^D = 2.5$ s and $t^D = 0.2$ s. The mean percentage baseline response rate and the average number of responses per session for the early t^D (unfilled circles) and for the late t^D (filled circles) placements are presented in Figure 3. Comparison of the two dependent variables within Figure 3 reveals that the percent baseline response rate transformation and the total responses per session both demonstrate similarly shaped functions and an inverse relationship with t^D duration. In a two-way analysis of variance, no evidence was found for rejecting the null hypothesis for equivalent main effects of early and late t^D placements on absolute response rate ($F_{1,6} = 2.25$; $p = .18$) nor on the t^D placement-duration interaction ($F_{9,54} = 1.3$; $p = .26$). However, the main effect for t^D duration was significant ($F_{9,54} = 23.83$; $p < .0001$).

Figure 4 shows that decreases in t^D duration decreased the reinforcer frequency as measured by the number of reinforcers received per session. Decreases in the duration of the early t^D produced a gradually declining function after $t^D = 20$ s for obtained reinforcers per session, whereas decreases in the late t^D duration did not affect the obtained number of reinforcers per session until 2.5 s, at which point a sharp decline began. Even though the independent variables were chosen so that the programmed reinforcer frequency could remain constant, the actual reinforcer frequency decreased. At all t^D durations and placements, given one response per t^D, reinforcer frequency would have remained at 1/T. In fact, as can be seen in the individual-subject graphs, subjects maintained 90% of their baseline reinforcer frequency for the first four t^D durations and two subjects (455L and 156L) maintained this performance until $t^D = 0.5$ s.

The obtained increase in percent baseline response rate and the decrease in reinforcement frequency combined to produce growth curves for the measure, responses per reinforcer (R/S^R), as seen in Figure 5. There was little difference between the mean R/S^R function for the early and late t^D placements.

As shown in Figure 6 the mean obtained response-reinforcer interval decreased as t^D duration decreased for the late t^D group. For the early t^D group, the same measure interval decreased after an increase at the intermediate t^D durations. For the plots of the individual subjects in Figure 6, unfilled symbols indicate a significant t-test difference ($p < .05$) from the individual subject's average obtained R-S^R time at $t^D = 0.1$ s. The apparent difference between the shape of the early and late t^D mean obtained R-S^R functions was not reflected in the other dependent variables, especially not in the rate measures (see Figures 2 and 3). Obtained R-S^R was, however, negatively correlated with response rate for six of the eight subjects.

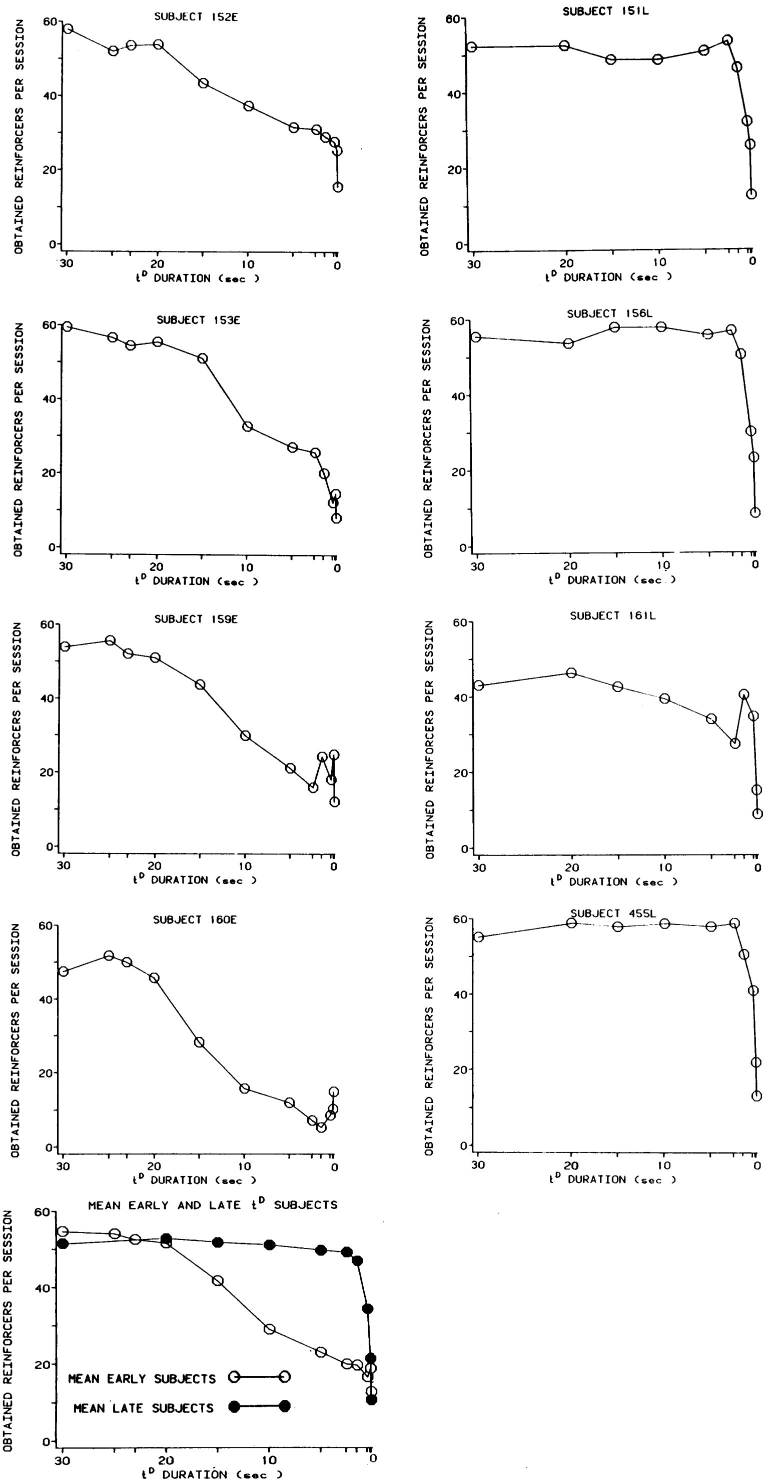

Fig. 4. Mean obtained reinforcers per session as a function of t^D duration for the four early and four late t^D placement subjects. In the bottom left panel the points plotted are means computed from the four subjects in the early t^D placement (unfilled circles) and the late t^D placement (filled circles). The x-axis is labeled from 30.0 s to 0.1 s (left to right) because this order reflects the systematic decreases in t^D duration to which the subjects were exposed.

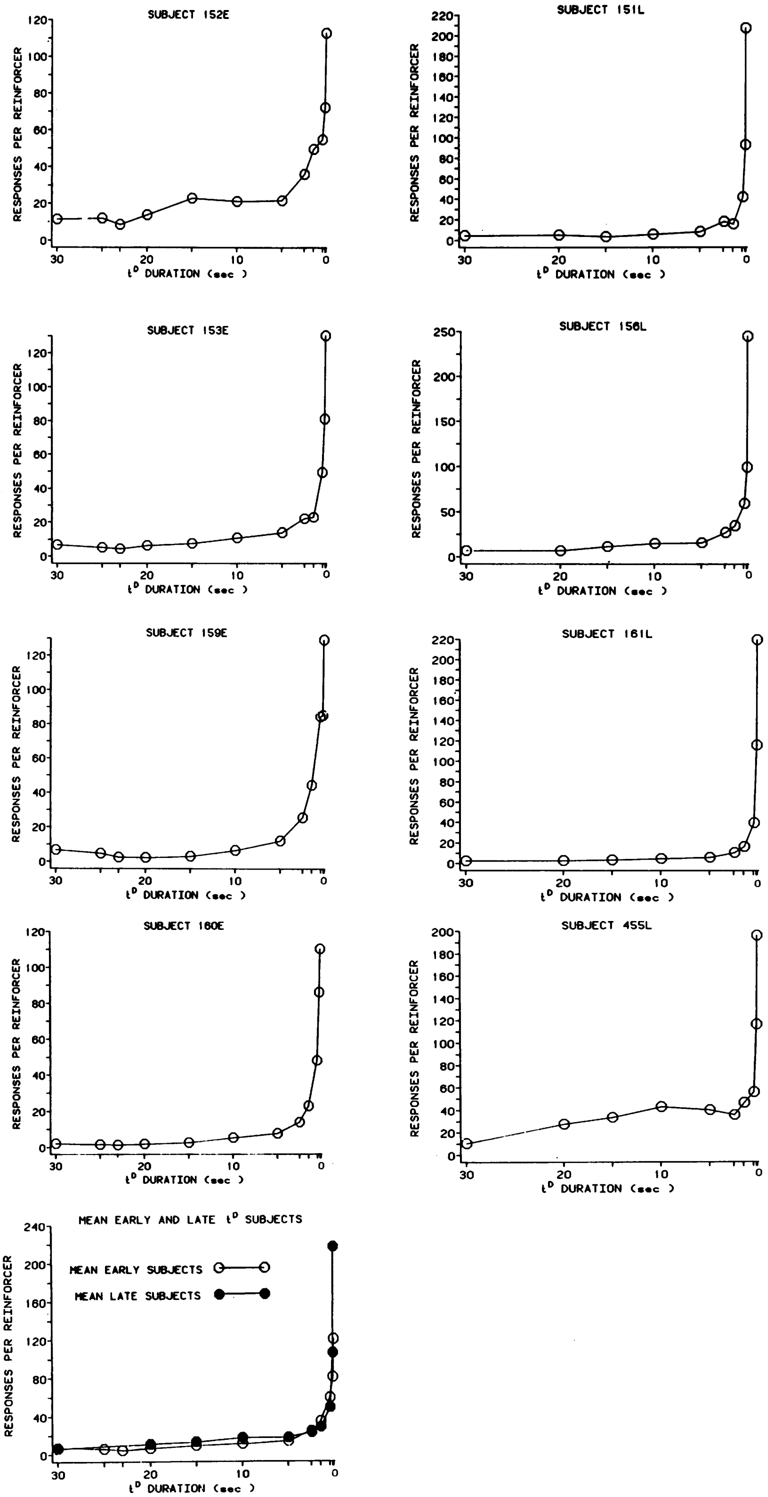

Fig. 5. Mean responses per reinforcer as a function of t^D duration for the four early and four late t^D placement subjects. In the bottom left panel the points plotted are means computed from the four subjects in the early t^D placement (unfilled circles) and the late t^D placement (filled circles). The x-axis is labeled from 30.0 s to 0.1 s (left to right) because this order reflects the systematic decreases in t^D duration to which the subjects were exposed.

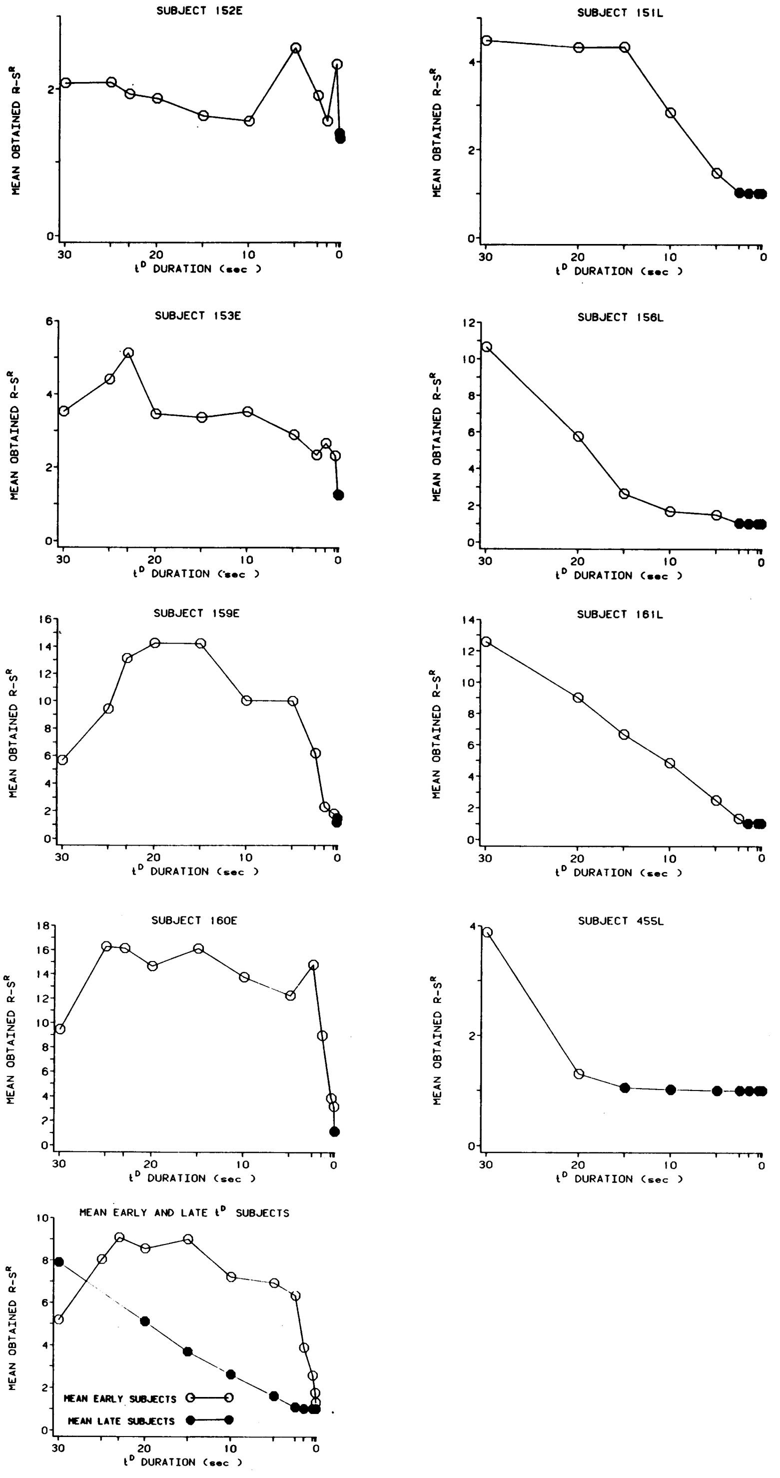

Fig. 6. Mean obtained R-S^R in seconds as a function of t^D duration for the four early and four late t^D placement subjects. In the bottom left panel the points plotted are means computed from the four subjects in the early t^D placement (unfilled circles) and the late t^D placement (filled circles). The x-axis is labeled from 30.0 s to 0.1 s (left to right) because this order reflects the systematic decreases in t^D duration to which the subjects were exposed.

Table 2

Multiple and stepwise regression for early and late t^D placement subjects. "D" is obtained delay and "S^R" is obtained reinforcer frequency, the two independent variables for log response rate in a two-independent-variable equation. Regression coefficients are presented to the right of each step variable's proportion of variance. See text for further explanation.

Early Subjects	R^2	$F_{2,9}$	*Step 1*	*Reg. Coef.*	$F_{1,10}$	*Step 2*	*Reg. Coef.*	$F_{1,9}$
152E	.879	15.33***	S^R .715	−.0112	25.10****	D .058	−.1341	2.294ns
153E	.957	49.36****	D .915	−.1850	108.20****	S^R .001	+.0007	.113ns
159E	.973	80.76****	D .943	−.0823	166.73****	S^R .004	−.0023	.648ns
160E	.928	27.71****	D .859	−.0795	61.10****	S^R .002	+.0009	.059ns
Mean Early	.953	45.19****	D .887	−.0767	78.12****	S^R .023	−.0037	2.277ns

Late Subjects	R^2	$F_{2,7}$	*Step 1*	*Reg. Coef.*	$F_{1,8}$	*Step 2*	*Reg. Coef.*	$F_{1,7}$
151L	.956	36.86****	D .728	−.1574	21.39***	S^R .185	−.0155	14.968**
156L	.910	16.96***	D .676	−.0645	16.66***	S^R .153	−.0071	6.275*
161L	.866	10.54**	S^R .619	−.0192	13.01**	D .131	−.0567	3.691ns
455L	.982	94.05****	D .943	−.2064	131.56****	S^R .021	−.0018	4.183ns
Mean Late	.992	224.01****	D .855	−.0851	47.10****	S^R .130	−.0075	59.06****

*$p < .05$.
**$p < .01$.
***$p < .005$.
****$p < .001$.

A multiple regression analysis was performed on the dependent variables of log response rate, obtained delay, and reinforcer frequency with the latter two dependent variables used as independent variables. In Table 2, *F* ratios and *p* levels for the multiple R^2 are presented; they were significant for all individual subjects as well as for the pooled data for early and late subjects. A stepwise regression was then performed to examine the contribution of obtained delay and/or reinforcer frequency to log response rate. In Table 2, Step 1 refers to the first variable selected (either obtained delay, D, or reinforcer frequency, S^R) and Step 2 refers to the second variable selected (D or S^R). Also shown for the selected step variable is the proportion of the variance of the log rate reduced with its corresponding *F* ratio and *p* level. The regression coefficient presented to the right of each step variable's proportion of variance is for the two-independent-variable fitted equation, also with log response rate as the dependent variable. Obtained delay was the first variable selected in the stepwise regression for three of four subjects in each t^D placement. For these subjects, reinforcer frequency was significant as a second-step variable for two of the late t^D subjects. For the remaining subject in each t^D placement (152E and 161L) where reinforcer frequency was the first-step variable selected, obtained delay was not significant as the second-step variable. It is interesting to note that these two subjects also had the lowest multiple R^2s.

DISCUSSION

In the past, all delayed reinforcement procedures have manipulated the interval between response and reinforcer ($R\text{-}S^R$) and, even though reinforcement frequencies were confounded with manipulations of delay, all behavioral effects have been attributed to the $R\text{-}S^R$ independent variable. The level of behavior that was maintained by delayed reinforcement was always assessed against that level maintained by immediate reinforcement or, at the other end of the continuum, extinction. Delay studies have generally reported that an increase in the $R\text{-}S^R$ interval produced a decrease in response rate that was accompanied by a decreased reinforcer frequency and an increased obtained delay between the last response and the reinforcer (Sizemore & Lattal, 1978; Williams, 1976). With programmed reinforcer frequency controlled, the degree to which the present results replicate previous delay findings depends upon whether one wants to consider "delay" as defined solely by the independent-variable manipulations or by the unique empirical relationship of obtained delay with other behavior measures. It may be simpler to commit oneself to one line of discussion; however, both have merit.

The t^D duration and placement independent variables in the present design provide for ranges of response-reinforcer temporal separations to occur which do not necessarily influence the availability of the programmed reinforcers. Based on previous delay studies, then, one would expect proximity of t^D placement to the reinforcer (see Figure 1) and decreases in early t^D duration to be directly related to response rate. On the other hand, since decreasing late t^D duration approaches immediate reinforcement as a limit, one would expect response rate to increase. There was no indication that long R-S^R temporal separations (i.e., the early t^D placement) produced less responding than short R-S^R temporal separations (i.e., the late t^D placement). Furthermore, the shapes of the responses per reinforcer, reinforcer frequency, and obtained R-S^R functions for the early and late t^D placements were similar. In sum, any differences between the data functions for the early and late t^D placements did not replicate the loss of behavioral control reported in delay experiments when R-S^R temporal separation was increased.

In the present results, all dependent variables were systematically related to variations in t^D duration rather than to variations in the defined R-S^R contingency as manipulated by t^D placement. Work reported by Clark (1959), Hearst (1958), and Schoenfeld, Cumming, and Hearst (1956) differed from the present experiment in that they used immediate reinforcement for the first response in t^D. The results for response rate, responses per reinforcer, and reinforcer frequency in the present experiment replicated the results of these t-system studies. One must further question the necessity of immediate reinforcement for maximal behavior control; not only were similar results obtained with either immediate or delayed reinforcement for the first response in t^D, but also there was little difference between the early and late t^D placements.

Using two different manipulations of response-reinforcer delay as an independent variable, the present research and Williams (1976) failed to replicate the well documented inverse relation between R-S^R delay and response rate. These are the only two experiments to date in which manipuations of the R-S^R delay did not confound with either the programmed or obtained reinforcer frequency. The detrimental effect of increased R-S^R delay can, therefore, be traced to its covariation with the programmed and/or obtained reinforcer frequency. Williams (1976) compared delays of 3, 8, and 15 s with approximately equal obtained reinforcer frequencies across those delays. There were no significant changes in response rate accompanying manipulations of delay. Although there were slight decreases in response rate as delay was increased, Williams' (1976) data do not support a conclusion that response rate decreases as delay increases inasmuch as those decreases were found to be nonsignificant (p. 444). In the present design, early and late t^D placements of equal duration had different programmed delays that did not affect the programmed reinforcer frequency. The present finding that early and late t^Ds of equal duration had slight but nonsignificant effects on response rate replicated Williams' (1976) findings. One would have to conclude, not only from the similar effects produced by the independent-variable manipulations of delay in the present study (i.e., early or late t^D placement), but also from Williams' nonsignificant effect of delay on response rate, that delay is not a potent independent variable when it does not covary either the programmed or obtained reinforcer frequency.

One might conclude that delay as an independent variable does not affect response rate. However, examination of the regression analysis (see Table 2) reveals the contribution of obtained delay (as distinct from programmed delay) as an "independent" variable to response rate. For six of eight subjects in a stepwise regression analysis, obtained delay was the first significant variable selected. The eight regression coefficients (including the two nonsignificant second-step effects) for obtained delay were negative, thus further replicating the inverse relationship between response rate and delay as reported in the literature. Obtained reinforcer frequency was a significant step variable four times—twice as a first variable and twice as a second-step variable. Six of eight regression coefficients for reinforcer frequency were negative, replicating the inverse relationship between reinforcer frequency and response rate as reported in a number of prior t-system reinforcement schedule experiments (e.g., Schoenfeld & Cole, 1972). Obtained delay was significant as the first-step variable for the averaged data of both t^D placements, and obtained reinforcer frequency was also significant as the second-step variable in the late t^D placement. Thus both obtained delay and reinforcer frequency appear to contribute to response rate, but obtained delay does so to a much greater degree. This result supports the inverse relationship between obtained delay and response rate. However, the confirmation by the present research of the inverse relationship between response rate and delay must be limited to obtained delay, and one must recognize that mean obtained delay may not be the most appropriate measure (Killeen, 1968).

Even though the history of delayed-reinforcement procedures dates back to Hunter (1913), there are only two other reports which include data for both reinforcer frequency and obtained delay (Sizemore & Lattal, 1978; Williams, 1976). The present discussion of the relationships among response rate, obtained delay, and reinforcer frequency will help clarify their impact upon each other. In all prior delay studies except Williams (1976), increases in the programmed delay necessarily decreased the programmed and obtained reinforcer frequency (see introduction and, for example, Sizemore & Lattal, 1978, Table 1). In addition, obtained delays were positively related but shorter than programmed delays (see Figure 6), also replicating Sizemore and Lattal (1978). One might thus conclude for those delay studies that did not report reinforcer frequency or obtained delay that decreases in reinforcer frequency and response rate accompanied increases in obtained delay. In the present study, decreases in the obtained reinforcer frequency and decreases in obtained delay accompanied increases in the response rate. Thus, for all delay research to date, obtained delay is inversely related with response rate. However, the conclusion that obtained delay controls response rate may not be justified. For example, as the response rate increases in interval schedules, the time between the subject's last response and the end of the interval will tend to shorten. The measurement of obtained delay might only highlight one source of control of the response distribution. Response rate and obtained delay are both measures of the underlying temporal distribution of response. The significant multiple regressions may be explained by the selective constraints placed upon the response distribution by the decrease in t^D duration (e.g., Clark, 1959; Hearst, 1958; Morse, 1966).

REFERENCES

Ainslie, G. (1975). Specious reward: A behavioral theory of impulsiveness and impulse control. *Psychological Bulletin*, **82**, 463-496.

Baron, A., Kaufman, A., & Fazzini, D. (1969). Density and delay of punishment of free-operant avoidance. *Journal of the Experimental Analysis of Behavior*, **12**, 1029-1037.

Catania, A. C., & Reynolds, G. S. (1968). A quantitative analysis of the responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, **11**, 327-383.

Chung, S-H. (1965). Effects of delayed reinforcement in a concurrent situation. *Journal of the Experimental Analysis of Behavior*, **8**, 439-444.

Chung, S-H., & Herrnstein, R. J. (1967). Choice and delay of reinforcement. *Journal of the Experimental Analysis of Behavior*, **10**, 67-74.

Clark, F. C. (1958). The effect of deprivation and frequency of reinforcement on variable-interval responding. *Journal of the Experimental Analysis of Behavior*, **1**, 221-228.

Clark, R. (1959). Some time-correlated reinforcement schedules and their effects on behavior. *Journal of the Experimental Analysis of Behavior*, **2**, 1-22.

Dews, P. B. (1960). Free-operant behavior under conditions of delayed reinforcement. I. CRF-type schedules. *Journal of the Experimental Analysis of Behavior*, **3**, 221-234.

Findley, J. D. (1958). Preference and switching under concurrent scheduling. *Journal of the Experimental Analysis of Behavior*, **1**, 123-144.

Hearst, E. (1958). The behavioral effects of some temporally defined schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, **1**, 45-55.

Hull, C. L. (1932). The goal gradient hypothesis and maze learning. *Psychological Review*, **39**, 25-43.

Hull, C. L. (1943). *Principles of behavior: An introduction to behavior theory*. New York: Appleton-Century-Crofts.

Hunter, W. S. (1913). The delayed reaction in animals and children. *Behavior Monographs*, **2**, 1-86 (whole No. 1).

Hursh, S. R., & Fantino, E. (1973). Relative delay of reinforcement and choice. *Journal of the Experimental Analysis of Behavior*, **19**, 437-450.

Killeen, P. (1968). On the measurement of reinforcement frequency in the study of preference. *Journal of the Experimental Analysis of Behavior*, **11**, 263-269.

Kimble, G. A. (1961). *Hilgard and Marquis' Conditioning and learning* (2nd ed.). New York: Appleton-Century-Crofts.

Lawrence, D., & Hommel, L. (1961). The influence of differential goal boxes on discrimination learning involving delay of reinforcement. *Journal of Comparative and Physiological Psychology,* **54,** 552-555.

Morse, W. H. (1966). Intermittent reinforcement. In W. K. Honig (Ed.), *Operant behavior: Areas of research and application* (pp. 52-108). New York: Appleton-Century-Crofts.

Perin, C. T. (1943a). A quantitative investigation of the delay-of-reinforcement gradient. *Journal of Experimental Psychology,* **32,** 37-51.

Perin, C. T. (1943b). The effect of delayed reinforcement upon the differentiation of bar responses in white rats. *Journal of Experimental Psychology,* **32,** 95-109.

Perkins, C. C., Jr. (1947). The relation of secondary reward to gradients of reinforcement. *Journal of Experimental Psychology,* **37,** 377-392.

Pierce, C. H., Hanford, P. V., & Zimmerman, J. (1972). Effects of different delay of reinforcement procedures on variable-interval responding. *Journal of the Experimental Analysis of Behavior,* **18,** 141-146.

Rachlin, H., & Green, L. (1972). Commitment, choice and self-control. *Journal of the Experimental Analysis of Behavior,* **17,** 15-22.

Renner, K. E. (1964). Delay of reinforcement: A historical review. *Psychological Bulletin,* **61,** 341-361.

Schoenfeld, W. N., & Cole, B. K. (1972). *Stimulus schedules: The t-tau systems.* New York: Harper & Row.

Schoenfeld, W. N., Cole, B. K., Lang, J., & Mankoff, R. (1973). "Contingency" in behavior theory. In F. J. McGuigan & D. B. Lumsden (Eds.), *Contemporary approaches to conditioning and learning* (pp. 151-172). Washington, DC: Winston & Sons.

Schoenfeld, W. N., & Cumming, W. W. (1957). Some effects of alternation rate in a time-correlated reinforcement contingency. *Proceedings of the National Academy of Sciences,* **43,** 349-354.

Schoenfeld, W. N., Cumming, W. W., & Hearst, E. (1956). On the classification of reinforcement schedules. *Proceedings of the National Academy of Sciences,* **42,** 563-570.

Shull, R. L., Spear, D. J., & Bryson, A. E. (1981). Delay or rate of food delivery as a determiner of response rate. *Journal of the Experimental Analysis of Behavior,* **35,** 129-143.

Sizemore, O. J., & Lattal, K. A. (1978). Unsignalled delay of reinforcement in variable-interval schedules. *Journal of the Experimental Analysis of Behavior,* **30,** 169-175.

Skinner, B. F. (1938). *The behavior of organisms: An experimental analysis.* New York: Appleton-Century.

Spence, K. W. (1947). The role of secondary reinforcement in delayed reward learning. *Psychological Review,* **54,** 1-8.

Tarpy, R. M., & Sawabini, F. L. (1974). Reinforcement delay: A selective review of the last decade. *Psychological Bulletin,* **81,** 984-997.

Williams, B. A. (1976). The effects of unsignalled delayed reinforcement. *Journal of the Experimental Analysis of Behavior,* **26,** 441-449.

Wilson, M. P. (1954). Periodic reinforcement interval and number of periodic reinforcements as parameters of response strength. *Journal of Comparative and Physiological Psychology,* **47,** 51-56.

Wolfe, J. B. (1934). The effect of delayed reward upon learning in the white rat. *Journal of Comparative Psychology,* **17,** 1-21.

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