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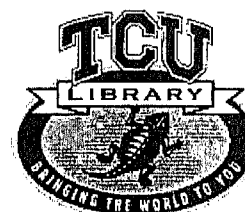
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RESPONSE ACQUISITION AND MAINTENANCE WITH A TEMPORALLY DEFINED SCHEDULE OF DELAYED REINFORCEMENT

LA ADQUISICIÓN Y EL MANTENIMIENTO DE LA RESPUESTA CON
UN PROGRAMA DE REFORZAMIENTO DEMORADO
DEFINIDO TEMPORALMENTE

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ABSTRACT

The acquisition and subsequent maintenance of lever pressing by rats was examined using a time-based variable delay-of-reinforcement schedule. Holding T cycle length constant at 64 s, nominal delays of reinforcement of either 8 s, 16 s, 32 s, 48 s, or 56 s were generated by two different t^D placements, either early or late within the T cycle. Three rats each were assigned to a combination of nominal delay and t^D placement. Response rates were a decreasing function of lengthening nominal delay regardless of t^D placement. For any given nominal reinforcement delay, response rates were higher under the late than under the early t^D placement. These results extend the generality of response acquisition with delayed reinforcement to temporally defined schedules. In addition, the results suggest that delay-of-reinforcement gradients can be obtained under constant reinforcement rates. The results also suggest a critical role for the reinforcement-producing response in determining the effects of delayed reinforcement.

Key words: acquisition and maintenance of responding, temporally defined schedules, delay of reinforcement, lever pressing, rats

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RESUMEN

Se examinó la adquisición y el posterior mantenimiento del palanqueo en ratas usando un programa temporal de demora de reforzamiento variable. Manteniendo constante un ciclo T en 64 s, se generaron demoras de reforzamiento nominales de 8 s, 16 s, 32 s, 48 s, o 56 s con dos diferentes ubicaciones de t^D , al inicio o al final del ciclo T. Se asignó a tres ratas a cada combinación de demora nominal y ubicación de t^D . Las tasas de respuesta fueron una función decreciente de alargar la demora nominal sin importar la ubicación de t^D . Para cualquier demora nominal de reforzamiento, las tasas de respuesta fueron más altas bajo la ubicación de t^D al final que al principio del ciclo. Estos resultados extienden la generalidad de la adquisición de la respuesta a los programas definidos temporalmente. Además los resultados sugieren que se puede obtener gradientes de demora de reforzamiento bajo tasas de reforzamiento constantes. Los resultados también sugieren un papel crítico para la respuesta procuradora de reforzamiento en la determinación de los efectos del reforzamiento demorado.

Palabras clave: adquisición y mantenimiento de la respuesta, programas definidos temporalmente, demora de reforzamiento, palanqueo, ratas

New responses such as lever pressing by rats can be established in the absence of shaping, directly exposing the subjects to schedules of un signaled delayed reinforcement. In their initial demonstration, Lattal and Gleeson (1990) showed the acquisition of lever pressing by rats and key pecking by pigeons under 30-s resetting and non-resetting delays. Subsequent research has shown that lever pressing by rats can be established with un signaled reinforcement delays as long as 60 s (Avila & Bruner, 1995; Dickinson, Watt, & Griffiths, 1992).

Although delay-of-reinforcement gradients are the most common outcome in parametric examinations of different delay durations in both the establishment of new responses (e.g., Avila & Bruner, 1997; Bruner, Avila, Acuña, & Gallardo, 1998) as well as during its subsequent maintenance (e.g., Lattal, 1987), such findings are not universal. For example, Wilkenfield, Nickel, Blakely, and Poling (1992) compared the effects of three different delay-of-reinforcement procedures on the acquisition of lever pressing by rats. Their procedures differed in the type of delay contingency for responding during the delay interval, either resetting, non-resetting or "stacked" reinforcement delays (where each response produced delayed reinforcement). Un signaled delays of either 0 s, 1 s, 4 s, 8 s, or 16 s were programmed according to each of their procedures. While their resetting procedure produced the familiar delay-of-reinforcement gradient; i.e., higher response rates related to shorter reinforcement delays, the same delay durations were not systematically related to response rate under both, their non-resetting and "stacked" procedures.

Another example is a study conducted by Weil (1984), who examined the effects of different delay intervals during the maintenance of key pecking by pigeons. He used a variation of temporally defined schedules of reinforcement (Schoenfeld & Cole, 1972) known as variable delay of reinforcement, where a response during a fixed-time cycle produced reinforcement at cycle's end. Using such procedure, Weil examined the effects of different delay durations under two different conditions. One condition limited the maximum delay between the criterion response and reinforcement, such that delays shorter than the nominal value, and even contiguity between the criterion response and reinforcement could occur. The second condition limited the minimum delay between the criterion response and reinforcement, such that longer than nominal delay intervals were possible. Weil found that when maximum reinforcement delay was limited, lengthening delay duration lowered response rates in the form of a delay gradient. In contrast, when minimum delay of reinforcement was limited, longer delays were associated with higher response rates. As one can see, the latter finding is rather counterintuitive, but to some degree congruent with the non-systematic response-rate function reported by Wilkenfield et al. (1992) for their different non-resetting delay intervals during response acquisition. In view of his findings Weil concluded that delay of reinforcement does not have systematic effects on response rate when reinforcement frequency is held constant.

It has been difficult to interpret contradictory findings in delay of reinforcement studies. One persistent problem consists in determining whether the effect of a given delay is due to the introduction of an interval-to-reinforcement between either, a criterion response (nominal delay) or the last response during the delay (obtained delay). Although in some studies, such as the one conducted by Wilkenfield et al. (1992) a resetting contingency has been used to insure the identity between obtained and nominal delays, this procedure forcefully reduces response rate and thus confounds the effects of reinforcement delay with spaced-responding. Another problem in delay-of-reinforcement studies is that the introduction of an interval between the criterion response and its reinforcer concomitantly lengthens the interval between successive reinforcers, thus lowering overall reinforcement rate. Given that lower reinforcement rates control correspondingly low response rates (Catania & Reynolds, 1968), the effect of a given delay is often confounded with the concomitant reduction in reinforcement rate. Hitherto only one study, by Sizemore and Lattal (1978) attempted to determine the effect of reinforcement delay under a constant reinforcement rate. In this study a tandem variable interval (VI) 60 s fixed-time (FT) X s schedule was used. The duration of the VI schedule in the first component was the complement of the FT delay in the second component, so that the average reinforcement rate was held

constant at one reinforcer every 60-s. They found that the rate of key pecking in pigeons decreased monotonically as a function of lengthening reinforcement delay from .5 to 10 s, in spite that reinforcement rate was held constant across all delay conditions.

The present experiment systematically replicated the procedure used by Weil (1984), using the acquisition of lever pressing by different groups of rats exposed to the same delay of reinforcement instead of the maintenance of key pecking by pigeons exposed successively to different reinforcement delays. The experiment had several purposes. One was to evaluate the generality of temporally defined procedures of variable reinforcement delay on response acquisition. As suggested by Schoenfeld and Cole (1972) temporally defined schedules are advantageous over the traditional schedules of reinforcement in part because they allow replication of known data by a set of procedures derived from the continuous variation of fewer variables (*cf.* Sidman, 1960). The second purpose was to record the temporal distribution of responding across a constant interreinforcement cycle to evaluate the contribution of non-criterion responding to the effects of a given reinforcement delay. The third purpose was to examine response rates under different reinforcement delays using a procedure that keeps reinforcement rate constant. The fourth purpose of the study was to determine if Weil's "inverse gradient" could be obtained during the acquisition of lever pressing by rats under early t^D delays that have been explored before and that are known to yield the familiar delay-of-reinforcement gradient (*e.g.*, Avila, Bruner, & Gallardo 1994).

METHOD

Subjects

Thirty experimentally naive male Wistar rats, obtained from the vivarium of the School of Psychology of the National University of Mexico, approximately five months old were used. The rats were housed in individual cages, with free access to water. Throughout the experiment, rats were kept at 80% of their free-feeding weight.

Apparatus

The experimental chamber (Gerbrands Model 62150) was 23.5 cm in length by 20 cm in height and 21.5 cm in depth and was enclosed within a sound-attenuating cubicle (BRS/LVE Model 20705), equipped with a fan, which provided ventilation and a masking noise. The chamber contained a single lever,



5 cm wide, 1 cm thick and protruded 1.5 cm into the chamber. It was located at the center of the panel, 7 cm above the grid floor and operated by a downward force of 0.20 N. The front panel also was equipped with a recessed 4.5 cm square food tray, located 2.5 cm to the left of the lever and 1 cm above the grid floor. The houselight was located near the ceiling above the food tray. Food pellets of 0.25 mg were made by remolding pulverized Purina Nutri Cubes, and were dispensed by a Gerbrands (Model D-1) pellet dispenser. Experimental events were programmed and recorded using solid state BRS/LVE equipment.

Procedure

During the first session, with the lever absent from the chamber, each rat was magazine trained by delivering response-independent food pellets until the rat reliably approached the food tray and consumed the pellet on thirty consecutive operations of the pellet dispenser. Beginning with the second session and thereafter, the response lever was in place in the chamber. Without further training, each subject was exposed to the temporally defined schedule schematically diagramed in Figure 1. A constant reinforcement cycle (T) was divided into two alternating unsignaled components, t^D and t^A . The first lever press within t^D scheduled reinforcement, to be delivered at the end of the T cycle, while additional responses, in either t^D or t^A , had no consequences. The onset of t^D was in either of two locations of the T cycle, before the termination of the subsequent cycle (designated as late t^D placement) or after the end of the preceding T cycle (designated as early t^D placement).

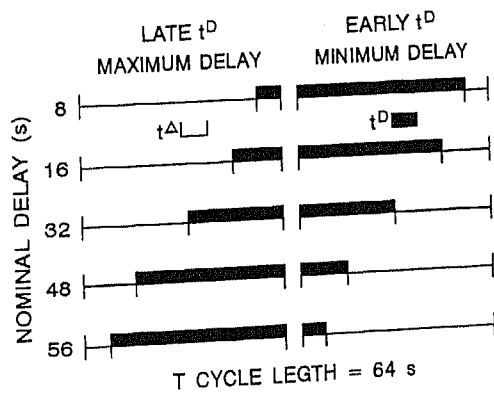


Figure 1. Schematic representation of the different durations of the early and late t^D placements.

The duration of the T cycle was always constant at 64 s. The duration

of t^D was 8 s, 16 s, 32 s, 48 s, or 56 s because these delay durations had been explored before during the acquisition of lever pressing by rats (Avila, Bruner, & Gallardo, 1994; Dickinson, Watt, & Griffiths, 1992). Three rats each were exposed to a combination of a fixed t^D duration and placement (late or early). The different schedules of reinforcement were in effect for 40 sessions, the duration of which was one hour or the time necessary to obtain 30 reinforcers whichever occurred first. Sessions were conducted six days per week.

RESULTS

Figure 2 shows rates of responding for each subject, distributed into eight 8-s subintervals of the T cycle, as the mean of the first and last block of ten sessions of the experiment. To facilitate the description of these data, the delays of reinforcement programmed by the late and early t^D placements, are shown as nominal delays (e.g., for both, the late $t^D=8$ s and the early $t^D=56$ s, the nominal delay of reinforcement was 8 s).

For the late t^D placement, lever pressing during the first 10-session block occurred at low rates in about two thirds of the subjects, regardless of delay duration. During the last block of ten sessions responding occurred in all but one animal at higher rates. During the latter block, the most common pattern of responding was an increasing rate that asymptoted at about the middle of the cycle. For the early t^D placement, when the nominal delay of reinforcement was 8 s, substantial rates of responding occurred for two subjects during the first block and by the last 10-session block response rates by the three subjects in the group increased noticeably. During the last block of sessions, the pattern of responding by two rats consisted of a slowly increasing rate that continued until the end of the cycle, while for the third rat the response pattern consisted of a high rate at the beginning of the cycle that decreased gradually until T cycle termination. When delay of reinforcement was 16 s, the rates of responding by the three rats during the first 10-session block were also near zero. However, the low response rate of Rat 10 increased slightly from the first to the last block of sessions. When delay was 32 s, 48 s, or 56 s, virtually no lever pressing occurred for all animals in both blocks of sessions.

The following results are based on the means of the depicted indices for the three rats at each condition over the last 10 sessions of the experiment. The top-left graph of Figure 3 shows mean rate of responding for the three rats exposed to each nominal delay of reinforcement. For the late t^D placement, there was a generally decreasing function between response rates and longer nominal delays of reinforcement. For the early t^D placement, mean response

rates were higher when the nominal delay was 8 s, lower when delay was 16 s and near zero when delay duration was between 32 s and 56 s. For all delay durations, response rates were higher in the late t^D than in the early t^D placement. The effects of the combinations of the different nominal delays of reinforcement with the late and early t^D placements on response rates were analyzed using a two-way 5 X 2 ANOVA (5 delays: 8 s, 16 s, 32 s, 48 s, or 56 s X 2 t^D placements: early or late). Nominal delay of reinforcement had a significant main effect [$F(4,29) = 18.33, p < .01$]. The placement of t^D , either late or early, also had a significant main effect [$F(1,29) = 58.05, p < .01$]. The interaction between nominal delay and t^D placement was not significant [$F(4,29) = 2.11, p > .05$]. To analyze the individual contribution of the two variables, a one-way ANOVA was performed for nominal delay of reinforcement under each t^D placement. For the late t^D placement there was a significant effect of nominal delay on mean response rate [$F(4,14) = 10.61, p < .01$]. Tukey post-hoc tests showed that an 8-s delay controlled the highest rates of responding ($\bar{x} = 7.45$), followed by the 32-s delay ($\bar{x} = 4.52$), which in turn controlled higher response rates than 16-s ($\bar{x} = 2.90$), 48-s ($\bar{x} = 1.48$), and 56-s ($\bar{x} = 2.24$) delays, which controlled response rates that were no different from each other. For the early t^D placement there was also a significant effect of nominal delay on mean response rates [$F(4,14) = 9.35, p < .01$]. A Tukey post-hoc test showed that mean response rate was significantly higher under 8-s nominal delay ($\bar{x} = 3.14$) than under any other longer delay duration, which controlled response rates that were no different from each other ($\bar{x} = 0.28, \bar{x} = 0.00, \bar{x} = 0.00, \bar{x} = 0.00$ for delays ranging from 16 s to 56 s).

The top-right graph of Figure 3 shows the mean rate of reinforcement of the three rats exposed to each t^D duration. The percentage of T cycles that ended with reinforcement is indicated above each data point. For the late t^D placement, reinforcement rates were much higher than for the early t^D placement for all nominal delays, but did not vary systematically with delay of reinforcement. For the early t^D placement, reinforcement rate was higher when delay was 8 s and decreased when delay was 16 s. Few reinforcers occurred when the nominal delay was between 32 s and 56 s. Mean rates of responses per reinforcer are shown in the bottom-left graph of Figure 3. The shape of these functions is similar to those for response rate, showing that for both t^D placements more responses per reinforcement were emitted under shorter nominal delays. The bottom-right graph shows the mean interval between the last response within T and the subsequent reinforcer; i.e., the mean obtained delay in the early and late t^D placements. Given the limited hold for reinforcement imposed by the termination of each T cycle, the reinforcement delay could not exceed T cycle duration (i.e., 64 s). Only those cycles that terminated with reinforcement delivery were included in the 10-session means.

For the late t^D placement, obtained delays were shorter under the 8-s delay and gradually lengthened as nominal delay was increased up to 48 s. Obtained delays were similar under nominal delays of 48 s and 56 s. For the early t^D placement, the mean obtained delay was short when the nominal delay was 8 s, and lengthened when delay was 16 s. Given that few reinforcers occurred under nominal delays between 32 s and 56 s, the corresponding obtained delays have been omitted in the graph.

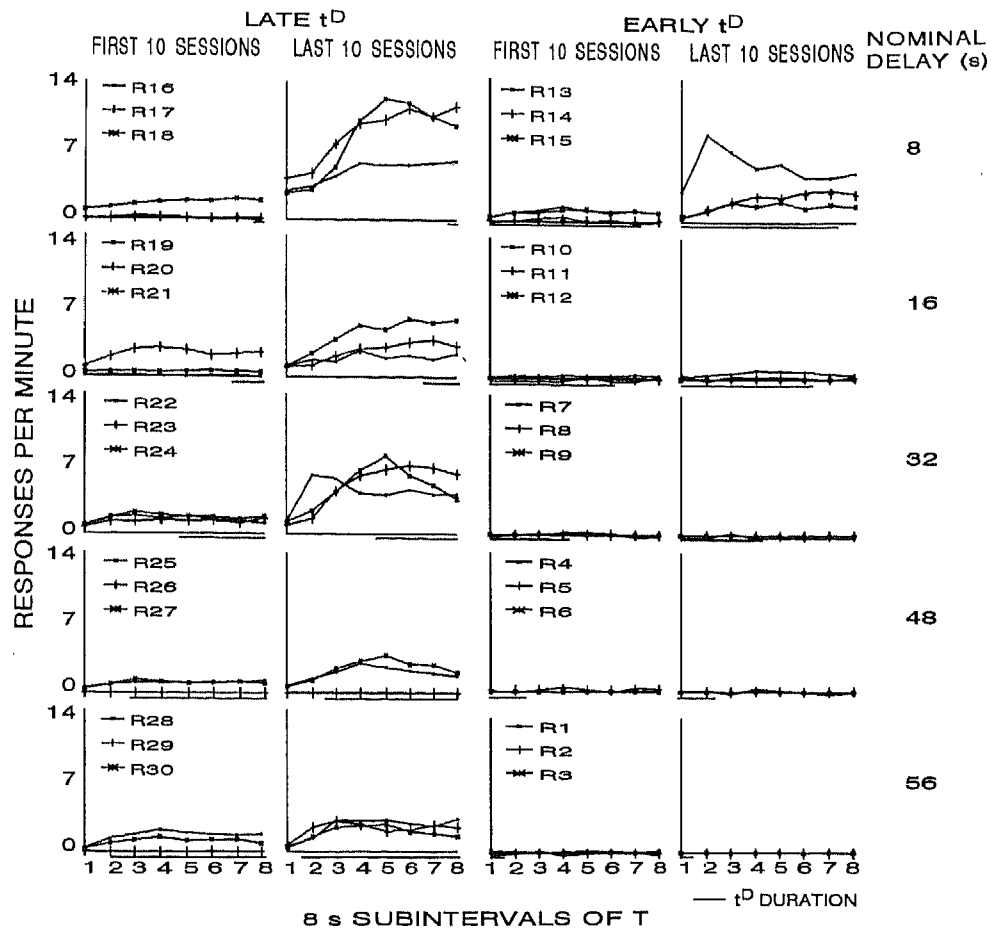


Figure 2. Mean individual rates of responding distributed across eight 8-s subintervals of T. For both, late and early t^D placements, these data are shown separately for the first and for the fourth block of ten sessions. The duration of t^D is shown in the abscissa of each graph as a line.

Lever pressing by rats has been established using a variety of unsignaled delay-of-reinforcement procedures. These have included both resetting and non-resetting contingencies for responding during the delay interval (e.g., Lattal & Gleeson, 1990). "Stacked" reinforcement delays, where each lever press produced delayed reinforcement has also been shown to facilitate response acquisition (Dickinson, Watt, & Griffiths, 1992; Wilkenfield, Nickel, Blakely, & Poling, 1992). The present study extended the generality of response acquisition with delayed reinforcement to a type of temporally defined schedule of reinforcement termed variable delay-of-reinforcement procedures. In comparison to the traditional tandem-type schedules of delayed reinforcement, temporally defined schedules have several advantages. Most importantly they both replicate traditional schedules of reinforcement and relate the specific time-based procedures to other temporally defined schedules of reinforcement. For example, the temporally defined schedules of delayed reinforcement used in the present research can be viewed as a limited-hold version of the more traditional tandem fixed-interval fixed-time (i.e., tandem FI s FT s) schedule of delayed reinforcement. Another advantage of a temporally defined schedule of variable delay of reinforcement is that such schedule allow the recording of response patterns across the fixed-duration T cycle, an analysis more difficult to obtain using the traditional schedules of reinforcement. Still another advantage of the present temporally defined schedules was that the constant duration of the T cycle kept programmed reinforcement rate constant, instead of allowing delay durations to systematically lengthen the interreinforcement interval, as frequently happens when traditional reinforcement delay procedures are used.

Concerning the maintenance of lever pressing, the data from the last 10-session block were defined arbitrarily as steady-state responding and described in terms of the same dependent variables reported by Weil (1984). Describing the data of the last block of sessions as means of the different dependent variables allowed for both a statistical analysis of the effects of late and early nominal delays of reinforcement as well as a direct comparison with the results from Weil's experiment. Mean response rates and the ratio of responses per reinforcement under both, late and early t^D placements, were decreasing functions of lengthening nominal delay of reinforcement. Mean reinforcement rates did not vary systematically with nominal delay duration in the late t^D placement, but decreased steadily along with early t^D delay durations. Mean obtained delays of reinforcement; i.e., the interval between the last response in each T cycle and reinforcement increased as nominal delay was lengthened, regardless of t^D placement. Thus the late and early t^D response functions replicated the familiar delay-of-reinforcement gradient (Lattal, 1987). Furthermore, such delay gradient was reproduced under the different late t^D

delays without systematic variations in reinforcement rate. This finding is consistent with the results of Sizemore and Lattal (1978) where reinforcement rate was held constant across different reinforcement delays and nevertheless delay gradients were obtained during the steady-state maintenance of key pecking by pigeons. Thus delay effects can be shown in the absence of concomitant reductions in reinforcement rate.

The primary difference between the results from Weil's study and the present one was in terms of the manipulation of the early t^D placement. Weil found higher mean response rates under shorter early t^D delays, but this finding did not occur in the present study. Furthermore, in the present study as the early t^D delays were lengthened, decreases in response rate were accompanied by systematic decreases in obtained reinforcement rate. This finding suggests that when response rates are low, reinforcement rate may vary unavoidably with response rate (due to the response-reinforcer dependency, an assumption of operant conditioning includes a responding subject). As mentioned before, Weil's finding is counterintuitive and could be potentially related to the non-systematic delay of reinforcement gradients obtained by Wilkenfield et al. (1992). Had the present investigation replicated Weil's "inverse delay gradient", a basis for interpreting the findings by Wilkenfield et al. could have been provided. Such a replication also would have supported Weil's assertion that delay of reinforcement is not a powerful variable when reinforcement rate is held constant. This, however, was not the case. While the reason for the anomalous finding reported by Wilkenfield et al. during the acquisition of a new response remain unclear, the results from the present research suggest an interpretation for Weil's early t^D data. In Weil's experiment T was 30 s and the early t^D durations ranged from very short (0.1 s, 0.2 s, 0.5 s, 1.5 s, 2.5 s, or 5 s), to durations comparable to those studied here. Within the t -system of reinforcement schedules (Schoenfeld & Cole, 1972), it is well known that shortening t^D relative to T (i.e., a variable known as \bar{T}), results in increased response rates (cf. Hearst, 1958). Therefore, it is possible that in Weil's early t^D placement, response rates increased under smaller t^D/T ratios regardless of t^D duration.

The fact that delay gradients can be obtained during the acquisition of a new response replicates the findings of previous parametric studies on response acquisition with different unsignaled reinforcement delays (Avila & Bruner, 1997; Bruner, Avila, & Gallardo, 1994; Bruner, Avila, Acuña, & Gallardo, 1998). The most striking finding of the present study was, however, that although the late and early t^D placements programmed identical nominal delays of reinforcement, mean response rates under any given delay were systematically higher in the late than in the early t^D placements. Such a difference was likely due to the fact that the late t^D placement limited the

maximum delay interval between the criterion response and reinforcement, thus allowing for shorter obtained delays and even occasional contiguity between the criterion response and reinforcement. In contrast, the early t^D placement limited the minimum delay that could occur between the criterion response and reinforcement, thus allowing for longer criterion response-reinforcement intervals than those specified by the schedule. Such a finding may be relevant to behavior controlled by delayed reinforcement in natural settings, where variability in the interval between the criterion response and reinforcement may more likely be the rule than a fixed-delay duration. From a theoretical point of view, the latter finding is congruent with previous research on response maintenance under temporally defined schedules of variable delay of reinforcement (e.g., Cole, Lachter, & Schoenfeld, Experiment 1; Lang & Mankoff, Experiment 2 in Schoenfeld, Cole, Lang, & Mankoff, 1973). These investigations emphasized that the interval between the criterion response and reinforcement is a more powerful variable in determining the decremental effects of reinforcement delay on response rates than the obtained interval between the last response during the delay interval and reinforcement. The response patterns recorded during the present investigation further support the critical role of the criterion response-reinforcement interval by showing that in spite of the fact that responding indeed occurred during the different delay intervals, nevertheless orderly decreases in response rates followed increases in the nominal delay intervals.

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