DELAY OF REINFORCEMENT EFFECTS UNDER TEMPORALLY DEFINED SCHEDULES OF REINFORCEMENT

EFECTOS DEL REFORZAMIENTO DEMORADO EN PROGRAMAS DEFINIDOS TEMPORALMENTE

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ABSTRACT

Response maintenance under temporally defined schedules has proven insensitive to change in response-reinforcer temporal separation. This finding could probably be attributed to lack of adequate stability criteria and carry over effects. In the present study performance based stability criteria and a reversible experimental design were used. Three rats were exposed to different 32-s repetitive time cycles of fixed duration (T). Each cycle was divided into two portions t^d and t delta. A response during t^d produced reinforcement at the end of T; responses that occurred during t delta had no programmed consequences. t^d placement was varied (early and late) in order to produce two different response-reinforcer temporal relations; t^d duration was also varied (4 or 8-s) for the same reason. Three different signal conditions were assessed: 1. Unsignaled t^d 2. Response produced signal may occur during t^d 3. Non-contingent signal occurred during t^d. Results showed response rates were significantly lower in the early placement condition; t^d duration produced

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inconsistent effects on response rate. Response rates were significantly high-er in unsignaled and response produced signal conditions. Results suggest delay of reinforcement effects may be produced by temporally defined sched-ules of reinforcement. Results also suggest signal effects be strongly related to schedule contingencies.

Key words: *delay of reinforcement, lever-pressing, rats, temporally de-fined schedules of reinforcement.*

RESUMEN

Variar la separación temporal entre la respuesta procuradora y el reforza-dor parece tener pocos efectos sobre la tasa de respuesta en programas definidos temporalmente. Este hallazgo podría deberse a que en estudios previos se han utilizado criterios de estabilidad laxos y diseños que permiten la aparición de efectos de acarreo. En el presente estudio se evaluó el efecto de la demora del reforzador utilizando criterios de estabilidad basados en la ejecución del sujeto y un diseño reversible. Tres ratas fueron expuestas a diferentes ciclos de tiempo repetitivo de 32-s (T). Los ciclos se dividieron en dos porciones, t^d y t delta; la primera respuesta emitida durante t^d produ-cía reforzamiento al final del ciclo, las respuestas durante t delta no tenían consecuencias programadas. Se varió la colocación de t^d dentro del ciclo de reforzamiento (al inicio o al final) para exponer a los sujetos a distintas condiciones de separación temporal entre la respuesta y el reforzador. Por el mismo motivo se varió la duración de t^d (4 u 8-s). También se varió la forma de señalar t^d a los sujetos: 1. Sin señal; 2. Señal contingente durante t^d y 3. Señal no contingente durante t^d. Los resultados mostraron que la tasa de res-puesta fue más baja cuando t^d se colocó al inicio del ciclo. Variar la duración de t^d tuvo efectos poco consistentes. Las tasas de respuesta fueron altas y muy similares en las condiciones no señaladas y de señal no contingente. Los resultados mostraron que los efectos característicos de la demora de reforzamiento sí pueden producirse en programas definidos temporalmente. También mostraron la estrecha relación que existe entre las contingencias de reforzamiento y la función de la señal.

Palabras clave: *demora de reforzamiento, palanqueo, ratas, programas de reforzamiento definidos temporalmente.*

The temporal separation between a response and its programmed conse-quence is frequently referred to as a "delay of reinforcement interval" (Tarpy and Sawabini, 1974). An important number of studies have found that re-inforcement delay duration maintains an inversely proportional relation with

response rate on steady state performance experiments (Skinner, 1938; Williams, 1976). Delay of reinforcement has also been associated with problems in achieving performance criteria in response acquisition studies (Renner, 1964).

Within the Experimental Analysis of Behavior most studies of delay of reinforcement effects use remarkably similar procedures; most often a tandem VI (FT or DRO) schedule is compared with an immediate reinforcement VI schedule (Pierce, Hanford and Zimmerman, 1972; Williams, 1976; Richards, 1981). Several scientists have suggested that this procedure may be inadequate to assess delay of reinforcement effects because increase in delay duration produces a concomitant increase in interreinforcer interval duration (and thus a decrease on reinforcer frequency) (Meunier and Ryman, 1974; Lattal, 1987). As reinforcer frequency is strongly related with response rate (Herrnstein, 1970) its importance as an extraneous variable can not be ignored.

In an attempt to vary delay duration without simultaneously changing programmed reinforcement rate, Weil (1984) used a different and interesting procedure. Weil exposed pigeons to 30-s temporally defined schedules of unsignaled reinforcement. The reinforcement cycle was divided into two components t^d and t delta; the first response emitted during t^d produced reinforcement at the end of the reinforcement cycle (responses during t delta had no programmed consequences). Weil reasoned that by changing t^d placement within the reinforcement cycle it would be possible to produce different response-reinforcer temporal relations without changing interreinforcer interval duration. Changing t^d duration could also produce different delay values because t^d duration may allow the target response to occur in close proximity (or far away) from reinforcement delivery. Weil´s findings did not agree with his predictions. Early t^d placement (that is t^d is located at the beginning of the reinforcement cycle and is thus temporally separated from reinforcement delivery) did not produce lower response rates than late t^d placement conditions (that is t^d is located at the end of the reinforcement cycle). Also t^d value did not behave as Weil had predicted, for both early and late t^d placement the only consistent finding was that decrease in t^d duration produced an increase in response rate. This last finding may be easy to interpret on late t^d placement conditions (were a decrease in t^d value will bring the target response closer to response delivery) but is entirely counter intuitive on the early t^d placement conditions.

A careful analysis of Weil´s experimental procedure reveals that the experimental subjects were exposed to at least 24 different combinations of t^d value and t^d placement. Furthermore performance on each condition was considered stable when the subject was exposed to fifteen consecutive experimental sessions (instead of assessing performance variability visually or

comparing it with a predetermined stability criterion). Thus there is a probability that carry over effects may have contaminated the experimental procedure and that the inadequate stability criteria was incapable of filtering these effects (Sidman, 1960).

One way to reassess Weil´s findings would involve using more stringent stability criteria. Additionally using an ABA design would allow each experimental condition to depart from a similar response requirement (and thus it would be easier to filter out carry over effects). In the present study Weil´s procedure was replicated using both an ABA design and performance based stability criteria. In order to further explore Weil´s procedure, two different signaled delay of reinforcement procedures were also assessed. In the first case a cue occurred if at least one response was produced during t^d (this procedure replicates the typical signaled delay of reinforcement procedure). In the second case a non-contingent signal was always present during t^d (this last manipulation has no precedent in delay of reinforcement studies).

METHOD

Subjects

Three naïve, male Wistar Lewis rats were used as subjects. The subjects were littermates and were 90 days old at the beginning of the study. Each subject's weight was registered on five consecutive days under free feeding conditions to determine *ad-libitum* body weight; food was then restricted until the subjects reached 80% of their free-feeding weight. Subjects were kept at their prescribed body weights through out the experiment by means of supplementary feeding following each experimental session. Subjects were kept on the laboratory *vivarium* under constant temperature conditions and a twelve-hour light–dark cycle (lights on at 7:00 a.m.). All experimental subjects were kept in individual cages with free access to water.

Apparatus

Sessions were conducted in a custom-built rodent operant conditioning chamber made of transparent Plexiglas. The space in which the subjects were studied measured 18.5 cm in height by 23.5 cm length by 23.5 cm depth. A stainless steel lever made of a 3 cm bar toped by a 2 cm in diameter metal disk was placed on the front wall of the chamber. The lever was placed 5.5 cm above the floor and 11 cm apart from each wall. The lever required a force of at least 24 grams for depression. A depression of the lever produced an audible click and was counted as a response. A 5 cm in diameter metal plate, located 2 cm

below and to the right of the lever was used as a pellet receptacle. A BRS-LVE, PDH-020 pellet dispenser delivered 4 .25 mg pellets in each emission. Pellets were produced by means of remolding pulverized Purina Nutri Cubes. Two 1.1 W, 28 Vdc pilot lights with a glass translucent cover were used to illuminate the experimental chamber. One light was located inside the box 7 cm above the food receptacle. The second light was placed outside the chamber pasted directly on the center of its Plexiglas ceiling. A sonalert which delivered a 87.62 dB auditory signal was attached to the external front wall of the experimental chamber, 5 cm to the left of the lever. The conditioning chamber was housed inside a sound-attenuating larger wooden box equipped with a ventilating fan. Experimental events were programmed and recorded using an IBM compatible 386 microcomputer equipped with an industrial automation card (Advantech PC-Labcard 725) coupled to a relay rack.

Procedure

During the first session, with the lever absent from the chamber, each rat was exposed to a magazine training procedure. Magazine training consisted of 30 consecutive response-independent food deliveries using a FT-30-s schedule. All experimental subjects consumed the food on the tray after just one exposure to the schedule. During the second session (and during 30 additional consecutive sessions) the lever was placed inside the experimental chamber and all subjects were exposed to a 32-s temporally defined schedule of reinforcement (Schoenfeld and Cole, 1972). The schedule consisted of a repetitive time cycle of fixed duration (T). The first response emitted during the cycle produced reinforcement at the end of T. This first program was used to develop consistent responding at the beginning of the experiment and was later on used as a baseline condition through out the study. In all experimental conditions, schedules consisted of two different components that alternated within the reinforcement cycle (t^d and t delta). A response emitted during t^d produced reinforcement at the end of the cycle; responses during t delta were recorded but had no programmed consequences. The experiment can be conceptualized as a within subject factorial design with three factors: 1) t^d placement (at the beginning of the cycle or at the end of the cycle). t^d duration (4 s or 8 s). Signal conditions (no signal, non-contingent signal, and contingent signal). t^d placement was varied in order to produce at least two response-reinforcer temporal relations. When t^d was placed at the beginning of the cycle, the reinforcement was temporally separated from the response; the opposite occurred when t^d was placed at the end of the cycle. Because responses could occur during t delta (and after one response had occurred during t^d), the experimental procedure used in the study may be characterized as a variable delay of reinforcement procedure (Lattal, 1987; Schoenfeld,
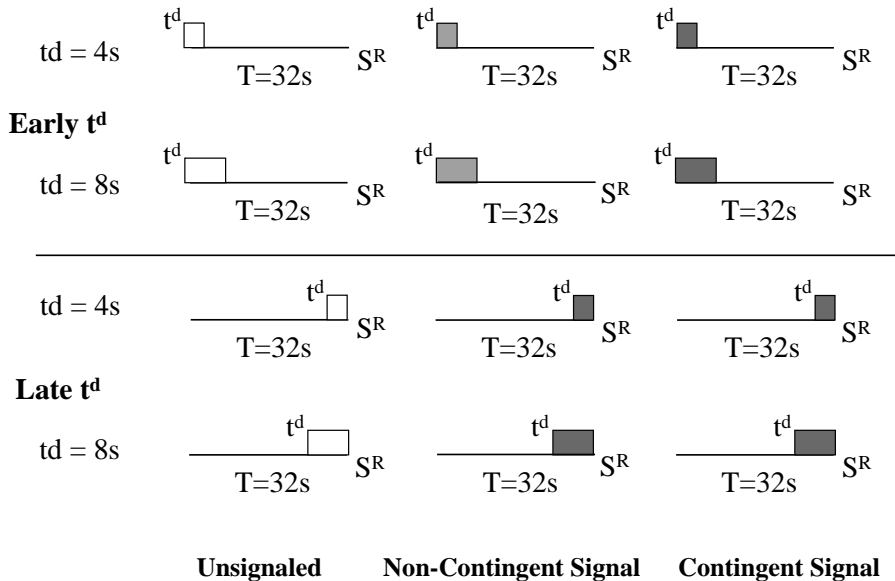
Figure 1. Schematic representation of the experimental procedure

Cole, Lang and Mankoff, 1973). In contrast with Weil´s study (where at least twelve different duration of td of were asessed) in the present study only two different t^d values were used (4 and 8-s). This decision was based on the fact that rodents life expectancy is considerably shorter than that of pigeons (and thus only a limited number of experimental conditions could be assessed). Furthermore the two selected t^d values were found by Weil to produce contrasting response rates. For instance, response rates produced by an 8-s t^d duration were low and very similar to those produced by longer t^d durations; in contrast t^d values of less than 5 s produced comparably higher response rates that reached a maximum at 0.1 s.

In signaled experimental conditions an audible tone and a change in illumination (the pilot light located on the front wall was extinguished; the pilot light located on the ceiling of the chamber was turned on) occurred during t^d. Contingent signals were produced by the first response during t^d (and thus may be considerably shorter than t^d duration). Non-contingent signals were presented automatically by the program throughout t^d. In unsignaled delay experimental conditions no programmed exteroceptive stimuli (other than reinforcement delivery) occurred during the reinforcement cycle. Figure 1 shows a schematic representation of the experimental procedures.

The three animals were exposed to all experimental conditions in different order; each experimental condition was preceded and followed by the previ-

ously detailed baseline condition. Both experimental and baseline conditions were in effect for at least fifteen sessions; once the fifteenth session was reached response rates were studied daily in order to determine if stability criteria had been met. Performance was considered stable if response rates in five consecutive sessions did not differ by more of twenty percent of their common mean. Sessions were conducted six days per week at approximately the same time each day. Each session lasted one hour or the time necessary to obtain thirty reinforcers, whichever occurred first.

RESULTS

Figures 2A, 2B and 2C show response rate per minute for the last five sessions of each experimental condition. Each figure shows the data for one subject. In the three figures signal conditions may be identified vertically; from top to bottom the figures show unsignaled, non-contingent signal and contingent–signal conditions. In all figures early t^d placement conditions are located on the left side of the graph and t^d =4-s conditions precede the longer t^d duration. In all figures experimental conditions are preceded by their anteceding baselines.

Figure 2A shows the data produced by subject D4. Response rates of this subject in the late t^d conditions are consistently higher than those produced in the early t^d conditions. The finding is consistent across the different signal conditions and more notable in both the unsignaled and contingent-signal condition. Effects of t^d duration are not as consistent as those produced by t^d placement. Response rates under the shorter t^d duration appear slightly higher than those produced by the longer t^d value in unsignaled t^d conditions. Response rates produced by both t^d durations appear similar under the non-contingent and the response-produced signal conditions.

Figure 2B shows the data produced by subject D20. The effects of t^d placement on this subject are notable on both the non-contingent and the contingent signal conditions (where late t^d placement is associated with higher response rates than early t^d placement). Response rates produced by the different t^d values are similar in the late t^d placement conditions; however in early t^d placement conditions response rates on the shorter t^d value appear slightly higher (at least in the non-contingent and contingent signal conditions).

Figure 2C shows the data produced by subject D6. The effects of t^d placement are notable in both the unsignaled and the contingent signal conditions with the short t^d duration (where late t^d placement is associated with higher response rates than early t^d placement conditions). Complementary t^d duration effects are notable in the late t^d placement conditions (were the short t^d value is associated with higher response rates than the longer t^d value in both the
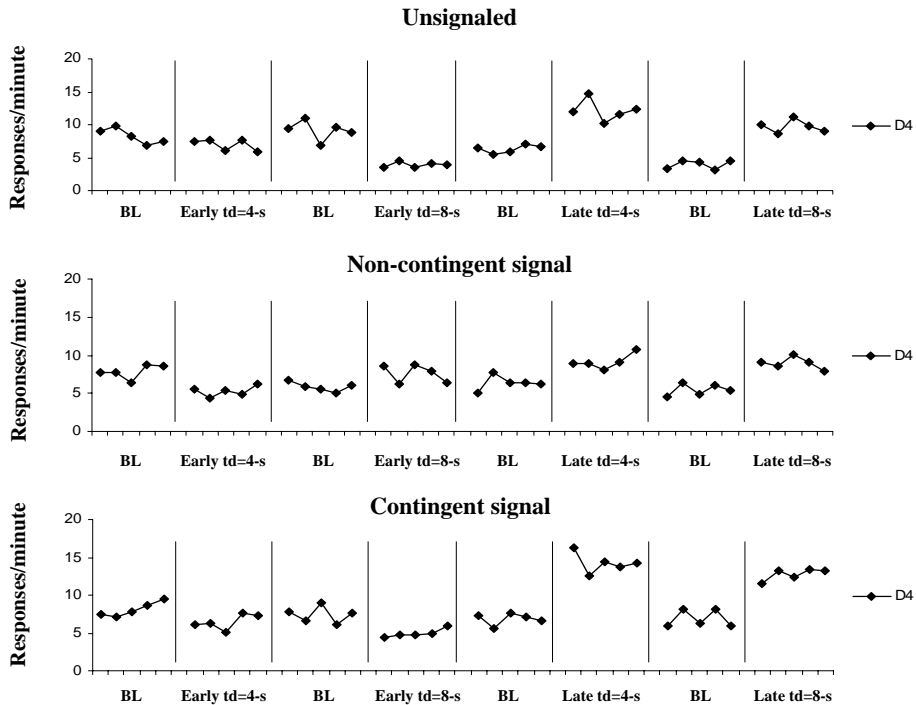
Figure 2A. Response rate per minute for each of the last five sessions in all experimental conditions. Subject D4.

unsignaled and contingent signal condition). t^d duration shows inconsistent effects on response rate in the early t^d placement conditions.

In order to further assess the effects of the independent variables on response rate, a three-way analysis of variance (t^d duration x t^d placement x signal condition) was conducted. Response rates from the three subjects on the last five experimental sessions of each condition were used as the dependent variable. Main effects from all independent variables reached statistical significance (t^d duration F(1/168)=7.12, p<.01); (t^d placement (1/168)=233.3, p<.0001); (signal condition (2/168)=25.22, p<.001). All interactions between the independent variables reached statistical significance. The statistical analysis suggests lower response rates occurred in the early t^d placement than in the late t^d placement conditions (X=4.97<9.72). Additionally conditions with the long t^d duration produced lower response rates than those conditions with the shorter t^d value (X=6.93<X=7.76). A Newman-Keuls test (with a .05 significance level) revealed that response rates were significantly lower in the non-contingent signal condition than on both the unsignaled and the
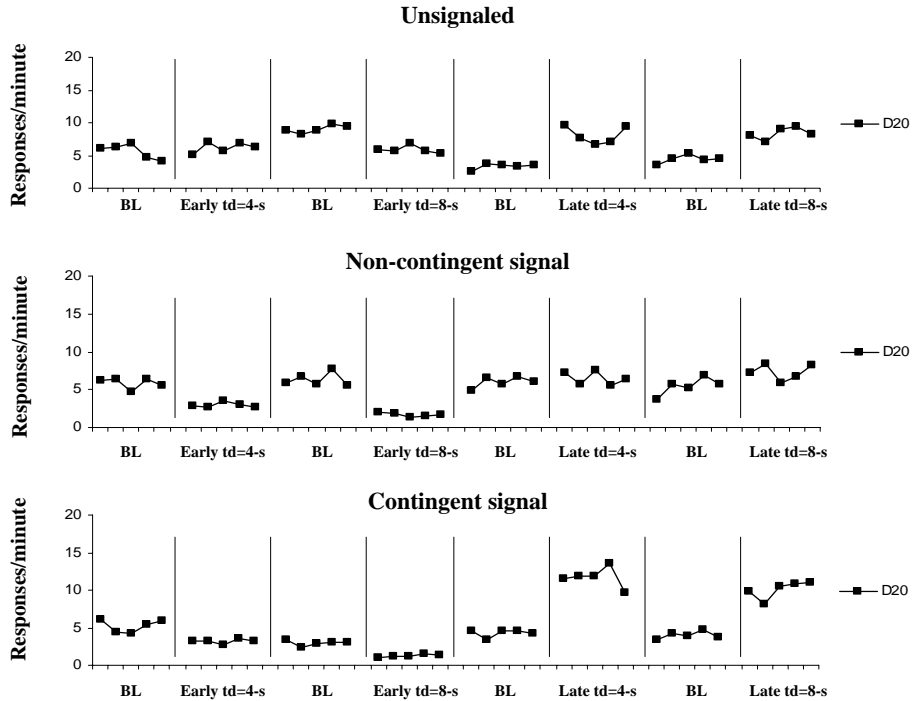
Figure 2B Response rate per minute for each of the last five sessions in all experimental conditions. Subject D20.

contingent-signal conditions (which in turn did not differ significantly amongst themselves) (X=5.03<X=7.45<X=8.55).

Figure 3 shows local response rates produced by the three subjects. The "y" axis shows average response rate per minute for the last five experimental sessions; the "x" axis shows 8-s subintervals of the interreinforcer interval (the T cycle ends when the fourth 8-s bin is over). The early t^d conditions are located in the upper part of the figure; late placement conditions are located in the bottom of the figure. For both early and late t^d conditions the short t^d duration is presented at the top. Each column represents a different signal condition.

In general, response rates produced in the early t^d placement conditions appear relatively flat. Perhaps the only exceptions occur in the non-contingent signal condition (where both D4 and D20 show slightly higher response rates at the beginning of the cycle) and in the contingent signal condition (were D4 shows slightly higher response rates at the beginning of the cycle). In contrast, local response rate produced in the late placement conditions ap-
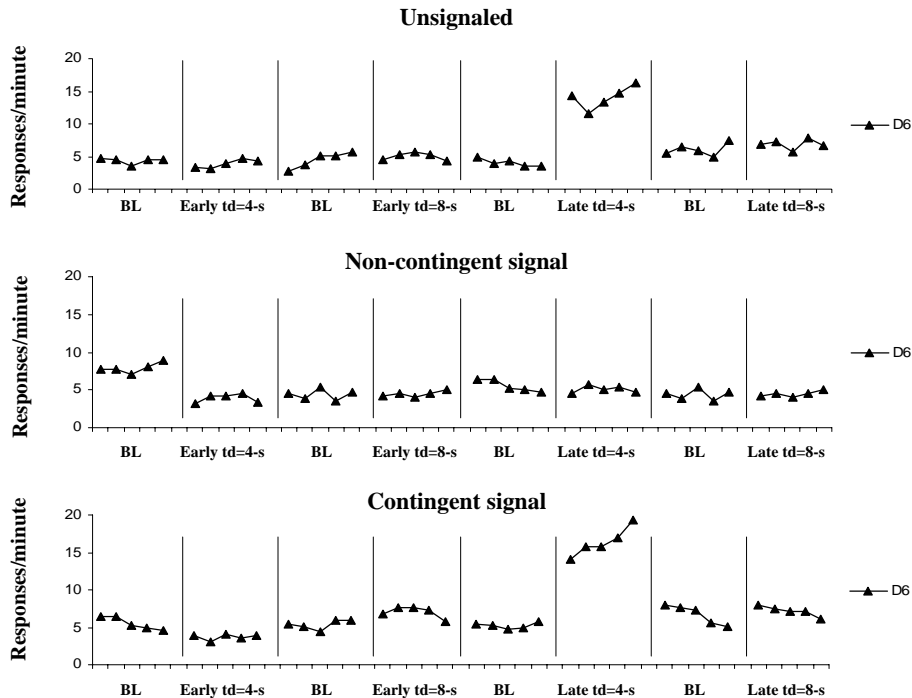
Figure 2C. Response rate per minute for each of the last five sessions in all experimental conditions. Subject D6

pears to be an increasing function of interreinforcer interval duration. In both the unsignaled and the contingent signal conditions response rates increase throughout the cycle in a more or less homogeneous way for most subjects. In contrast, response rates in the non-contingent signal condition increase in a scalloped pattern for all subjects in the t^d=8-s condition and for D4 in the t^d=4-s condition.

Table 1 shows the number of sessions required to reach the stability criterion by the three subjects in all experimental conditions. The Table was constructed to assess whether Weil´s "stability criterion" was supported by empirical data. In the Table rows correspond to different experimental subjects, t^d placement and t^d duration conditions. Columns correspond to different signal conditions. The numbers represent the number of sessions required to reach the stability criterion used in the present study; the number located inside the parentheses indicates schedule presentation order for each subject.

In twenty-three out of thirty-six experimental conditions subjects required more than fifteen sessions to reach the stability criterion defined in this study.
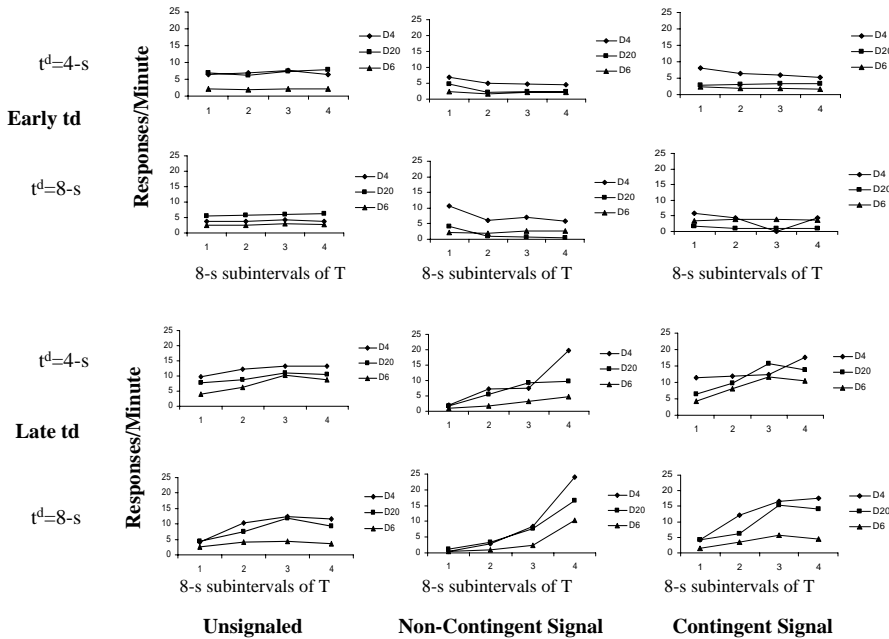
Figure 3. Local response rates produced by the three subjects.

Unsignaled t^d conditions required an average of nearly twenty-one sessions to reach stability (followed by the contingent signal condition and the non-contingent signal condition with 18 and 16.83 sessions respectively). For both D20 and D6 the stability criterion was difficult to achieve in the early placement condition with the short t^d duration. In the unsignaled late t^d=4-s condition D6 required 41 sessions to reach the stability criterion (this represents the highest number of sessions required to reach the stability criterion in the study).

In contingent signal conditions, signal presentation maintains a perfect correlation with reinforcer delivery (every time a signal occurs reinforcement will eventually be delivered); in non-contingent signal conditions however signals may occur without reinforcement delivery. Table 2 was designed in order to assess reinforcer-signal correlation in the non-contingent signal condition. Experimental conditions are located in the left side margin of the Table; each column represents the data produced by each subject. The fractions in the Table 2 show, in the numerator, mean earned reinforcers of the last five sessions; the denominator shows mean number of signals presented on the last five sessions.

The reinforcer-signal correlation (the number of times signal presentation was followed by reinforcement) was considerably higher in the late t^d place-

ment condition. Also in most cases reinforcer-signal correlation was higher with the long t^d duration (except in the early t^d condition for subject D20). Reinforcer-signal correlation reached its maximum for subject D4 (and its minimum for subject D6).

Table 1. Number of sessions required to reach stability criteria for all subjects in all experimental conditions.

Rat	t^d placement and duration.	Signal Condition		
D4		Unsignaled	Non Contingent	Contingent
	Early t^d=4	16 (6)	15 (7)	16 (12)
	Early t^d=8	31 (2)	17 (4)	15 (10)
	Late t^d=4	15 (5)	15 (8)	15 (11)
	Late t^d=8	15 (1)	18 (3)	15 (9)
D20				
	Early t^d=4	20 (9)	16 (6)	36 (12)
	Early t^d=8	16 (4)	16 (2)	15 (7)
	Late t^d=4	17 (10)	17 (5)	15 (11)
	Late t^d=8	25 (3)	15 (1)	18 (8)
D6				
	Early t^d=4	24 (5)	24 (11)	25 (9)
	Early t^d=8	16 (1)	17 (3)	16 (8)
	Late t^d=4	41 (6)	16 (12)	15 (10)
	Late t^d=8	15 (2)	16 (4)	15 (7)

Table 2. Reinforcer/Signal ratio obtained on the last five sessions for all subjects in non-contingent signal conditions.

t^d Placement and Duration	Reinforcer/signal ratio, last five sessions.		
Rat	D4	D20	D6
Early t^d=4	30/82.8	30/71.8	30/87.4
Early t^d=8	30/47	30/82.2	30/74
Late t^d=4	30/30.6	30/43.6	30/44.8
Late t^d=8	30/30	30/34.2	30/32.6

DISCUSSION

The main purpose of the present study was to determine if delay of reinforcement effects could be produced by systematically changing t^d placement and t^d duration within a temporally defined schedule of signaled and unsignaled delay of reinforcement. Results suggest that varying t^d placement within the interreinforcer interval will produce changes in response rates that are congruent with a delay of reinforcement interpretation. Response rates were substantially lower in the early t^d placement condition than in those conditions where reinforcement was delivered in close temporal proximity to the response. Furthermore, the analysis of local response rates suggests temporal and cue discrimination were considerably enhanced in the late t^d conditions (relative to discrimination occurring in the early t^d conditions). Discrimination enhancement of reinforcer and cue contingencies in the late t^d placement condition is also suggested by the fact that fewer sessions were required to reach stability criteria in the late t^d conditions. Bruner, Pulido and Escobar (2000) showed t^d placement had important effects on response acquisition by naïve rats. Rats exposed to schedules where t^d was separated from reinforcement delivery showed substantially less evidence of response acquisition than those subjects exposed to schedules were t^d placement and reinforcement delivery were contiguous. Thus both the present study and that by Bruner et al suggest Weil´s finding is the less typical one. The present study also suggests that Weil´s less typical finding could probably be attributed to inadequate stability criteria and poor experimental design selection; the fact that all subjects needed more than fifteen sessions in most experimental conditions to reach the stability criterion favors this idea. Of course species idiosyncrasies may not be ruled out as an alternative explanation to the different findings produced by the studies (in fact if a research agenda should be built around the results delivered by the present study, a comparison of the behavior of birds and rodents in temporally defined schedules of delayed reinforcement should be first in line).

Effects of t^d duration on response rate are more difficult to reconcile with a delay of reinforcement hypothesis. Short t^d duration in the late t^d placement condition should bring the target response closer to reinforcement delivery and thus would be expected to produce higher response rates. In contrast the short t^d duration in the early td placement condition should "pull" the target response away from reinforcement delivery and thus would be expected to produce lower response rates than the longer t^d duration. Results show that the short t^d duration in the late t^d placement condition substantially increased response rate (especially in the unsignaled and contingent signal conditions); however t^d duration has inconsistent effects in the early td placement condition. This finding is in general agreement with the results reported by Bruner,

Pulido and Escobar (1999). Bruner et al exposed naïve rats to 64-s temporally defined schedules of delayed unsignaled reinforcement that differed in both t^d placement and duration. Response rates were a decreasing function of lengthening t^d duration on late t^d placement groups; in contrast response rates were homogeneously low in most early t^d groups. Both the results of the present study and those of Bruner et al, differ from Weil´s findings (where decrease in t^d duration was always associated with an increase in response rate). The present authors find no clear explanation to account for the differences between the studies (regarding this manipulation); future experiments could determine if they may be attributed to carry over effects, species idiosyncrasies or other variables.

Results from the present study showed that delay of reinforcement effects are strongly related to the presence (or absence) of signals during delay interval. A frequent and consistent finding regarding signaled delay of reinforcement procedures suggests cue presentation during delay interval is associated with higher response rates than those produced under unsignaled delay conditions (see Pulido, Lanzagorta, Morán, Reyes and Rubí, 2004 for a review). In view of the consistency of this finding, the results of the present study are perplexing. In this study, the response rates produced by unsignaled and contingent-signal conditions were very similar; in contrast, response rates produced by non-contingent signal conditions were significantly lower than those produced on the later conditions. Thus the previous hypothesis developed to explain the more usual finding is inadequate to account for the present data. Results from the present study could probably be accounted for by a theory based on the assumption that signal function during delay of reinforcement interval strongly depends on the particular reinforcement contingencies that each schedule presents to the subject. Temporally defined schedules of reinforcement were initially developed to produce a vast array of behavioral effects by making it "easier" or "more complicated" to allocate a response during t^d. Small t^d values promote high rates of responding because they have a higher probability of allocating a response during t^d and thus producing reinforcement. In contrast, as the t^d /T ratio approaches the unity response rate and reinforcement rate cease to maintain a strong correlation and pauses in responding may develop. If temporally defined schedules of reinforcement modulate response rate by making interreinforcer interval probing more (or less) relevant for reinforcement delivery then a non-contingent cue occurring during t^d should disrupt schedule control of behavior and homogeneously low response rates should appear (which is actually the case in the present study). In contrast unsignaled t^d conditions and response-produced signals conditions should "force" the animal to produce continuous and frequent interreinforcer interval "probing behavior", and thus homogeneously high rates of responding should be associated with these conditions (which are actually

the findings of the present study). To summarize data from the present study suggest signal function in delay of reinforcement studies is not static, rather its effects on behavior should be understood in terms of the particular reinforcement contingencies each schedule presents to the subject.

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