

## **EFFECTS OF SIGNAL DURATION ON RESPONSE ACQUISITION WITH DELAYED REINFORCEMENT UNDER TEMPORALLY DEFINED SCHEDULES OF REINFORCEMENT**

*EFFECTOS DE LA DURACIÓN DE LA SEÑAL SOBRE  
LA ADQUISICIÓN DE LA RESPUESTA CON PROGRAMAS DE  
REFORZAMIENTO DEMORADO DEFINIDOS TEMPORALMENTE*

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### **ABSTRACT**

This study assessed the effects of signal duration and  $t^d$  duration on response acquisition of lever-pressing by rats. Thirty naïve male Wistar rats were exposed to one of ten different 32-s temporally defined schedules of delayed, signaled reinforcement. Reinforcement cycles were divided into two temporal time windows,  $t^d$  and  $t$  delta; responses emitted during  $t^d$  produced reinforcement at the end of the cycle; responses emitted during  $t$  delta had no programmed consequences.  $t^d$  was located at the beginning of the reinforcement cycle and was fixed at one of two different values (4-s or 8-s). The first response emitted during  $t^d$  produced an audible tone of different duration; tone duration

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was varied across groups. Results showed variability, however evidence of response acquisition was more apparent with the long  $t^d$  duration and with the longer signals. This effect could probably be attributed to the interaction of Pavlovian, and mnemonic variables with stimulus discrimination processes.

**Key words:** Delayed reinforcement, lever-pressing, response acquisition, signal duration, temporally defined schedules,

## RESUMEN

Se evaluaron los efectos de la duración de la señal y la duración de  $t^d$  sobre la adquisición del palanqueo en ratas. Treinta ratas macho de cepa Wistar fueron expuestas a uno de diez programas de reforzamiento demorado señalado, definidos temporalmente de 32-s. Los programas se dividieron en dos porciones,  $t^d$  y  $t$  delta. La primera respuesta durante  $t^d$  producía alimento al finalizar el ciclo; las respuestas durante  $t$  delta no tuvieron consecuencias programadas.  $t^d$  se colocó al inicio del ciclo y se fijó en uno de dos valores (4-s u 8-s). La primera respuesta emitida durante  $t^d$  produjo un tono auditivo; la duración del tono varió entre los grupos. Los resultados mostraron que la adquisición de la respuesta fue más aparente cuando  $t^d$  tuvo un valor de 8-s y con las señales más largas. El efecto podría atribuirse a la interacción de variables Pavlovianas, y mnémicas así como a procesos de discriminación de estímulos.

**Palabras clave:** Reforzamiento demorado, palanqueo, adquisición de la respuesta, duración de la señal, programas definidos temporalmente.

Studies have shown that lever pressing by rats and key pecking by pigeons may be established in the absence of explicit shaping and under conditions of delayed un signaled reinforcement (Lattal & Gleeson, 1990; Van Haaren, 1992, Dickinson, Watt & Griffith, 1992). Response acquisition with delayed reinforcement may occur under different delay of reinforcement procedures (Wilkenfield, Nickel, Blakely & Poling, 1992) and under intermittent reinforcement schedules (Bruner, Avila & Gallardo, 1994). Critchfield & Lattal, (1993) and Lattal & Metzger (1994) have found evidence of response acquisition under delayed reinforcement of spatially defined operants by rats and Siamese fighting fish.

The previous studies suggests some research has focused on the description of the conditions under which response acquisition of free-operant responding may occur, other studies however have centered on the description of variables that may facilitate the development of new behavior reper-

tories. For instance, Critchfield & Lattal (1993) exposed rats to tandem FR1, RDO 30-s schedules where the response identified for reinforcement was the interruption of an infrared light beam located at the top of a conditioning chamber. The authors compared conditions where the emission of the response produced a brief auditory signal with conditions in which the response produced no programmed signal. Results showed response frequency in both groups increased gradually and reached very similar rates. Results also showed that the response-reinforcer ratio was higher in the signaled group than in the unsignaled group .

Schlinger, & Blakely (1994), exposed rats to tandem RF1, RDO 4 and 10-s where light beam interruption produced reinforcement after the delay interval. Results showed that light beam interruption rate consistently increased in both the signaled and the unsignaled groups, however subjects exposed to the condition where the response was followed by a brief tone, produced higher response rates, in fewer sessions, than subjects that did not receive the cue. The effect of the tone was consistent across both delay durations.

Williams, (1999) exposed groups of naïve rats to tandem FR1, FT 30-s schedules where subjects could be exposed to and unsignalled delay condition or to signaled conditions that differed in cue temporal location during the delay interval. For some subjects a 5-s change in illumination occurred immediately after the response; other subjects received the cue 5-s before reinforcement delivery. Results showed signal location had opposite effects, when the signal immediately followed the response, it substantially facilitated learning, in contrast, when the signal occurred just before reinforcement delivery, response acquisition did not develop. Both reinforcement and response rates produced by the unsignaled delay condition were intermediate between the two signaled conditions.

Using temporally defined schedules of reinforcement (Schoenfeld, & Cole, 1972), Pulido, Lanzagorta & Lopez (2005) exposed experimentally naive rats to 32-s reinforcement cycles (T) where a response located at the beginning of the cycle produced reinforcement at the end of T. In some groups a response produced a 4-s tone, in other groups the response produced an 8-s tone, in still other groups the response identified for reinforcement was unsignaled. In general, lever pressing in signaled reinforcement conditions was higher than lever pressing frequency in the unsignaled group. Lever pressing rates produced by the two signaled conditions were similar, however response variability was higher in the group with the shorter signal.

In general, the studies presented in this paper suggest response acquisition may be enhanced by the presentation of exteroceptive stimuli, immediately after the response identified for reinforcement occurs. Results produced so far also suggest signal duration may modulate the response enhancing properties of the signal. For instance in the previously described study by

Critchfield & Lattal, response rates produced by groups exposed to briefly signaled and unsignaled conditions did not differ. In contrast, results produced in both the previously described Pulido et al. and Williams studies, showed that longer signals following the response, may produce response rates that are considerably higher than those produced under unsignaled conditions.

The idea that long signals may be associated with evidence of response acquisition is in general agreement with studies conducted by Schaal & Branch using key pecking maintenance as dependent variable. In a first study, Schaal & Branch (1988) exposed pigeons to tandem VI 60-s, FT 1, 3, 9 and 27-s. Pigeons received the tandem schedules arranged within a multiple schedule where, in one component, a .5-s change in illumination signaled component transition; in a second component the illumination change was presented throughout the FT. In general, results suggested the long signal maintained higher key pecking rates than the brief signal (especially with the longer delay duration). In a second study Schaal & Branch (1990) exposed pigeons to a tandem VI 60-s FT 27 schedule, and signal duration was systematically varied throughout the FT component. In general, results showed a direct relationship between signal duration and response rate. Schaal & Branch compared their results with experiments conducted using a classical conditioning procedure where trace conditioning has been found to sustain lower CR frequencies than delay conditioning (Newlin & Lolordo, 1976). This comparison led the authors to suggest that their studies probably show how signals acquire response eliciting properties during signaled delay of reinforcement procedures. Thus a first purpose of the present study was to assess the generality of the previous finding using response acquisition as dependent variable and rats as subjects. The selection of response acquisition as dependent variable will permit a more direct comparison with the classical conditioning literature cited by Schaal & Branch (where the dependent variable is generally CR acquisition). The use of rodents as experimental subjects will permit the assessment of species generality regarding the Schaal & Branch's findings.

With the exception of the Pulido et al (2005) study, the rest of the studies featured in this paper have used experimental procedures that allow programmed reinforcement rate to co vary with change in delay duration (Lattal, 1987). Because programmed reinforcement rate has been found to have important effects on response rate (Clark, 1958) a second purpose of the present study was to assess the effects of signal duration on response acquisition using temporally defined schedules of delayed signal reinforcement (Schoenfeld, Lang & Mankoff, 1973) to program reinforcement contingencies. Weil suggested this type of temporally defined schedule could avoid confusion between programmed reinforcement rate and delay duration because interreinforcer interval is fixed at a predetermined value and delay duration is varied by means of systematically changing the duration of the opportunity to

respond ( $t^d$ ). Experiments conducted using this metric have been previously used to study unsignaled delay of reinforcement effects on response acquisition (Bruner, Pulido & Escobar, 1999; 2000) and the effects of signaled delay of reinforcement on the same dependent variable (Pulido, Lopez & Lanzagorta 2005; Pulido & Lopez, 2006).

## METHOD

### *Subjects*

Thirty experimentally naive male Wistar Lewis rats were used as subjects. All subjects were approximately five months 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; access to food was then restricted until all subjects reached 80% of their free-feeding weight. Subjects were kept at their prescribed body weights throughout the experiment by means of supplementary feeding following each experimental session. Subjects were kept in the Laboratory *vivarium* under constant temperature conditions and a twelve-hour light-dark cycle (lights on a 7:00 a.m.). All experimental subjects were kept in individual cages with free access to water.

### *Apparatus:*

Sessions were conducted in a Med Associates (ENV 008) rodent operant conditioning chamber made of stainless steel and transparent Plexiglas. The space in which the subjects were studied measured 21 cm in height by 30.5 cm length by 24.1 cm depth. A 3 cm stainless steel rolled lever was placed on the left panel of front wall of the chamber. The lever was placed 3.0 cm above the floor and 3.0 cm apart from a trough type pellet receptacle located on the center panel of the front wall. The pellet receptacle was placed 1 cm above the floor and consisted of a 5 cm square opening 2cm in depth. A force of at least 30.5 grams was required to register the response. A depression of the lever produced an audible click and was counted as a response. A .45 mg pellet dispenser delivered 2 .20 mg pellets in each emission. Pellets were produced by means of remolding pulverized Purina Nutri Cubes. Two 1.1 W, 28 Vdc lights were used to illuminate the experimental chamber. One light was placed on the center panel of back wall of the chamber and was used as a house light. The second light (a pilot light with a white glass translucent cover) was placed 5 cm above the lever and was used to present visual stimuli to the subjects. A sonalert, which delivered a 74.13 dB auditory signal, was attached to the external back wall of the experimental chamber, 5 cm to the right of the house light. The conditioning chamber was placed inside a sound-attenuating larger wooden box equipped with a ventilating fan. Ex-

perimental 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 thirty consecutive response-independent food deliveries using an FT 30-s schedule. All experimental subjects consumed the food in the tray after just one exposure to the schedule. On the second session (and on thirty additional consecutive sessions) the lever was inside the experimental chamber and all subjects were exposed to temporally defined schedules of reinforcement (Schoenfeld & Cole, 1972). The schedules consisted of a repetitive time cycle of fixed duration (T). Two different components alternated within the reinforcement cycle ( $t^d$  and  $t$  delta). The first response emitted during  $t^d$  produced reinforcement at the end of the 32-s cycle; responses during  $t$  delta were recorded but had no programmed consequences.  $t^d$  was always placed at the beginning of the cycle in order to separate the response identified for reinforcement from food delivery. Because responses could occur during  $t$  delta, (or 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, Cole, Lang & Mankoff, 1973). This experiment can also be conceptualized as a between subjects factorial design with two factors: 1)  $t^d$  duration (4-s or 8-s).  $t^d$  was varied in order to assess at least two different response-reinforcer temporal relations. For the shorter  $t^d$  value, programmed reinforcer delay could reach a minimum duration of 28-s; for the longer  $t^d$  value programmed reinforcement delay could reach a minimum duration of 24-s. 2) Signal duration. For those subjects exposed to  $t^d=4$ -s signal duration could be fixed at either 0, .5, 4, 8 or 32-s; for those subjects exposed to  $t^d=8$ -s conditions, signal duration could be fixed at either 0, .5, 8, 16 or 32.s. It may be objected that this design does not allow the comparison of the same signal durations across the two  $t^d$  values, however it allows a perfect proportionality between  $t^d$  duration and signal duration. Without pertinent data to make an empirically supported design decision, proportionality was chosen over comparability.

In signaled conditions, the cue was always produced by the first response emitted during  $t^d$ , and thus obtained signal duration could be shorter than nominal signal duration. The signal consisted of the simultaneous darkening of the house light, and illumination of the pilot light (accompanied by the presentation of the previously described audible tone). Figure 1 shows a schematic representation of the experimental procedures.

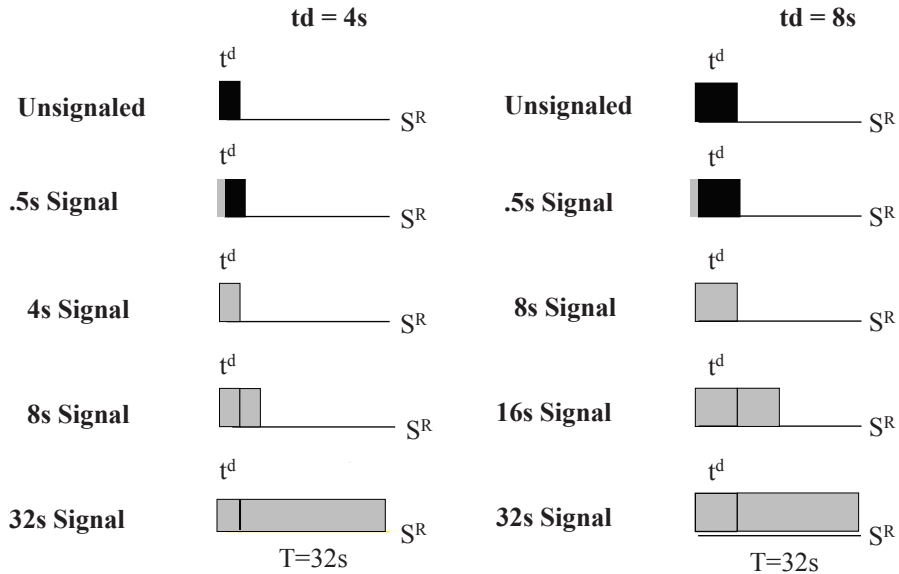


Figure 1. Schematic representation of the experimental procedure.

Three animals were assigned to each experimental condition. Sessions were conducted 6 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

Figure 2 shows mean number of responses emitted per minute for all three animals in each session for all sessions and experimental conditions. Response rate is shown as a function of exposure to the different reinforcement schedules used in the study. To facilitate the description of the data, short  $t^d$  conditions are placed on the upper part of the figure; long  $t^d$  conditions are placed on the lower part of the figure. The first column in the figure shows the unsignaled  $t^d$  condition. For both  $t^d$  conditions, signal duration increases from left to right

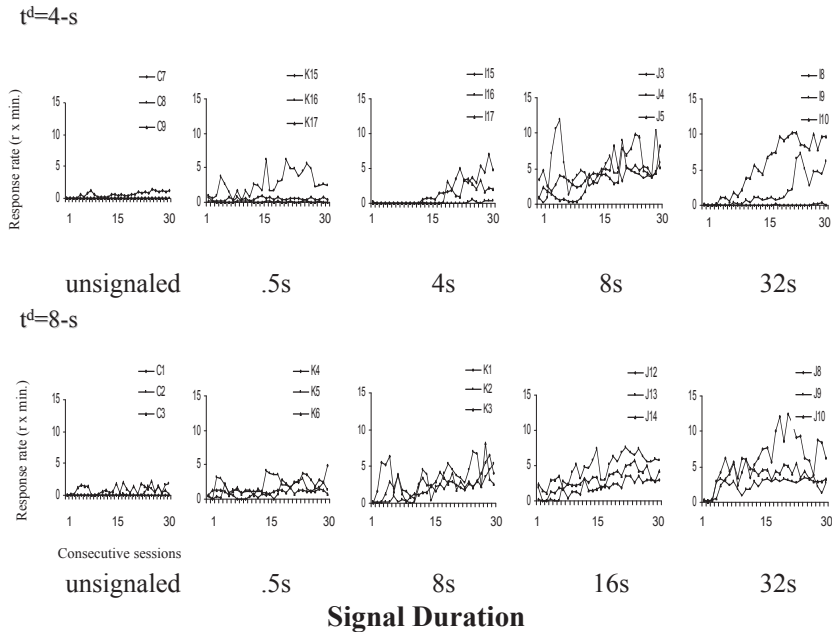


Figure 2. Response rate per minute for each subject on each experimental session for all experimental conditions.

In general, results showed response rates were lower in unsignaled conditions than in those conditions where a cue occurred during delay interval. Response rate variability differed among the two  $t^d$  conditions; in general responding was more consistent in the long  $t^d$  conditions. Under long  $t^d$  conditions, response rates were low in the unsignaled and .5-s signal conditions and comparatively higher with longer signal durations (reaching its maximum height with subject J8 in the 32-s signal condition). Under short  $t^d$  conditions responding in the unsignaled, .5-s and 4-s conditions was relatively low and generally circumscribed to one subject (K16 in the .5-s signal condition) or the later experimental sessions (as was the case of subjects I15 and I17 in the 4-s signal condition). Five subjects reached high response rates under 8-s and 32-s signal conditions, particularly J4 (in the 8-s signal condition) and I10 (in the 32-s signal condition).

Due to the high response variability shown by figure 2, and in order to assess the effects of the independent variables in the first and last experimental sessions, figure 3 was designed to show the mean response rate of each subject for the two  $t^d$  conditions in the first and last 5 experimental sessions.



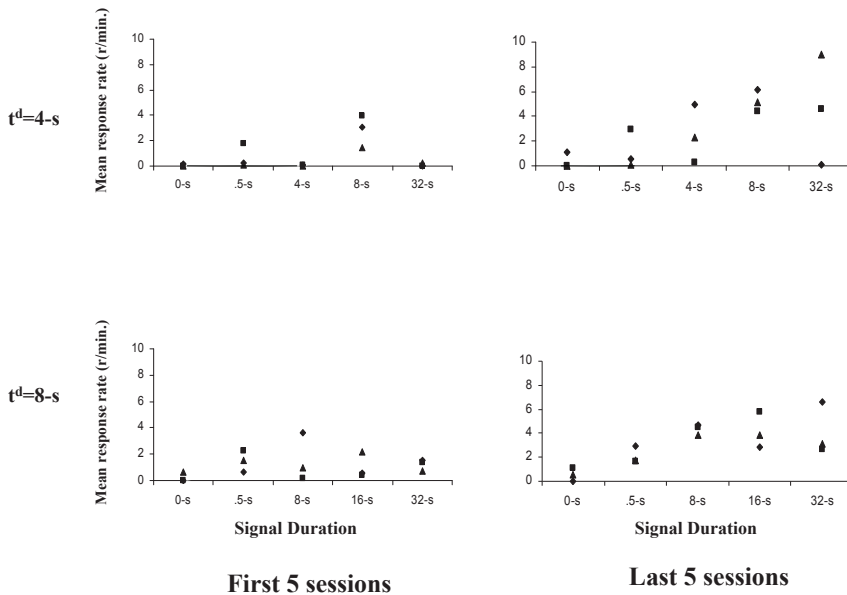


Figure 3. Mean response rate per minute for each subject on each experimental condition in the first and last 5 experimental sessions.

Figure 3 confirms the pattern showed in figure 2, regarding response variability; in general individual means were more closely “bunched together” under the long  $t^d$  duration than in the short condition. Also response rates in the first and last sessions differed less under the long  $t^d$  condition than in the short condition. In relation with the first experimental sessions, response rates reached higher numbers under signaled conditions when  $t^d=8-s$ ; with the shorter  $t^d$  value this was only true with .5-s and 8-s signals. Regarding the last experimental sessions, most subjects exposed to signaled conditions emitted more responses than those subjects exposed to unsignaled conditions. Additionally the highest response rates produced in each condition are a direct function of signal duration. A slope produced by the highest response rates produced under the long  $t^d$  value is less steep than that produced when  $t^d=4-s$ , however response variability is considerably smaller in the former than in the later condition. Evaluation of the slopes produced by the highest subject in each condition is only and indirect was of assessing the effects of signal duration on response rate; in order to more thoroughly weight the effects of this independent variable, the regression equation between signal duration and response rate produced in the last five experimental sessions was calculated for both  $t^d$  durations. The regression equation for  $t^d=4-s$  may be described as follows:

$y = (.107)x + 1.812$ . The slope of the equation attained statistical significance ( $t(74) = 4.203, p = .000$ ). The regression equation when  $t^d=8$ -s may be described as follows  $y = (.091)x + 1.990$ . The slope of the equation attained statistical significance ( $t(74) = 5.071, p = .000$ ). In order to further assess the effects of signal duration, and also assess the effects of  $t^d$  duration in the last five experimental sessions, an overall two-way analysis of variance was also calculated. The analysis showed signal duration had a significant effect on response rate ( $F(5/140)=22.849, p=.000$ ) however  $t^d$  duration did not ( $F(1/150)=.059, p=.809$ ); the interaction between  $t^d$  duration and signal duration did not attain significance ( $F(3/140)=1.014, p=.389$ ).

Figure 4 shows mean response rate per minute emitted during four different successive 8-s subintervals of the reinforcement cycle. The data are presented with the purpose of determining the effects of signal presentation on local response rate; the data are also presented as an indirect way of assessing obtained delay. Response rates from the last five experimental sessions, from each subject, were averaged to produce the figure. Long  $t^d$  duration conditions are displayed on the lower part of the Figure and short  $t^d$  conditions are presented on the upper part. For both  $t^d$  conditions, signal duration increases from left to right.

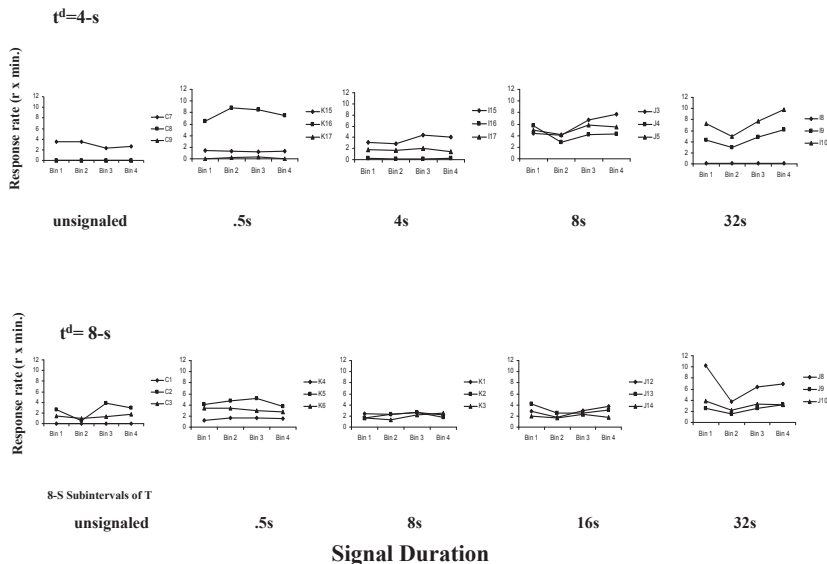


Figure 4. Mean response rate per minute in consecutive 8-s bins of the reinforcement cycle for the last five sessions. Response rate is shown for each subject and for all experimental conditions.

Figure 4 is in general agreement with the data presented in both figures 2 and 3; response rates in the signaled conditions are higher than those produced in the unsignaled conditions. Under the long  $t^d$  duration response distribution across the reinforcement cycle is relatively flat, the exception is the 32-s signal condition where response rate decreases during the second bin and then gradually increases again. Under  $t^d=4$ -s conditions, response rates are once again flat under unsignaled and brief signal conditions but at least one subject in the 8-s signal condition and two subjects in the 32-s signal condition show the distinctive “V” pattern previously described for the  $t^d=4$ -s groups. Data from figure 4 should be analyzed carefully as no provision was made, in the computer program, to separate cycles where a signal had occurred, from those cycles where a signal did not occur. A recent study by Pulido, Backer & Rubi (2003) suggests the distinctive “V” pattern previously described may be composed of signaled cycles where high response rates occur during the onset of the signal (bin 1) and are then followed by a sharp decline in responding once the signal has commenced (bin 2). The increase in response rate observed in bins 3 and 4 may occur in unsignaled cycles where the subject gradually increases response rate following reinforcement delivery. Data produced by Pulido, Paz & Sosa (2008) also suggest that once the response targeted for reinforcement has occurred, local response rate drops abruptly during the delay interval.

The issue regarding the identification of criteria that may be used to determine if response acquisition has taken place is far from solved. In the present study response acquisition was arbitrarily defined as obtaining at least 10 reinforcers at one of six different moments during the course of the experiment (5, 10, 15, 20, 25 or 30 sessions). Although any definition of response acquisition is arbitrary, the selection of 10 reinforcers as “the cut point” was preferred because the probability of earning at least 10 reinforcers given that no acquisition has occurred (zero mean), in a normal distribution is .0001. The decision to keep 10 reinforcers as response acquisition criterion was also supported by the fact that the frequency analyses carried on the data presented on table 1 did not change substantially with more stringent cut points.

Table 1 shows the experimental label of the subjects that had earned 10 reinforcers by the time a certain number of experimental sessions had elapsed. In the table the session number is presented in the top horizontal frame and the experimental conditions are presented in the left column.

**Table 1. Subjects that had earned 10 or more reinforcers by the “x” session**

<i>Experimental Conditions</i>	<i>Session</i>					
	5	10	15	20	25	30
<b>td=4</b>						
<b>0</b>	*	*	*	*	*	*
<b>0.5</b>	K16, K17	K16	K16	K16	K16	K16
<b>4</b>	*	*	*	I15, I17	I15, I17	I15, I17
<b>8</b>	J3, J4	J3, J4	J3, J4, J5	J3, J4, J5	J3, J4, J5	J3, J4, J5
<b>32</b>	*	I10	I10	I10	I9, I10	I9, I10
<b>td=8</b>						
<b>0</b>	C3	*	C3	C3	C2, C3	C2
<b>0.5</b>	K4, K5	K5, K6	K5, K6	K4, K5	K4, K5, K6	K4, K5
<b>8</b>	K1, K3	K1, K3	K1, K3	K1, K2, K3	K1, K2, K3	K1, K2, K3
<b>16</b>	J12, J14	J12, J13, J14	J12, J13, J14	J12, J13, J14	J12, J13, J14	J12, J13, J14
<b>32</b>	J8, J9, J10	J8, J9, J10	J8, J9, J10	J8, J9, J10	J8, J9, J10	J8, J9, J10

Subjects are identified by their experimental labels. If no subject had reached the criterion an asterisk is placed in the corresponding cell.

*Table 1. The Table shows the labels of the experimental subjects that had earned ten or more reinforcers by the time a determined experimental session had elapsed.*

In general table 1 shows that response acquisition criteria was met more frequently in the last three columns (sessions 20, 25, 30) than in the first three (sessions 5, 10, 15) (if subjects are counted only once). In table 1 the criterion was met 22 times in the last columns and only 17 times in the first columns.

Table 1 was also used to assess the effects of  $t^d$  duration on response acquisition. Results from the table showed that the response acquisition criterion was met more frequently in the long  $t^d$  conditions (14 times) than in the short  $t^d$  conditions (9 times).

Table 1 showed that the response acquisition criterion was met more frequently with the long signals than with the short ones. The table shows that in the absence of the signal, or in 0.5-s signal conditions, the response acquisition criterion was met only 7 times; in contrast response acquisition criterion was met 11 times with the longer signal durations (8-s and 32-s under  $t^d=4$ -s conditions and 16-s and 32-s under  $t^d=8$ -s conditions).

An important number of studies have shown that interreinforcer interval duration is strongly related to signal effects in delayed reinforcement studies (Schaal, Schuh & Branch, 1992; Schaal, Odum and Shahan, 2000). Programmed interreinforcer interval is always constant under temporally defined

schedules of reinforcement, however obtained cycle duration may be highly variable (Schoenfeld y Cole, 1972). To determine how interreinforcer interval duration could have affected the present results, table 2 shows mean reinforcement rate for each subject for the last five experimental sessions. Table 2 was also elaborated as an indirect way of assessing signal presentation effects. As the experimental procedure only presents signals when the subject emits a response during  $t^d$ , and only responses presented during  $t^d$  produce reinforcement, obtained reinforcement rates are also a measure of obtained signal presentation rates.

**Table 2, Reinforcement and signal presentation rate**

$t^d=4-s$			$t^d=8-s$		
	Signal Duration		Signal Duration		
0-s	C7	.164	0-s	C1	0
	C8	0		C2	.225
	C9	0		C3	.121
0.5-s	K15	.065	0.5-s	K4	.399
	K16	.184		K5	.243
	K17	0		K6	.22
4-s	I15	.488	8-s	K1	.642
	I16	.043		K2	.655
	I17	.303		K3	.451
8-s	J3	.506	16-s	J12	.648
	J4	.325		J13	.857
	J5	.259		J14	.583
32-s	I8	.012	32-s	J8	1.5
	I9	.439		J9	.616
	I10	.715		J10	.648

*Table 2. The Table shows mean reinforcement and signal presentation rate for each subject on each experimental condition for the last five sessions.*

The lowest reinforcement rates in the table occur in the short  $t^d$  condition and in the absence of the signal. Reinforcement rate for the long  $t^d$  conditions is significantly different than that produced by the short  $t^d$  conditions ( $t(28)=2.59$ ,  $p<.05$ ) (and thus the two  $t^d$  durations also differ in obtained signal presentation rate).

## DISCUSSION

The results from the present study suggest that the presentation of an exteroceptive stimulus during delay interval may considerably enhance evidence suggesting acquisition of free operant behavior. This finding is in general agreement with results produced by Critchfield & Lattal, (1993) Schlinger & Blakely, (1994) and Pulido, Lanzagorta & López, (2005). The results from the present study also showed longer signals are probably associated with higher response rates than shorter ones (at least under the long  $t^d$  duration). The effects of signal duration were however variable and lack the clear impact found in the Schaal & Branch studies (1988; 1990). The comparison of the present results with the Schaal and Branch experiments, suggest that the effects of independent variables may be more variable when response acquisition is used as a dependent variable, relative to those studies where steady state behavior is used as dependent variable. This finding had already been reported by Pulido, López & Lanzagorta (2005) and Pulido & López (2006) who exposed rats to temporally defined schedules and varied the type of signal the animals received during  $t^d$ . Results showed response rates were low when the subjects received a non-contingent signal and comparably higher when the signal was response-produced. The result was the same regardless of the dependent variable used, however response rate variability was considerably higher when response acquisition was the dependent variable. The authors acknowledge that lack of systematic effects and behavior variability could also be attributed to the experimental procedure, specifically to the subject's possibility of changing signal duration by responding early or late during  $t^d$ .

Schaal and Branch's 1990 study showed response rate during the delay interval was relatively unaffected by signal duration, a finding that generally agrees with the relatively flat functions showed in figure 4. As classical conditioning studies have shown that the CR varies with delay duration in trace conditioning procedures (Ellison & Konorski, 1964), the results of the present study appear to give support to the Schaal & Branch's suggestion that a respondent-conditioning account of signal effects in delayed signaled reinforcement schedules, appears insufficient (although this argument would be more compelling if the present study had been capable of presenting a separate analysis of response distribution during signaled and unsignaled reinforcement cycles). Reinforcement rates produced by the two different  $t^d$  durations showed reinforcement was more frequent under the long  $t^d$ ; signal effects were also more noticeable with the longer  $t^d$  duration. This last finding is also difficult to reconcile with a respondent-conditioning account of the present data, because most studies regarding the effects of interreinforcer interval on classical conditioning have shown that signal effects are more potent un-

der longer interreinforcer intervals (Gibbon, Baldock, Locurto, Gold & Terrace, 1977; Kaplan, 1984). It may be argued however that subjects assigned to the short  $t^d$  duration earned fewer reinforcers and were thus less exposed to the particularities of their corresponding reinforcement schedules. Perhaps if the present study had equated schedule exposure for both  $t^d$  durations based on a performance criterion (instead of simply equating them in terms of the number of experimental sessions) results could make a stronger case against (or in favor) of a respondent-conditioning interpretation of signaled delayed reinforcement.

If a respondent-conditioning interpretation is insufficient to adequately account for the present data, how can they be accounted for? Richards (1981) and Schaal & Branch, (1990) have suggested behavior different from the one selected for reinforcement may be superstitiously reinforced during the delay interval. In unsignaled delay conditions these behaviors may generalize to all components of the schedule and compete with lever pressing (thus lowering overall response rate). In the presence of a signal (specially a long signal) superstitious behaviors may come under discriminative control of the cue and thus their generalization to other components of the schedule may be minimized (which in turn increases overall response rate). As was the case of the respondent-conditioning hypothesis, a superstitious behavior generalization account of the present data could better be assessed had data from reinforced and unreinforced cycles been separated, (in any case however figure 4 suggests some subjects exposed to the longer signals may be behaving in the way predicted by the superstitious behavior hypothesis). As it was mentioned before, a study by Pulido, Backer & Rubi (2003) suggests that the distinctive "V" patterns that appeared in figure 4 may in fact consist of the added effects of two different conditions. The high response rates produced in the first bin and the subsequent decline observed in the second bin may in fact reflect what occurs in the signaled reinforcement cycles. Apparently the onset of the signal elicits high response rates which are subsequently followed by an abrupt decline in responding. In contrast responding during unreinforced cycles is relatively low following reinforcement delivery and gradually increases reaching a peak during the third and fourth bin. In summary, at least with the longer signals some subjects display behavior that may be consistent with a superstition hypothesis (that is response rates are low during the signal because competing behavior may suppress lever pressing; in contrast, response rates remain high during unsignaled cycles because superstitious behavior is under control by the cue and thus does not disrupt lever-pressing behavior).

But how can signal effects be explained in the vast majority of the subjects where response rates remained more or less homogeneous throughout the reinforcement cycle? One possibility could derive from an analysis of obtai-

ned delays. Figure 4 suggests responding during the reinforcement cycle was continuous throughout the reinforcement cycle and thus obtained delays were considerably shorter than programmed delays. Comparably lower response rates produced in un signaled conditions could probably favor longer obtained delays which would in turn further diminish response rate.

The differences in response rate between the un signaled and briefly signaled conditions could also be understood in terms of a marking hypothesis. Lieberman, McIntosh & Thomas (1979) suggested brief signals may increase operant behavior under conditions of delayed reinforcement because the response that produces the signal is "marked" in the subject's memory and this "mnemonic salience" makes it easier to associate the response with its consequence. In order to properly assess a marking hypothesis both responses during  $t^d$  and responses occurring outside  $t^d$  should have been followed by a signal (although the later should not produce food). In the absence of the appropriate control condition data from the present study can not confirm (or disconfirm) a marking account of the present data.

Results from the present study showed no significant differences between response rates produced in the two  $t^d$  conditions, (although reinforcement rates and signal presentation rates in both conditions did differ). This finding is in general agreement with data produced by Pulido, López & Lanzagorta (2005) and Pulido & López (2006). Taken together, these studies suggest manipulating reinforcement delay by varying  $t^d$  value produces inconsistent results. In the present study  $t^d$  was only varied across two different values (4 and 8-s) however other studies have assessed a greater number of  $t^d$  durations finding, in general, the same lack of effects (Bruner, Pulido & Escobar, 2000) or counterintuitive effects (Weil, 1984). These findings coincide with the ideas presented by Pulido & López (2006) who have suggested that delay gradients in temporally defined schedules of reinforcement appear when  $t^d$  placement is changed within the reinforcement cycle (but may not occur by exclusively varying  $t^d$  duration across the cycle). If both changing  $t^d$  placement and varying  $t^d$  duration change the temporal separation between the response and the reinforcer, it is not clear why one procedure should produce a delay gradient and the other should not. A possible explanation for this empirical problem is that in studies where  $t^d$  placement has been moved across T, relatively short  $t^d$  values have been used (granting a "tighter control" over obtained delays). However when  $t^d$  duration has been systematically varied, relatively long  $t^d$  values have produced highly variable obtained delays. A future study where long  $t^d$  values are systematically varied across de reinforcement cycle could probably give more information regarding the relevance of "tight control" over obtained delays on delay gradients produced by temporally defined schedules of reinforcement.



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