

**PUNISHMENT OF SCHEDULE-INDUCED DRINKING
BY LICK-DEPENDENT DELAYS IN FOOD
PRESENTED AT DIFFERENT FREQUENCIES**

RICARDO PELLÓN and JOSÉ LUIS CASTILLA
Universidad Nacional de Educación a Distancia, Madrid, Spain

Three food-deprived rats (80% of their free-feeding weights) developed schedule-induced drinking after being exposed to a multiple fixed-time schedule (FT 60-s FT 18-s) of food-pellet presentation. A 3-s signaled delay was then initiated by each lick, and the rate of licking was reduced to a much greater extent in the FT 18-s component in two rats. With these rats, a 9-s lick-dependent signaled delay then occurred in the FT 60-s component only, and a reduction was observed in licks per minute similar to that observed previously with the 3-s delay in the richer component. With the third rat the delays which were effective in reducing licking were 6 and 18 s in the FT 18-s and FT 60-s components, respectively. Measures of the percentage of interfood intervals with at least one lick produced less pronounced effects. These results suggest that the ratio between delay length and interfood interval length is critical for lick-dependent delays to be effective in punishing schedule-induced drinking.

Falk (1961) found that food-deprived rats exposed to a variable-interval schedule (VI 1-min) of food reinforcement drank excessive amounts of water concurrently with their performance of the operant task. This behavior is unusual because the rats were not deprived of water and no contingency was arranged between their drinking and the delivery of food. Falk (1971) suggested that this schedule-induced polydipsia was the prototype of a behavioral class named "adjunctive behavior," different from operant behavior. The amount of schedule-induced behavior is related to the parameters that define the food reinforcer, such as its magnitude or quality, the rate at which food is presented, or the animal's level of food deprivation (see reviews by Pellón, 1992; Reid & Staddon, 1990; Wetherington, 1982).

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There is now considerable evidence showing that the rate of schedule-induced drinking is sensitive to environmental consequences programmed in relation to the rats' licking, in a way similar to rats' lever pressing reinforced by food. For example, Bond, Blackman, and Scruton (1973) reported that schedule-induced drinking was reduced by a punishment procedure in which licking produced electric shocks. Pellón and Blackman (1987) showed that schedule-induced drinking can be reliably suppressed by lick-contingent delays in food presentation (see also Flory & Lickfett, 1974; Lamas & Pellón, 1995a). Reberg (1980) observed that schedule-induced drinking was increased when licks produced extra food and decreased when extra food was dependent on not licking. These functional similarities between adjunctive and operant patterns of behavior are important considerations for an adequate explanation of schedule-induced behavior.

The studies by Pellón and Blackman (1987) were the first to demonstrate convincingly a negative punishment effect on schedule-induced drinking. Well-established drinking induced by a fixed-time (FT) 1-min schedule of food pellet presentation (in which no operant response is required for food to be delivered) was punished by 10-s signaled and unsignaled lick-dependent delays in the delivery of food. The suppression of schedule-induced drinking was more marked and better modulated by signaled delays.

The literature on the effects of lick-dependent delays as punishers of schedule-induced drinking remains contradictory, however. Earlier reports suggested a relative insensitivity of schedule-induced drinking to being reduced or eliminated by delays in food presentation. Falk (1964) reported that drinking induced by a VI 1-min schedule of food reinforcement was not eliminated or even reduced by the imposition of a contingency that ensured a delay in food delivery of at least 15 s from the last lick. Hawkins, Schrot, Githens, and Everett (1972) reported that drinking induced by a FT 1-min schedule of food delivery was not reduced even by lick-dependent delays as long as 4 or 5 min. These studies arranged quite particular contingencies between licks and food delivery so that delays in food presentation were not initiated by all licks. In Falk's study, delays in food delivery were produced *only* by licks that occurred in the last 15 s of the interreinforcement intervals; in the study of Hawkins et al., delays occurred *only* after the first "drink" (defined as five licks) in each interfood interval.

Flory and Lickfett (1974) also reported that schedule-induced drinking is relatively resistant to the effects of lick-dependent delays in reinforcement. They found that rats' schedule-induced drinking was never eliminated, although it was systematically reduced, as the duration of lick-contingent time-outs from a fixed-interval schedule (FI 1-min) was increased through four values from 10 s to 80 s. During these periods, the operant response lever was retracted from the experimental test space and the timer that controlled the FI schedule was stopped. With 80-s periods of such lever withdrawal drinking was consistently reduced, and with 40-s and 20-s periods it was reduced in some animals. Similarly, Keehn and Stoyanov (1983) reported a suppression of water consumption when food was only available after 50 s or 60 s from the last lick, a contingency by which licks occurring late in the interfood intervals were more likely to be punished.

When lick-dependent delays in reinforcement have been introduced from the outset of an experiment, essentially similar results have been reported as with previously established schedule-induced drinking; however, the development of schedule-induced drinking has been shown to be more attenuated with un signaled than signaled delays (e.g., Moran & Rudolph, 1980; Lamas & Pellón, 1995b, 1997; Pellón & Blackman, 1991).

The effects of lick-dependent delays of reinforcement on the acquisition and maintenance of schedule-induced drinking appears to be a direct proportion of the delay length (Flory & Lickfett, 1974; Lamas & Pellón, 1995b; Moran & Rudolph, 1980). Such a conclusion is derived from studies where different delay values were superimposed on an interval schedule of a fixed value. The possibility that a fixed delay value would have differential effects on interval schedules of different values remains to be investigated, however. This is the purpose of the present experiment.

Rats were food deprived to 80% of their free-feeding weights and they were then exposed to a multiple FT 60-s FT 18-s schedule of food presentation. All rats developed schedule-induced drinking in both components. Each lick then initiated 3-, 6-, 9-, or 18-s delays in the delivery of the next pellet of food in different phases of the experiment, to determine the degree of punishment of schedule-induced drinking as a function of the different delay values. The lick-dependent delays were signaled by the extinguishing of the experimental houselights.

Method

Subjects

Three experimentally naive male Wistar rats were used. They were provided by IFFA-CREDO (Lyon, France) and were approximately 100 days old at the beginning of the experiment. They were housed individually in an environmentally controlled room (22 °C temperature, 60% relative humidity, and 8 am/8 pm light/dark cycle). The rats' weights were gradually reduced by controlled feeding to 80% of their previously determined free-feeding weights, which were 479, 485, and 490 g. Each animal was maintained at its specified weight by being weighed before each experimental session and being given after that session any food required in addition to that given during the session; this supplement was given at least 15 min after the end of each session. Water was always available in the subjects' home cages.

Apparatus

Three identical standard two-lever Letica Instruments (Barcelona, Spain) LI-836 rodent test chambers were used. These were 29 cm long by 24.7 cm wide by 35.5 cm high and were mounted inside ventilated sound-attenuating chests. The continuous ambient noise resulting from the ventilation fans was approximately 60 dB, which served as masking noise. The front panel of each test chamber was aluminum, the right side wall was dark acrylic, and the other two sides and the roof were

transparent acrylic. Each chamber was equipped with a Letica Instruments pellet dispenser behind the front panel, and it delivered 45-mg precision food pellets (Bio-Serv) to a hopper mounted in the center of the front wall at a distance of 3.7 cm from the grid floor. Both levers in the front wall were withdrawn during the experiment. A water bottle was mounted on the outside of the right wall of each of the chambers. The spout of this bottle was accessible through a hole 3.2 cm wide by 3.9 cm high situated 20 cm from the front wall and 7 cm above the grid floor. The spout was positioned 2 cm behind the hole, so the rat could lick it but could not maintain permanent contact with it. Licks at the spout resulted in a circuit closure, the other end connected to all 20 parallel stainless steel bars of the grid floor. The chambers were illuminated during experimental sessions by a 25-W bulb situated in the front wall of the chest and by two 3-W lamps located in the front panel of each chamber. Observation of the rats during sessions was possible through a small window.

The scheduling and recording of experimental events was achieved by a BBC microcomputer (Acorn Computers Ltd) programmed in SPIDER.

Procedure

When the weight of each rat had stabilized at 80% of its free-feeding weight, it was exposed to a baseline water-ingestion test in its home cage. On 2 successive days, forty 45-mg food pellets were placed together in a dish, and the volume of water consumed during the subsequent 26 minutes was measured. This procedure provided a baseline water intake for the drinking associated with the amount of food which was to be delivered intermittently in the subsequent experimental sessions (Pellón & Blackman, 1987).

The rats were then adapted to the chambers by being exposed to one 26-min session during which no experimental contingencies were operating: About twenty 45-mg food pellets had been placed in the food receptacle, and the houselights were illuminated throughout the session and the ventilation fan was on, but the drinking tubes were not installed.

The rats were then given daily 26-min experimental sessions. Before each session the water bottle in the test chamber was emptied, refilled with 100 ml of fresh tap water, and remounted as described above. The houselights were turned on at the beginning each session and turned off at the end.

In the first stage of the experiment (A), the rats were exposed to sixty 26-min sessions in which 45-mg food pellets were delivered independently of the rat's behavior at regular 60- (FT 60-s) or 18-s (FT 18-s) intervals. FT schedules alternated within a session as in a multiple schedule, the sequence being the same for a given animal during the entire experiment but balanced across animals. A tone was turned on during two 10-min blocks in which the FT 60-s schedule was in operation, and it was turned off during two 3-min blocks of the FT 18-s schedule. The duration of the components was calculated to allow the delivery of 10 food

pellets each time a component was presented. Components were separated by a 10-s time-out in which all lights were turned off. The number of licks at the spout and the number of interfood intervals with at least one lick were recorded separately for the two components each session. For each session the overall volume of water consumed (to the nearest ml) was also measured.

In the second stage of the experiment (B) the multiple FT 60-s FT 18-s schedule continued in operation, but now each lick made by a rat in either component initiated a 3-s delay in the delivery of the next pellet of food to that rat. This delay was accompanied by a blackout. Each lick during a signaled 3-s delay reset the delay. When no lick had occurred for 3 s, the houselights were relit and the FT schedule resumed at the point at which it had been interrupted. Daily sessions lasted 26 minutes, components being held at 10- or 3-min duration for the FT 60- and FT 18-s schedules respectively. Stage B lasted 30 sessions, and data were collected as in the first stage of the experiment. In addition, the number of food pellets presented was also recorded for each rat per component per session.

The procedure previously used in Stage A was then reinstated for an additional 10 sessions; the delivery of food pellets was therefore now once again determined solely by the FT 60-s or the FT 18-s schedules, and the houselights were continuously illuminated.

Stage C was identical to Stage B except for the duration of the signaled delays initiated by the licking of the rats. A 9-s delay was contingent on any lick of Rats 1 and 2 during the FT 60-s components, but no delay accompanied the licking of these rats during the FT 18-s components. Each lick made by Rat 3, however, initiated a 6-s delay in the delivery of the next food pellet in both the FT 60-s and the FT 18-s schedules. Stage C continued for 30 sessions with Rats 1 and 2, and for 10 sessions with Rat 3. Data were collected as described previously.

With Rat 3 two further experimental stages were run. During 10 sessions the procedure used in Stage A was reinstated. For the final 10 sessions, each lick during the FT 60-s components initiated an 18-s signaled delay in the next food pellet presentation (Stage D) but no contingency was added to the licks occurring during the FT 18-s components. Data continued to be collected as described previously.

Results

All three rats developed consistent patterns of behavior during the first stage of the experiment: They consumed the pellets of food promptly upon delivery and then licked and drank from the water spout. All rats drank much more water in each of the last sessions of Stage A than they had in the massed-food tests in their home cages before the experimental sessions began. The mean amount of water drunk during the massed-food tests was 3.7, 3.7, and 2.2 ml for Rats 1 to 3, respectively. The mean water consumption during the last five sessions of Stage A was 12.2 ml for Rat 1, 17.8 ml for Rat 2, and 25.9 ml for Rat 3. This excessive drinking

indicates the development of schedule-induced drinking with all rats, reaching levels of water intake that can be regarded as polydipsic (cf. Stein, 1964).

Table 1 summarizes the mean licks per minute obtained from each rat from the last five sessions of each Stage A of the experiment, in which delays in food delivery were not presented. These data were calculated for each component separately, by dividing the number of licks made per session by twenty or by six respectively for the FT 60-s and the FT 18-s components. Lick rates were between two to five times greater during the FT 18-s schedule than during the FT 60-s schedule at the end of the first stage (Sessions 56-60), reflecting a higher schedule-induced drinking with the greater food frequency. These differences in the rate of licking were maintained throughout the remaining stages without delays. It can be also seen that baseline licking was comparable for each rat across the experiment and was therefore not much affected by the interpolated treatments with delays. In any case, no significant reductions in licks per minute were observed as the experiment progressed from the first experimental phase to later stages without delays.

Table 1

Mean Licks per Minute ($\pm SD$) During Last 5 Sessions of Each Stage in Which Delays Were Not Presented

	Sessions 56-60		Sessions 96-100		Sessions 116-120	
	FT 60s	FT 18s	FT 60s	FT 18s	FT 60s	FT 18s
Rat 1	12.75 \pm 3.03	66.80 \pm 9.32	15.30 \pm 4.18	70.70 \pm 13.18	—	—
Rat 2	33.30 \pm 7.84	110.67 \pm 5.19	53.25 \pm 1.67	120.93 \pm 7.04	—	—
Rat 3	39.61 \pm 4.15	91.20 \pm 8.16	56.29 \pm 10.38	121.97 \pm 10.37	35.92 \pm 12.04	80.03 \pm 21.88

Figure 1 shows the mean number of licks per minute for each of the last five sessions of the stages with delays, represented as the percentage of change with respect to the corresponding preceding baseline response rates (see Table 1). This measure was calculated individually for each rat, by dividing the rate of licking during any of the sessions with the delays by the mean rate of licking of the previous baseline without delays and then multiplying the result by one hundred. The left-hand panel indicates for each rat the effect of the 3-s signaled-delay procedure introduced in Stage B. Licks per minute were decreased in Rats 1 and 2 during the FT 18-s component (open circles), but schedule-induced drinking was not completely abolished. Rat 1 reduced on average to about 20% of the licks per minute in the absence of the delay contingency, and the decreases of Rat 2 were on average to about 65% of the previous rate. However, 3-s lick-dependent delays were not sufficient reliably to reduce the licking of all three rats in the FT 60-s component (closed circles), nor the licking of Rat 3 during the FT 18-s component.

Figure 1 also shows the effects on licks per minute of longer lick-dependent delays. With the FT 60-s schedule and when signaled delays

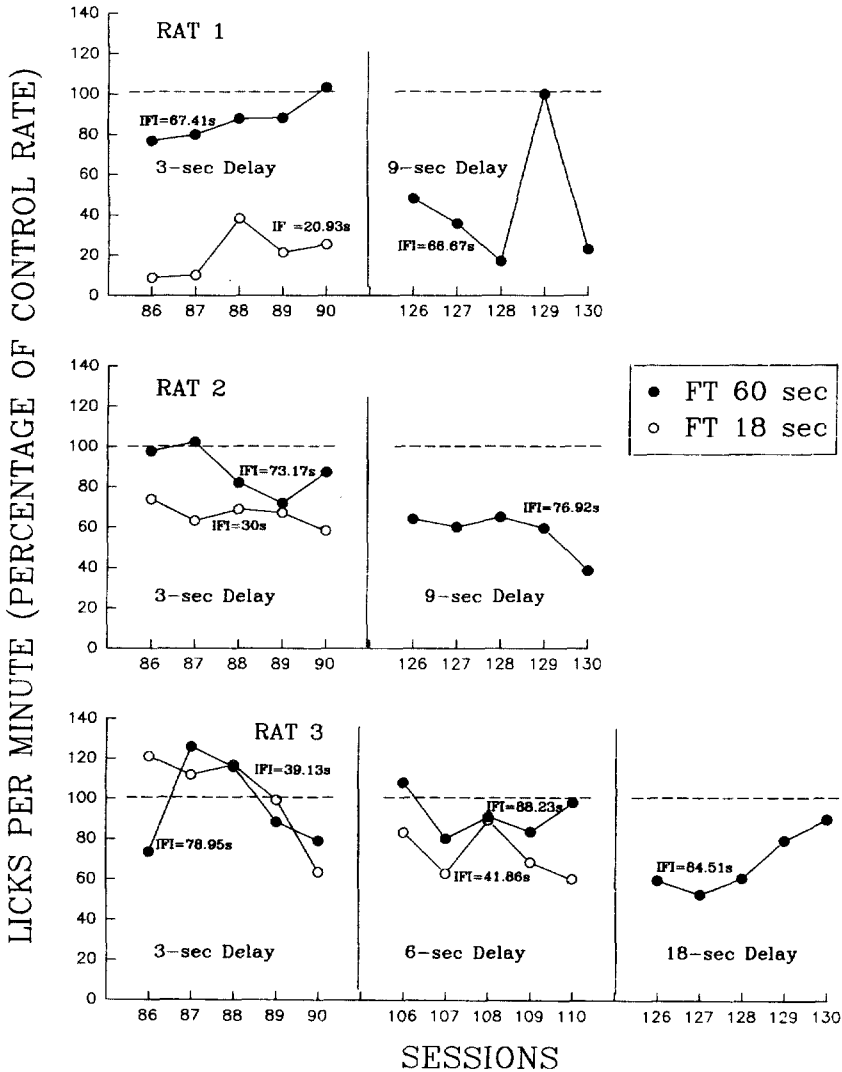


Figure 1. Mean licks per minute for each rat during the last five sessions of the stages with lick-dependent delays in food delivery, accompanied by blackout. These means were transformed into percentages of control rate (see the text). IFI = Interfood interval length given in seconds.

were of 9 s (Stage C), Rats 1 and 2 exhibited much lower scores than they had previously with the 3-s delay in the same schedule. The average reduction in licks per minute was to levels close to 45% and 60% of control rates for Rats 1 and 2 respectively. These levels of suppression were comparable to those observed with 3-s delays in the FT 18-s schedule.

Similar results were found with Rat 3, but at longer lick-dependent

signaled delays than those required to suppress schedule-induced drinking in Rats 1 and 2. In Stage C when a 6-s delay was initiated by any lick made by Rat 3 (middle panel at the bottom of Figure 1), the reduction in licks per minute was proportionally higher during the FT 18-s schedule. This came close on average to 70% of the preceding response rate (open circles), while there were no signs of a significant reduction in licking rate during the FT 60-s schedule (closed circles). In Stage D, and when each lick made by Rat 3 produced a 18-s signaled delay in the delivery of food during the FT 60-s schedule (right-hand panel at the bottom of Figure 1), an average reduction to close to 70% of control rates was obtained in licks per minute in comparison to the preceding behavioral baseline. This suppression was similar to that observed in the same rat with the 6-s lick-delay contingency during the FT 18-s schedule. Lick-dependent delays, however, were not sufficient at any value to cease the licking of Rat 3 completely.

Figure 1 finally includes the mean interfood interval length of the last five sessions for each of the conditions with lick-dependent delays. In all cases the rate of food delivery decreased in comparison to the nominal value of control sessions. These changes were not very substantive with Rat 1, but they were more noticeable with Rat 2 and in particular with Rat 3. Each rat in each component, however, showed very similar interfood intervals across the stages of the experiment despite different delay durations.

For each rat in each session, the number of interfood intervals with at least one lick in either component was divided by twenty and the result was then multiplied by one hundred, in order to calculate the percentage of interpellet intervals in which at least one lick occurred. A summary of the results with this measure is presented in Table 2 for the last five sessions in all stages without delays. At the end of the first stage of the experiment (Sessions 56-60) all animals came to lick during almost all the interpellet intervals, except Rat 1 during the FT 60-s component who licked in approximately 55% of the intervals. With the exception of this rat, therefore there were no differences between the times a rat made the transition to lick from the bottle during FT 60-s and FT 18-s components. This result indicates that the measure of the percentage of interpellet intervals with at least one lick was less sensitive to differences in food frequency than the measure of licks per minute. Baseline responding was not generally altered within the course of the experiment, except for a decrease with Rat 3 during the last presentation of the FT 60-s schedule without accompanying delays (Sessions 116-120).

Figure 2 represents the percentage of interfood intervals in which at least one lick occurred for each of the last five sessions of the stages with delays, graphed as the percentage of change with respect to their corresponding preceding behavioral baseline of each individual rat (see Table 2). This measure was derived as in Figure 1. The pattern of results with Rat 1 is broadly similar to that seen in Figure 1 for the measure of licks per minute. Rat 1 therefore licked in a fewer number of the 18-s intervals with 3-s signaled delays (open circles), and in a fewer number of the 60-s intervals with 9-s signaled delays (closed circles). These data

Table 2

Mean Percentage of Interfood Intervals ($\pm SD$) With at Least 1 Lick During Last 5 Sessions of Each Stage in Which Delays Were Not Presented

	Sessions 56-60		Sessions 96-100		Sessions 116-120	
	FT 60s	FT 18s	FT 60s	FT 18s	FT 60s	FT 18s
Rat 1	54 \pm 6.6	85 \pm 5.5	54 \pm 11.6	75 \pm 5.5	—	—
Rat 2	95 \pm 7.7	95 \pm 3.2	97 \pm 4.0	89 \pm 3.7	—	—
Rat 3	96 \pm 3.7	98 \pm 2.4	96 \pm 5.8	94 \pm 5.8	74 \pm 5.8	90 \pm 8.4

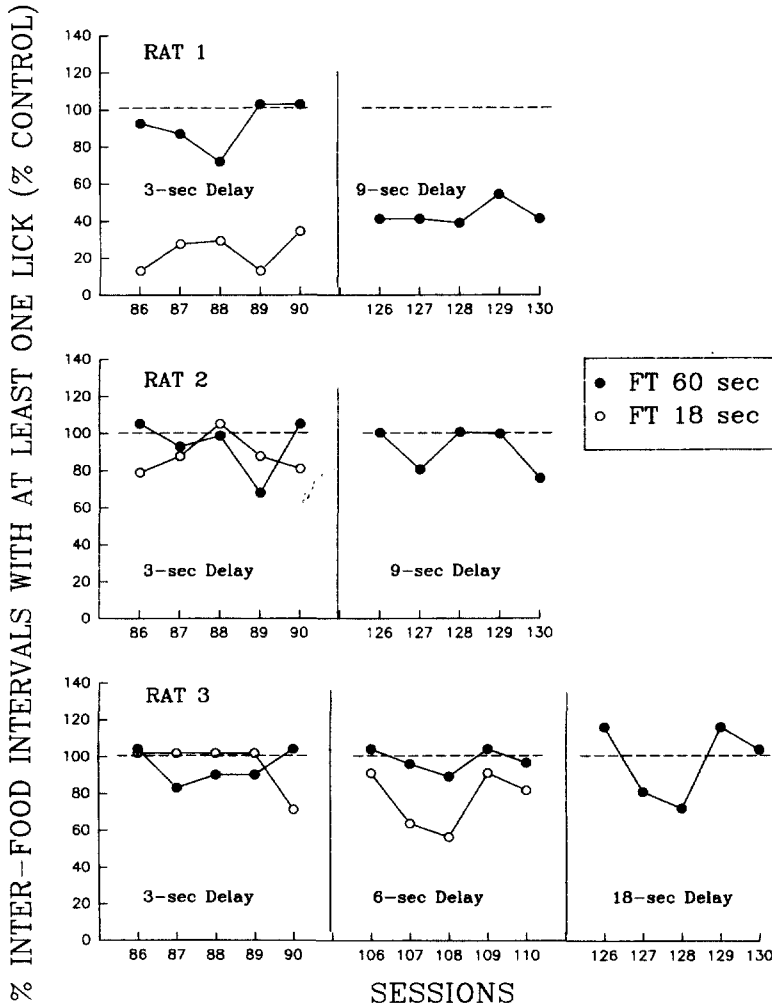


Figure 2. Mean percentage of interfood intervals in which at least one lick occurred for each rat during the last five sessions of the stages with lick-dependent delays in food delivery, accompanied by blackout. These means were transformed into percentages of control rate (see the text).

were on average about 25% and 45% of the percentage of intervals which included licks in control conditions. No appreciable changes were observed in this measure with Rat 1 after 3-s delays were added to the FT 60-s schedule, nor with Rat 2 at any schedule or delay. The percentage of interfood intervals followed by licks was also not generally affected by the delays in Rat 3. However, Rat 3 tended to lick less with the 6-s food-delay procedure during the FT 18-s schedule, which led to a measure which was on average 75% of the value recorded at the baseline.

Discussion

Results of this experiment show that the efficacy of lick-dependent delays to serve as punishers of schedule-induced drinking depends upon the duration of the interfood interval. Adjunctive drinking induced by a FT 60-s schedule was punished by signaled 9- or 18-s delays in food delivery, thus confirming previous results from our laboratory (Lamas & Pellón, 1995a; Pellón & Blackman, 1987). The drinking induced by the FT 18-s schedule was punished by shorter signaled delays, 3 or 6 s in the present study. This is the first demonstration of the punishment of schedule-induced drinking by such short lick-dependent delays.

The ratio of the interfood interval length to the duration of the lick-dependent delays seems to be the critical variable to account for the present results. Three times longer delays were needed to produce suppressive effects on the rate of licking induced by the FT 60-s schedule in order to be comparable to the effects seen by shorter delays on the licking rate induced by the FT 18-s schedule. Punishment effects were observed only when the duration of lick-dependent delays was increased in the same proportion of the interfood interval. The proportion of the delay duration to the food schedule duration appears to be constant across schedules for a punishment effect to be observed in a given animal. In the present experiment, lick-dependent delays needed to be a minimum of six-fold shorter than the interfood intervals to be effective in suppressing the behavior of Rats 1 and 2, but they needed to be three-fold shorter to suppress the behavior of Rat 3.

Flory and Lickfett (1974) performed the only previously published investigation in which different delay durations were used to punish drinking induced by a FI 60-s schedule, and they reported a systematic reduction in the rate of schedule-induced drinking as lick-dependent delays increased from 10 to 80 s. Lick-dependent delays became therefore more effective in reducing schedule-induced drinking as they were longer for a given fixed interreinforcement interval length. The present findings led to a complementary conclusion, using the different strategy of manipulating the interfood interval length for a given fixed delay value. The efficacy of lick-dependent delays to suppress established schedule-induced drinking is not solely determined by its absolute length, but based on its relation to the frequency of food presentation.

After omission training the suppression of operant behavior is not

determined by the absolute length of the response-reinforcement interval, but by the relationship of the response-reinforcement interval to the reinforcement-reinforcement interval (Rieg, Smith, & Vyse, 1993), a finding that resembles the results obtained here.

The punishment effect of lick-dependent delays was less pronounced and less generalized in the measure of the percentage of interfood intervals with at least one lick than in the measure of licks per minute (see also Flory & Lickfett, 1974; Lamas & Pellón, 1995a; but see Pellón & Blackman, 1987). However, it should be noted that every rat continued to lick during some proportion of the interpellet intervals, and so schedule-induced drinking was not completely abolished by any delay length in any of the two FT schedules used in the present experiment.

The measure of licks per minute was also more sensitive to variations in the frequency of food presentation. With a higher food frequency (FT 18 s vs FT 60 s), a higher rate of licking was recorded under control conditions. This result was not generally observed in the measure of the percentage of interfood intervals with at least one lick.

The present results should be taken cautiously for two reasons, however. First, it is well known that the amount of schedule-induced drinking changes with variations in food frequency (Falk, 1966; Flory, 1971). The interpellet interval inevitably increased with the introduction of the delay contingencies. The decreases in the frequency of food presentation could therefore account by themselves for the reductions observed in the amount of schedule-induced drinking. A way to evaluate this potential influence is to include a yoked-control procedure, in which some animals are exposed to the increases in interfood intervals without these changes being dependent on their own behavior. Based upon previous results from our laboratory, however, we should expect that the behavior of such controls would not change in a way similar to the animals submitted to the lick-contingent delays (Lamas & Pellón, 1995a; Pellón & Blackman, 1987). It is more likely that the increases in the duration of the interfood intervals during the conditions with delays did not result in reduced drinking, since such intervals could have fallen within the effective range of pellet delivery rates found to induce excessive drinking. This argument can be more easily understood if we look at the licking induced by the FT 60-s schedule. The longer delays (9 or 18 s) could in theory result in the maximal increase of the interfood interval length, but at the same time they produced a significant suppression of drinking. The final obtained interfood intervals were therefore shorter, or at least equivalent, to those produced after the introduction of the shorter delays (3 or 6 s), which were ineffective in suppressing licking. The same goes for the licking during FT 18-s components. For example, Rat 3 obtained a very similar rate of food presentation at the end of the stages with 3- or 6-s lick-dependent delays, but the delays had differential suppressive effects on licking rates. Thus it seems reasonable to conclude that the differences in the effects of the delays were not attributable to the changes in the actual value of the interfood interval. However, the possibility that the observed suppression effects on licking were due to a loss of food pellets cannot be

completely ruled out. A descending linear function normally relates the rate of drinking with the decreases in food frequency (Pellón, 1992; Reid & Staddon, 1990), and because the obtained interfood intervals effectively increased with the introduction of the delay contingencies, the animals reduced but never stopped licking.

A second limitation to the present results is more fundamental. The reductions in drinking caused by the lick-to-food delay contingencies could be seen as a case of the more general principle of rate dependency. This criticism is tenable because the effects of the various delays were more differentiated in the measure of licks per minute, where rats behaved differentially when exposed to the two food schedules with no accompanying delays. In the measure of the percentage of interfood intervals with at least one lick animals did not show such discrimination between the different food frequencies, and delays were not differentially effective. For example, Rat 1 which showed a five times higher drinking during the FT 18-s schedule, also showed a five times higher suppression with the 3-s delay under this same schedule. The suppression of behavior by aversive procedures is generally dependent on the basal rate of responding (e.g., Blackman, 1968; McKearney, 1972).

The present results contribute then to the view that schedule-induced behavior can be modified by variables that affect operant behavior in general, such as the magnitude of the punishing consequence (e.g., Appel, 1963). This is not to say that schedule-induced behavior is controlled exclusively by its consequences. Experiments designed more explicitly to investigate this theoretical issue are still required.

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