**FOOD-DEPRIVATION EFFECTS ON PUNISHED
SCHEDULE-INDUCED DRINKING IN RATS**

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Food-deprived rats (at 80% of their free-feeding weights) were exposed to a fixed-time 60-s schedule of food-pellet presentation and developed schedule-induced drinking. Lick-dependent signaled delays (10 s) to food presentation led to decreased drinking, which recovered when the signaled delays were discontinued. A major effect of this punishment contingency was to increase the proportion of interpellet intervals without any licks. The drinking of yoked control rats, which received food at the same times as those exposed to the signaled delay contingency (masters), was not consistently reduced. When food-deprivation level was changed to 90%, all master and yoked control rats showed decreases in punished or unpunished schedule-induced drinking. When the body weights were reduced to 70%, most master rats increased punished behavior to levels similar to those of unpunished drinking. This effect was not observed for yoked controls. Therefore, body-weight loss increased the resistance of schedule-induced drinking to reductions by punishment. Food-deprivation effects on punished schedule-induced drinking are similar to their effects on food-maintained lever pressing. This dependency of punishment on food-deprivation level supports the view that schedule-induced drinking can be modified by the same variables that affect operant behavior in general.

Key words: schedule-induced drinking, adjunctive behavior, punishment, signaled delays, food deprivation, fixed-time schedule, lick, rats

Falk (1961) reported that food-deprived rats exposed to a variable-interval schedule of food reinforcement drank excessive amounts of water during experimental sessions. This drinking occurred despite the fact that the rats were not water deprived. The term *schedule-induced polydipsia* was coined by Falk to describe this excessive drinking. Falk (1971) suggested that schedule-induced polydipsia was the prototype of a new behavioral class named *adjunctive behavior*, which was conceptualized as if it might be different from operant-maintained behavior. The drinking induced by intermittent food-reinforcement schedules occurs shortly after the delivery of food rather than before food presentation (Falk, 1961). Behavioral processes such as adventitious reinforcement (Clark, 1962) do not seem to account for this and other fea-

tures of schedule-induced polydipsia adequately (see review by Wetherington, 1982).

In addition to rats, schedule-induced polydipsia also develops in mice (Palfai, Kutscher, & Symons, 1971), guinea pigs (Porter, Sozer, & Moeschl, 1977), gerbils (Porter & Bryant, 1978), and rhesus monkeys (Allen & Kenshalo, 1976). Other induced or adjunctive patterns of behavior have been observed, including aggression in pigeons (Looney & Cohen, 1982, for a review), defecation in rats (Rayfield, Segal, & Goldiamond, 1982), and the ingestion of nonnutritive substances in monkeys (Villareal, 1967). Schedule-induced polydipsia and other adjunctive behavior have received much empirical and theoretical attention (see reviews by Falk, 1977; Staddon, 1977; Wetherington, 1982), but our understanding of these phenomena is still incomplete (see Reid & Staddon, 1990).

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, similar to the sensitivity of rats' lever pressing that is reinforced by food. For example, Pellón and Blackman (1987) have shown that schedule-induced drinking can be reliably suppressed by lick-contingent delays in food presentation (see also Flory & Lickfett, 1974). Similar effects were reported by

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Bond, Blackman, and Scruton (1973) using lick-contingent electric shocks. Furthermore, Reberg (1980) observed that schedule-induced drinking was increased or decreased by scheduling extra food to occur after drinking or not drinking, respectively. These functional similarities between adjunctive drinking and operant behavior are important if an adequate explanation of schedule-induced behavior is to be developed.

There are many other similarities between adjunctive and operant patterns of behavior. For example, the rate of schedule-induced drinking varies with changes in the magnitude or quality of the food reinforcer and with changes in the animal's level of food deprivation. The occurrence of schedule-induced drinking seems therefore to depend on motivational variables related to the food reinforcer (Falk, 1971; Pellón, 1992; Reid & Staddon, 1990). These variables have effects on schedule-induced drinking that are similar to the effects they exert on explicitly controlled operant behavior.

With regard to food deprivation, Falk (1969) and Freed and Hymowitz (1972) have reported that schedule-induced drinking is increased, or develops further, with increases in food deprivation from 100% to 90% or 95% of the animals' free-feeding weights, and that it is sustained thereafter at similar high levels of drinking despite further increases in food deprivation. This occurs despite the fact that increases in food deprivation lead normally to *reductions* in water consumption in the animals' home cages (e.g., Bolles, 1961). Similar relationships to food deprivation have been reported for schedule-induced drinking in mice (Palfai et al., 1971) and gerbils (Porter, 1983) as well as for schedule-induced attack in pigeons (Dove, 1976) and schedule-induced wood chewing in rats (Roper & Crossland, 1982).

Much more is known about the effects of variables such as food deprivation on explicitly reinforced operant behavior than on adjunctive behavior, however. Studies of schedule-controlled operant behavior have shown that the effects of aversive contingencies on already-established patterns of lever pressing in rats depend quite critically on the animal's level of food deprivation. Azrin, Holz, and Hake (1963), for example, showed that punishment with response-dependent electric

shock was more effective under moderate food deprivation (a reduction to 85% of the animals' free-feeding weights). When food deprivation was more severe (to 60% of free-feeding weights), the punishment contingency was less effective in reducing the rate of operant lever pressing. The purpose of the present study was to investigate whether food deprivation modulates punishment effects on schedule-induced drinking in rats in a way similar to its effects on explicitly controlled operant behavior.

Rats were food deprived to 80% of their free-feeding weights and were then exposed to a fixed-time (FT) schedule of food presentation (Condition A). All rats developed schedule-induced drinking. This drinking was subsequently reduced by having each lick initiate a 10-s delay in the delivery of the next pellet of food (Condition B). The weight of each animal was then varied, by adjusting food intake, to 90% (Condition C) and to 70% (Condition D) of their weights at the start of the study, to determine whether punished schedule-induced drinking changed as a function of the different food-deprivation levels. The lick-dependent delays were signaled by the extinguishing of the houselights, because signaled delays have been shown to be more effective than unsignaled delays as a punishment procedure with schedule-induced drinking (Pellón & Blackman, 1987). A yoked control procedure was incorporated into the study, in which yoked animals were exposed to the same signaled delays in food presentation, independently of their own licking. Yoked control rats were maintained throughout the different stages of the experiment at the same levels of food deprivation as the master animals.

METHOD

Subjects

Six experimentally naive male Sprague-Dawley rats of about 90 days of age were used. They were housed individually in an environmentally-controlled room (22 °C temperature, 60% relative humidity, and 12:12 hr light/dark cycle) of the animal laboratory of the Facultad de Psicología at Universidad Nacional de Educación a Distancia. The rats' weights were gradually reduced by controlled

feeding to 80% of their previously determined individual free-feeding weights ($M = 430$ g; range, 371 to 476 g). Each rat was then 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 continuously available in the subjects' home cages.

Apparatus

The experiment was conducted in six identical Letica Instruments LI-836 standard rodent test chambers (29 cm long by 24.7 cm wide by 35.5 cm high). Each chamber was contained inside a ventilated sound-attenuating chest with a small observation window in the left wall. The continuous ambient noise resulting from the ventilation fans was approximately 60 dB, which served as a masking noise. The front panel of the 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, which delivered 45-mg BioServe Precision food pellets 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 were sensed by a photocell beam situated in the hole 1 to 2 mm from the spout. Two 3-W houselights illuminated the chambers during experimental sessions.

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

individual living cage. On 2 successive days, 60 45-mg food pellets were placed together in a dish, and the volume of water consumed during the subsequent hour was measured. This procedure provided a baseline water intake for the drinking associated with the amount of food that was to be delivered intermittently in the subsequent experimental sessions (Pellón & Blackman, 1987).

All rats were then adapted to the chambers and to the consumption of the food pellets by being exposed to one 60-min session during which no experimental contingencies were operating: 20 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 water bottles were not mounted.

After this pretraining the experiment proper began, with sessions conducted 7 days per week. Before each session the water bottles were filled with 100 ml of fresh tap water and were installed as described above. Each session began with illumination of the houselights and delivery of one 45-mg pellet of food to the receptacle. The houselight was turned off at the end of each experimental session.

In the first stage of the experiment (Condition A), the rats were exposed to 42 60-min sessions in which one 45-mg food pellet was delivered regularly at 1-min intervals independent of the rat's behavior (FT 60-s schedule). Each session ended 60 s after the delivery of the 60th food pellet. For each session the volume of water consumed (to the nearest milliliter), the number of licks at the spout, and the number of 60-s intervals with at least one lick were recorded.

At the end of this first stage, the rats were matched into three pairs according to the amounts of water they had consumed and the numbers of licks they had made during experimental sessions. In each pair, 1 rat was randomly designated as a master and the other as its yoked control for the subsequent stages of the experiment. The 2 rats were subsequently tested simultaneously in adjacent test chambers. In the second stage of the experiment (Condition B), the FT 60-s schedule continued in operation, but now each lick made by a master rat initiated a 10-s delay in the delivery of the next pellet of food. This delay was signaled by offset of the houselights

(blackout). Each lick during the signaled 10-s delay reset the delay. When no lick had occurred for 10 s, the houselights were relit, and the FT schedule resumed at the point at which it had been interrupted. Sessions for a yoked control occurred concurrently with those of its master. A pellet of food was delivered to the yoked animal at the same time as to its master: Food delivery to both rats was thus affected by the master rat's licking, but it was independent of the licking of the yoked rat. Delays initiated by the licking of a master rat were also signaled by a blackout to its yoked control. For each master and yoked rat, each daily session ended at the end of the interval that followed the 60th presentation of food or 120 min after the beginning of the session, whichever occurred first. Condition B lasted 14 sessions, and data were collected as in the first stage of the experiment.

The rats' weights were subsequently increased or decreased by controlled home-cage feeding to 90% (Rats 1 to 4) or 70% (Rats 5 and 6) of their free-feeding weights. The body weight of each rat was stabilized at the above percentages after 7 days, a period during which the animals were not studied in the chambers. A third experimental stage was then introduced. For purposes of clarity, this stage was designated with a different label when the animals were food deprived to 90% (Condition C) or 70% (Condition D) of their weights at the start of the experiment. In Conditions C and D, identical experimental arrangements were programmed as in Condition B: Every lick by a master rat still initiated a 10-s signaled delay in food delivery to both that rat and its yoked control. After seven sessions under this procedure, the food-deprivation regime was reversed for the three pairs of rats. Therefore, the weights of Rats 1 to 4 were now decreased to 70% and the weights of Rats 5 and 6 were increased to 90% of their free-feeding weights. When these new weights were obtained by the rats, which occurred after 7 days (with no testing), the fourth experimental stage was introduced.

This condition is designated as D or C depending on the animals' level of food deprivation, and it lasted seven sessions. Data were collected during Conditions C and D as described for the first stage of the experiment.

At the end of the fourth stage, each rat's weight was returned to 80% of its free-feeding weight. Seven days were required for these weight changes. During that time, the animals were not studied in the chambers. Rats were then tested for 10 further sessions with the delay-to-food contingency operating on the licks made by the master rats, being therefore a replication of Condition B. Finally, the procedure used in Condition A was reinstated for an additional 10 sessions: The licks of the master rats no longer had any programmed consequences, the delivery of food pellets was thus determined solely for all rats by the FT 60-s schedule, and the houselights were continuously illuminated.

RESULTS

Figure 1 shows the daily water intake for each rat throughout the experiment. During the first experimental sessions, rats did not drink much water. As sessions progressed, however, all rats started to consume the water and schedule-induced drinking developed smoothly and to a similar extent in all pairs of master rats and their yoked controls. By the end of Condition A, all rats drank much more water 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 4.5, 5.0, 1.5, 4.5, 3.5, and 3.5 ml for Rats 1 to 6, respectively. This increase in water consumption shows that schedule-induced drinking developed with all rats in this study, reaching levels of water intake that can be regarded as excessive or polydipsic (cf. Stein, 1964). In the course of Condition A the rats also developed consistent patterns of behavior: They consumed the pellets of food

Fig. 1. Daily water intake for each rat. Condition A: FT 60-s schedule of food delivery. Conditions B, C, and D: FT 60 s, but with each lick made by a master rat initiating a 10-s delay in food delivery, accompanied by blackout. A yoked rat received food and blackouts at the same time as its master. Body weights were at 80% (Conditions A and B), 90% (Condition C), or 70% (Condition D) of the animals' free-feeding weights.

promptly upon delivery and then licked the spout and drank from the water bottle.

Figure 1 indicates for each pair of rats the effect of the signaled delay introduced in Condition B. Water intake was decreased in all master rats, but this decrease took different forms in each master. Rat 1 showed a slow and consistent decrease across sessions, the drinking of Rat 3 was not affected during the first nine sessions but was abruptly decreased thereafter, and drinking in Rat 5 was reduced sharply as soon as the delay was introduced. With all 3 master rats, the amount of water drunk was much less at the end of Condition B than it had been at the end of Condition A. In contrast, all yoked controls showed no appreciable decreases in water consumption during Condition B in comparison with Condition A. Further, Rat 2 showed an increase in water intake. These results provide a replication of the punishment of schedule-induced drinking by 10-s signaled lick-contingent delays reported by Pellón and Blackman (1987). Even though decreases were observed in the drinking of master rats with the delay-to-food contingency, these decreases were not sufficient to abolish schedule-induced drinking completely. Indeed, all 3 master rats drank more at the end of the condition with delays (B) than they had in the massed-food condition.

Figure 1 also shows the effects on punished schedule-induced drinking produced by the shifts in the animals' level of food deprivation. When food deprivation was changed to 90% of the animals' free-feeding weights in Condition C, Master Rat 1 decreased further the amount of water consumed in comparison to the end of Condition B. A similar decrease, but of a greater extent, was also observed for Yoked Control 2. Decreases were not observed in the drinking of Rats 3 and 4, however. When body-weight level was at 70% during Condition D, Master Rat 3 increased the consumption of water quite rapidly in comparison to previous conditions with the food-delay contingency, reaching levels of

drinking that were comparable to those recorded for this same rat at the end of Condition A. Rat 1 showed no increases in drinking from Condition C (90%) to Condition D (70%). Yoked Control 2 drank more during Condition D than it had during Condition C, approaching the levels of drinking that were recorded for this animal at the end of Conditions A and B (80%). Rat 4 showed no marked increases in water intake during Condition D, mainly because its drinking was not decreased during the previous Condition C.

Conditions C and D were given in a reverse order to Rats 5 and 6. They were first food deprived to 70% of their free-feeding weights (and thus exposed to Condition D) and then were food deprived to 90% (Condition C). The water intake of Rat 5 increased considerably by the end of Condition D, to the extent that water consumption was similar during the last two sessions of Condition D to its consumption at the end of Condition A and comparable to the drinking amount of Yoked Control 6. This control rat showed some small increases in water intake. When food deprivation was set at 90% during a later Condition C, Rats 5 and 6 decreased the amount of water consumed.

The weights of all rats were subsequently adjusted by food deprivation to 80% of their values at the start of the experiment. Figure 1 shows the extent to which the behavioral baselines returned to previous values with the introduction of the final two stages of the experiment, which were a repetition of Conditions B and A, respectively. Water intake of Master Rats 3 and 5 increased or decreased, respectively, during the second Condition B in comparison to the previous experimental stage. Therefore, water consumption approached the levels recorded at the end of the first Condition B. The other master (Rat 1) showed no changes in water intake during Condition B in comparison to previous Conditions C and D. In general, control rats also showed no marked changes in this condition in comparison to the previous stage of the

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Fig. 2. Daily mean licks per interpellet interval for each rat. Condition A: FT 60-s schedule of food delivery. Conditions B, C, and D: FT 60 s, but with each lick made by a master rat initiating a 10-s delay in food delivery, accompanied by blackout. A yoked rat received food and blackouts at the same time as its master. Body weights were at 80% (Conditions A and B), 90% (Condition C), or 70% (Condition D) of the animals' free-feeding weights.

experiment, but water intake increased in Rat 6 from the low levels that were recorded during the previous Condition C.

When the punishment procedure was discontinued in the final stage of the experiment (Condition A), all 3 master rats showed sustained increases in water intake throughout the sessions. The final amounts of water consumption were comparable to those recorded at the end of the first stage of the experiment, except that there was not a complete recovery of the initial behavioral baseline in Rat 1. For all 3 yoked controls, however, there were no major changes in drinking during the final stage of the experiment.

Figure 2 shows the daily mean number of licks per interval for each rat throughout the entire experiment, with the data for each yoked rat depicted in conjunction with its master. These data were calculated by dividing the number of licks made per session by the number of food pellets delivered, which was always 60. (Note that the 2-hr time limit was never encountered, and that these data are not expressed as licks per minute, because the mean interpellet interval varied in Conditions B, C, and D of the experiment.) The development of schedule-induced licking can be seen with all rats in the first stage of the experiment (Condition A), with the number of licks per interval being similar within each pair of rats. In Condition B, when licks by master rats produced 10-s signaled delays in the delivery of food, all 3 master rats showed marked decreases in licks per interval; with Rats 1 and 3, this decrease developed consistently but slowly across sessions, and with Rat 5 the decrease developed quite quickly. In spite of these orderly and sustained decreases, Figure 2 shows that none of the master rats ceased licking completely. Figure 2 shows slight (Rat 4) or no decreases (Rats 2 and 6) in the mean licks per interval during Condition B for the yoked controls.

When body weight was changed to 90% in Condition C for the first two pairs of rats, licks per interval in Master Rats 1 and 3 decreased quite rapidly from the levels that were obtained at the end of Condition B, and they were sustained at these low levels thereafter. The mean licks per interval for Yoked Controls 2 and 4 also decreased during Condition C. When body weight was decreased to

70% during Condition D, the mean number of licks for Master Rat 3 recovered to levels approximating its licking before the introduction of the food-delay contingency in Condition B. Licks per interval, however, did not change in Rat 1 from Condition C to Condition D. Yoked Controls 2 and 4 increased their mean licks per interval in Condition D in comparison to Condition C, reaching the levels of licking that they showed before the introduction of Condition C. However, the increase observed for the number of licks in Rat 3 was much more pronounced than in any of the yoked controls.

The last pair of rats (5 and 6) received Conditions C and D in the reverse order. Licks per interval of Rat 5 increased considerably during the course of Condition D, developing by the end of this condition to a level similar to that previously recorded in Condition A and comparable to the licks per interval of its yoked control. The yoked control did not show appreciable changes in the number of licks per interval during Condition D in comparison to Condition B. When body weight was increased to 90% (Condition C), both Rat 5 and Rat 6 decreased the number of licks per interval.

Rats were then maintained at 80% of their free-feeding weights, and Condition B was reintroduced. Master Rat 1 showed no changes in licks per interval. Master Rats 3 and 5 licked to a degree similar to that of the final sessions of the previous Condition B; thus, Rat 3 decreased and Rat 5 increased the number of licks per interval from the preceding stage of the experiment. Yoked Controls 2 and 4 showed no noticeable changes in licks per interval during this Condition B in comparison to the preceding stage, and Yoked Control 6 increased the licks per interval to reach a level of licking similar to that obtained previous to the introduction of Condition C. When the signaled delay was finally removed and Condition A was reinstated, all 3 master rats showed marked increases in licks per interval. Yoked controls did not show changes in the number of licks per interval during the final stage of the experiment.

Figure 3 presents the daily percentages of interpellet intervals in which at least one lick occurred. The patterns of these data are broadly similar to those shown in Figures 1

Fig. 3. Daily percentage of interpellet intervals in which at least one lick occurred for each rat. Condition A: FT 60-s schedule of food delivery. Conditions B, C, and D: FT 60 s, but with each lick made by a master rat initiating a 10-s delay in food delivery, accompanied by blackout. Each yoked rat received food and blackouts at the same time as its master. Body weights were at 80% (Conditions A and B), 90% (Condition C), or 70% (Condition D) of the animals' free-feeding weights.

and 2, with some exceptions. In the first stage of the experiment, all animals came to lick during most of the interpellet intervals; within each pair, masters and yoked controls were almost indistinguishable. For the 3 master rats, the decreases in this measure when signaled delays in food presentation were introduced in Condition B reflect those seen in previous figures, but note that Rat 5 showed signs of recovery on this measure during the later sessions in Condition B. Yoked controls did not show appreciable changes from Condition A to Condition B, although more variability was observed in the behavior of Rat 6.

When body weights were at 90% of the initial free-feeding weights in Condition C (given to Rats 5 and 6 in a later experimental stage), all master and yoked control rats initially decreased the percentage of intervals that included licks. These decreases were later recovered in Rats 3 and 4, and to a lesser extent in Rat 2. When food deprivation was more severe in Condition D (70%), Master Rat 3, but not Rats 1 and 5, increased the percentage of intervals followed by licks in comparison to Conditions B or C. Yoked controls again licked in most of the interpellet intervals. During the last two stages of the experiment, when body weights were again at 80%, controls continued to lick in most of the interpellet intervals, but all master rats showed a food-then-lick pattern that was severely diminished during Condition B. In the final stage (Condition A), when the food-delay contingency was removed, all master rats resumed licking in most of the interpellet intervals (although recovery was not complete).

Figure 4 shows the mean number of licks per interval with at least one lick; the figure is therefore a combination of the data shown in Figures 2 and 3. These data were calculated by dividing the total number of licks made per session by the number of interpellet intervals that contained at least one lick. During Condition A, all animals except Rat 4 began by showing little licking in the intervals

with licks, but this measure increased slowly with sustained training. By the end of the first stage, all rats within each pair showed a similar steady licking in the intervals containing licks, which were effectively most of the interpellet intervals (see Figure 3). The behavior of yoked controls did not change significantly in this measure during the rest of the experiment (except Rat 6 in Condition C); thus, the remaining results will be limited to descriptions of the master animals. With the introduction of the delay contingency in Condition B, no reliable decreases were observed in licks per interval with at least one lick for master rats. Lick-contingent delays produced a decrease in both licks per minute (cf. Figure 2) and the percentage of intervals with at least one lick (cf. Figure 3) in all master rats, but these animals licked the same amount during the intervals in which they continued licking. Even more, Master Rat 1 increased in Condition B the number of licks in the intervals with licks, because the delay contingency was more effective in reducing the percentage of interpellet intervals with at least one lick than the total number of licks in this rat. A reduction in the number of licks per interval with licks was observed in all master rats (and in Yoked Control 6) during Condition C when body weights were maintained at 90%. This decline disappeared during the course of Condition C in Rats 1 and 3, which maintained final levels of licking that were comparable to their levels of licking at the end of Condition A. The sustained decline in this measure of licking with Rat 5 is an indication that suppression was more effective in licks per interval than in the percentage of intervals with at least one lick (cf. Figures 2 and 3). During Condition D, when body weights were maintained at 70%, Rats 3 and 5 increased their number of licks per interval with at least one lick. This again indicates that the modulation by food deprivation of the suppression by lick-contingent delays was more sensitive in the measure of licks per in-

Fig. 4. Daily mean licks per interpellet interval with at least one lick for each rat. Condition A: FT 60-s schedule of food delivery. Conditions B, C, and D: FT 60 s, but with each lick made by a master rat initiating a 10-s delay in food delivery, accompanied by blackout. Each yoked rat received food and blackouts at the same time as its master. Body weights were at 80% (Conditions A and B), 90% (Condition C), or 70% (Condition D) of the animals' free-feeding weights.

LICKS PER INTERVAL WITH AT LEAST ONE LICK

terval than in the measure of the percentage of intervals with at least one lick. Rat 1 showed an increase in licks per interval with licks in only a single session. Variability increased in this rat when Condition B was reinstated, but licking was maintained in this and the other master rats at the levels shown in previous Conditions A and B. When the delay contingency was removed in the final stage of the experiment (Condition A), no appreciable changes were observed in master animals.

DISCUSSION

Results of this experiment show that the efficacy of punishment on schedule-induced drinking is dependent upon the degree of food deprivation. Well-established drinking and licking induced by an FT 60-s schedule of food delivery were suppressed (but were not abolished) by 10-s lick-dependent signaled delays to food presentation. This punishment effect was observed in all master rats when they were maintained at 80% of their free-feeding weights, in measures of water consumption, licks per interpellet interval, and the percentage of interpellet intervals with at least one lick. When body weights were changed to 90% of the rats' free-feeding weights, all 3 master animals showed a further decrease in measures of punished schedule-induced drinking. Decreases were also observed for yoked controls. These results can be interpreted as a reflection of a decline in drinking due to an increase in body weight (Falk, 1969; Keehn, 1979; Roper & Nieto, 1979). When body weights were maintained at 70%, Master Rats 3 and 5 increased punished responding to levels approximately equal to the unpunished drinking and licking that was observed for these same animals during the first and final stages of the experiment (but not in the measure of the percentage of intervals with at least one lick in Rat 5). This recovery brought their measures of drinking and licking to the levels recorded for their yoked controls. Master Rat 1 did not show changes in punished schedule-induced drinking that were related to the variations in food-deprivation level once its weight had been increased to 90% in Condition C. In general, however, the present results suggest that lick-dependent delays in food presenta-

tion are less effective in punishing schedule-induced drinking when food deprivation is very severe, as in a 70% food-deprivation regime.

Results of this experiment also show that punishment of schedule-induced drinking by lick-dependent delays in food delivery took the form of an increase in the proportion of interpellet intervals without any licks, but when licks did occur in an interval they occurred at about the same frequency as they did when punishment was not arranged. This conclusion is supported by the finding that no master rat decreased the number of licks per interval with at least one lick when the punishment contingency was introduced in Condition B, but decreases were observed in all these rats in the measures of licks per interval and the percentage of intervals with at least one lick. This result resembles the experimental outcomes when schedule-maintained behavior is punished; the patterns of unpunished operant responding are not normally disrupted by punishment contingencies. For example, punishment affects operant performance under fixed-ratio schedules in a way analogous to what we have shown here; postreinforcement pauses are lengthened, but responding, once initiated, occurs at rates similar to those when no punishment is present (Azrin, 1959).

The present results confirm previous findings in which the signaled delay served to punish schedule-induced drinking (Pellón & Blackman, 1987). In addition, the present results also show that the signal alone and non-contingent delays were not sufficient to reduce established schedule-induced drinking (yoked controls). In contrast to Pellón and Blackman's study, control animals were exposed both to the delay and to the signal initiated by their master rats rather than merely to the delay. Neither in the present experiment nor in Pellón and Blackman's study did yoked controls show behavioral changes that could be attributed to the delays initiated by the licking of the master rats in the punishment conditions. Therefore, the decreases in drinking observed for master rats cannot be attributed simply to changes in the duration of interpellet intervals (although this measure was unfortunately not recorded in the present study). Pellón and Blackman (1987, Experiment 2) confirmed that lick-depen-

dent blackouts, with no accompanying delays, were also insufficient to reduce established schedule-induced drinking.

A potential problem for the interpretation of the present results comes from the consideration that control animals could have been drinking and licking at asymptote during Condition A of the experiment, when they were maintained at 80% of their free-feeding weights and the delay contingency was not in operation for the licking of master rats. If this were the case, no increases could be observed in the behavior of control animals when body weight was set at 70%. However, studies that have related the amount of schedule-induced drinking with the amount of food deprivation (e.g., Falk, 1969) have shown that drinking is not normally further increased despite decreases in body weight from about 85% of the rats' free-feeding weights. Therefore, the increases in punished schedule-induced drinking should be attributed to the specific enhancing effects of severe food deprivation on punished licking.

Body-weight loss generally increases the resistance of food-maintained response to reductions by dependent (e.g., Azrin et al., 1963) and independent (Millenson & de Villiers, 1972) electric shocks. Similar results with response-independent shocks have been reported for schedule-induced drinking (Hymowitz, 1976, 1981). For example, Hymowitz (1976) reduced the weights of his rats to 70% and 90% of their initial free-feeding weights. Food was delivered according to an FT 40-s schedule, and electric shocks were presented concurrently at variable-time 60-s intervals. These components alternated with periods in which only the FT 40-s schedule was in operation. A 5-s or 10-s delay was imposed between licks and shock presentation to ensure that no shock followed a lick. With this lick-independent shock procedure, Hymowitz (1976) reported reliable reductions in the rate of licking during the shock periods in comparison to the shock-free periods when animals were food deprived to 90%. When rats were food deprived to 70%, however, shock presentations did not reduce drinking. The data of Hymowitz (1976) indicate that the resistance of schedule-induced drinking to suppression by response-independent shock increased as the degree of body-weight loss increased. This was true for measures of

water consumption and the percentage of food pellets followed by licks.

The present results, together with those of Hymowitz (1976, 1981), suggest that as body-weight loss is increased, the resistance of schedule-induced drinking to reduction by response-dependent and independent negative consequences is increased. These results extend to lick-dependent delays the previous findings of Hymowitz (1976) with lick-independent electric shocks.

The effect of food deprivation on punished schedule-induced drinking is similar to its effect on food-maintained lever pressing. Azrin et al. (1963) reported that the resistance of lever pressing during punishment was directly related to the degree of body-weight loss. The present results therefore suggest a similar dependency of punishment on the animals' level of food deprivation in schedule-induced and schedule-maintained behavior. The present results thus contribute to the view that schedule-induced drinking can be modified by the same variables that affect operant behavior.

REFERENCES

- Allen, J. D., & Kenshalo, D. R. (1976). Schedule-induced drinking as a function of interreinforcement interval in the rhesus monkey. *Journal of the Experimental Analysis of Behavior*, 26, 257-267.
- Azrin, N. H. (1959). Punishment and recovery during fixed-ratio performance. *Journal of the Experimental Analysis of Behavior*, 2, 301-305.
- Azrin, N. H., Holz, W. C., & Hake, D. (1963). Fixed-ratio punishment. *Journal of the Experimental Analysis of Behavior*, 6, 141-148.
- Bolles, R. C. (1961). The interaction of hunger and thirst in the rat. *Journal of Comparative & Physiological Psychology*, 54, 580-584.
- Bond, N. W., Blackman, D. E., & Scruton, P. (1973). Suppression of operant behavior and schedule-induced licking in rats. *Journal of the Experimental Analysis of Behavior*, 20, 375-383.
- Clark, F. C. (1962). Some observations on the adventitious reinforcement of drinking under food reinforcement. *Journal of the Experimental Analysis of Behavior*, 5, 61-63.
- Dove, L. D. (1976). Relation between level of food deprivation and rate of schedule-induced attack. *Journal of the Experimental Analysis of Behavior*, 25, 63-68.
- Falk, J. L. (1961). Production of polydipsia in normal rats by an intermittent food schedule. *Science*, 133, 195-196.
- Falk, J. L. (1969). Conditions producing psychogenic polydipsia in animals. *Annals of the New York Academy of Sciences*, 157, 569-593.

- Falk, J. L. (1971). The nature and determinants of adjunctive behavior. *Physiology & Behavior*, 6, 577-588.
- Falk, J. L. (1977). The origins and functions of adjunctive behavior. *Animal Learning & Behavior*, 5, 325-335.
- Flory, R. K., & Lickfett, G. G. (1974). Effects of lick-contingent timeout on schedule-induced polydipsia. *Journal of the Experimental Analysis of Behavior*, 21, 45-55.
- Freed, E. X., & Hymowitz, N. (1972). Effects of schedule, percent body weight, and magnitude of reinforcement on acquisition of schedule-induced polydipsia. *Psychological Reports*, 31, 95-101.
- Hymowitz, N. (1976). Effects of electric-shock delivery on schedule-induced water intake: Delay of shock, shock intensity, and body-weight loss. *Journal of the Experimental Analysis of Behavior*, 26, 269-280.
- Hymowitz, N. (1981). Effects of signaled and unsignaled shock on schedule-controlled lever pressing and schedule-induced licking: Shock intensity and body weight. *Journal of the Experimental Analysis of Behavior*, 35, 197-207.
- Keehn, J. D. (1979). Schedule-induced polydipsia, schedule-induced drinking, and body weight. *Bulletin of the Psychonomic Society*, 13, 78-80.
- Looney, T. A., & Cohen, P. S. (1982). Aggression induced by intermittent positive reinforcement. *Neuroscience and Biobehavioral Reviews*, 6, 15-37.
- Millenson, J. R., & de Villiers, P. A. (1972). Motivational properties of conditioned anxiety. In R. M. Gilbert & J. R. Milleson (Eds.), *Reinforcement* (pp. 97-128). New York: Academic Press.
- Palfai, T., Kutscher, C. L., & Symons, J. P. (1971). Schedule-induced polydipsia in the mouse. *Physiology & Behavior*, 6, 461-462.
- Pellón, R. (1992). Polidipsia inducida por programa: II. Variables motivacionales [Schedule-induced polydipsia: II. Motivational variables]. *Revista de Psicología General y Aplicada*, 45, 251-265.
- Pellón, R., & Blackman, D. E. (1987). Punishment of schedule-induced drinking in rats by signaled and unsignaled delays in food presentation. *Journal of the Experimental Analysis of Behavior*, 48, 417-434.
- Porter, J. H. (1983). Schedule-induced polydipsia as a function of percent of body weight in the Mongolian gerbil. *Physiology & Behavior*, 31, 137-139.
- Porter, J. H., & Bryant, W. E. (1978). Acquisition of schedule-induced polydipsia in the Mongolian gerbil. *Physiology & Behavior*, 21, 825-827.
- Porter, J. H., Sozer, N. N., & Moeschl, T. P. (1977). Schedule-induced polydipsia in the guinea pig. *Physiology & Behavior*, 19, 573-575.
- Rayfield, F., Segal, M., & Goldiamond, I. (1982). Schedule-induced defecation. *Journal of the Experimental Analysis of Behavior*, 38, 19-34.
- Reberg, D. (1980). Reinforcing the occurrence or non-occurrence of interim drinking. *Animal Learning & Behavior*, 8, 120-128.
- Reid, A. K., & Staddon, J. E. R. (1990). Mechanisms of schedule entrainment. In S. J. Cooper & C. T. Dourish (Eds.), *Neurobiology of stereotyped behavior* (pp. 200-231). Oxford: Oxford University Press.
- Roper, T. J., & Crossland, G. (1982). Schedule-induced wood-chewing in rats and its dependency on body weight. *Animal Learning & Behavior*, 10, 65-71.
- Roper, T. J., & Nieto, J. (1979). Schedule-induced drinking and other behavior in the rat, as a function of body-weight deficit. *Physiology & Behavior*, 23, 673-678.
- Staddon, J. E. R. (1977). Schedule-induced behavior. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 125-152). Englewood Cliffs, NJ: Prentice-Hall.
- Stein, L. (1964). Excessive drinking in the rat: Superstition or thirst? *Journal of Comparative and Physiological Psychology*, 62, 449-454.
- Villareal, J. (1967, April). *Schedule-induced pica*. Communication presented at the Eastern Psychological Association, Boston, MA.
- Wetherington, C. L. (1982). Is adjunctive behavior a third class of behavior? *Neuroscience and Biobehavioral Reviews*, 6, 329-350.

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