SUPPRESSION OF OPERANT BEHAVIOR AND SCHEDULE-INDUCED LICKING IN RATS¹

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The first experiment studied the effects of punishment on rats' lever pressing maintained by a fixed-interval schedule of food reinforcement and on the associated schedule-induced licking. When licking was followed by shock, licking was suppressed but lever pressing was largely unaffected. When lever pressing was followed by shock, lever pressing was suppressed but licking was unaffected. In both cases, the punished behavior recovered its previous unpunished level when the shocks were discontinued. In a second experiment, the rats' lever pressing was maintained by a variable-interval schedule of food reinforcement under which polydipsic licking also developed. Both lever pressing and licking were partially suppressed during a stimulus correlated with occasional unavoidable electric shocks. With a higher shock intensity, both behaviors were suppressed further. Both lever pressing and licking recovered their previous levels when shocks were discontinued. These results show that schedule-induced licking, which has been described as adjunctive behavior, can be suppressed by procedures that suppress reinforced lever pressing, an operant behavior.

If food-deprived rats are exposed to an intermittent food reinforcement schedule, they drink excessive amounts of water after each pellet is delivered. For example, Falk (1961) reported that the water intake during a 3.17-hr experimental session may be three to four times the normal daily intake, and has termed this phenomenon "schedule-induced polydipsia". Falk (1969) suggested that the licking characteristic of schedule-induced polydipsia is not an operant behavior, but rather one example of behaviors that he has termed "adjunctive", *e.g.*, schedule-induced aggression (Azrin, Hutchinson, and Hake, 1966) pica (Villareal, 1967), wheel running (Levitsky and Collier, 1968), air licking (Mendelson and Chillag, 1971), and nitrogen drinking (Taylor and Lester, 1969). According to Falk, the initiating conditions of adjunctive behaviors have certain similarities to those of the "displacement activities" studied by ethologists. Displacement activities are usually observed in situations in which thwarting, *i.e.*, the lack of an appropriate releasing stimulus, or conflict prevent a consummatory act. When food pel-

lets are delivered intermittently, each pellet is not only a signal for eating but also an indication that the probability of further pellet deliveries is momentarily at its lowest value. Food intake is thus thwarted and displacement drinking, *i.e.*, adjunctive drinking, is induced. To distinguish adjunctive behavior from operant behavior, Falk (1971) defined adjunctive behavior as "behavior maintained at high probability by stimuli whose reinforcing properties in the situation are derived primarily as a function of schedule parameters governing the availability of another class of reinforcers" (p. 586).

If adjunctive behaviors are to be regarded as a class separate from operant behaviors, it seems reasonable to compare and contrast the characteristics of these two types of behaviors. For example, what is the effect on adjunctive behaviors of procedures that have been shown to suppress operant behaviors? One of the main reasons for Falk's (1969) classification of polydipsic drinking as non-operant is that response-dependent delays in reinforcement that rapidly suppress operant behavior, *e.g.* Zeiler (1970), do not suppress polydipsic drinking. The failure to suppress schedule-induced polydipsia by these techniques (Falk, 1964; Hawkins, Schrot, Githens, and Everett, 1972; Segal and Oden, 1969) has been used to argue against the interpretation of the phenomenon

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as an operant behavior adventitiously reinforced by delivering a food pellet (Clark, 1962).

This disparity between the two classes is not necessarily general. For example, Dunham (1971) studied the effects of shocks on polydipsic licking and lever pressing maintained by a variable-interval (VI) 1-min schedule of food reinforcement. One rat was shocked after every lever press, and a second rat after every lick. In both cases, the punished response was suppressed. After recovering the behavioral baselines, the punishment conditions were reversed for each subject and again the punished responses were suppressed. These findings demonstrated that schedule-induced licking is sensitive to punishment by relatively low shock levels (0.2 mA, 0.5 sec). In the present study, lever pressing (operant behavior) and polydipsic licking (adjunctive behavior) were generated by intermittent schedules of reinforcement. The first experiment studied in more detail the changes in both behaviors induced by punishing either one with shock. The second experiment investigated the effects on both behaviors of superimposing a stimulus correlated with unavoidable shocks, *i.e.*, a "conditioned suppression" procedure (Estes and Skinner, 1941). Such a procedure generally decreases the frequency of food-reinforced responding during the pre-shock stimulus.

EXPERIMENT I

The present experiment sought to replicate and extend the findings of Dunham (1971) by comparing the changes in rates of lever pressing and licking behavior when lever pressing was maintained by a fixed-interval food reinforcement schedule and either behavior was punished.

METHOD

Subjects

Three experimentally naive male Wistar rats, approximately 120 days old at the beginning of the experiment, were housed individually and maintained at 80% of free-feeding weights, which were approximately 315 g. Water was always available in their living cages.

Apparatus

The test chamber was a Grason-Stadler 1111P rat station mounted inside a sound-attenuating chest. This model contains two

levers, both 10 cm (4 in.) above the grid floor and requiring a force of approximately 0.15N for operation, but only the lever to the left of the food hopper was used. The nozzle of a water bottle was mounted 0.5 cm (0.125 in.) behind a small hole situated 15 cm (6 in.) to the right of the operative lever and 9 cm (3.75 in.) above the grid floor. The rats could obtain water by licking through the hole. Licks at the bottle were sensed through a contact relay and associated pulse former.

A 10-W houselight illuminated the test chamber during each experimental session, and white noise could be delivered through a speaker located behind the operative lever. Electric shock was delivered through the grid floor of the chamber from a Grason-Stadler 700 shock generator and scrambler. The water bottle was not included in the shock circuitry. The reinforcers were 45-mg pellets of standard rat food (P. J. Noyes Co.).

The experiment was automated by means of conventional electromechanical switches and timers in an adjacent room. Licks, lever presses, and reinforcements were counted on digital counters.

Procedure

The rats were adapted to the experimental chamber, magazine trained, and then given one session, during which each lever press was followed by a reinforcer. The daily experimental sessions were terminated after 61 reinforcements except during Phase 4, when the sessions were terminated after 90 min or 61 reinforcements, whichever occurred first. It was not possible to test all three rats during Phase 4 because at first, sessions lasted longer; Rat 2 was therefore maintained at its 80% weight by controlled feeding.

Throughout the experiment, the reinforcement schedule was FI 1-min, in which a reinforcer followed the first lever press emitted 1 min after the preceding reinforcer. In the various phases of the experiment, either licking or lever pressing was followed by a brief scrambled shock pulse (0.2 mA; 0.75 sec) as described in Table 1.

RESULTS AND DISCUSSION

Figure 1 shows the daily lever pressing and licking rates for all six phases except the first 10 sessions of Phase 1. These rates were computed by dividing the session duration (min-

Table 1

Mean water intakes per session and mean reinforcement rates during each phase of Experiment 1 for each subject. The data are taken from the last five sessions of each phase.

Phase	Response Punished	Sessions	Mean Water Intake (ml)			Mean Reinforcers/min		
			R1	R2	R3	R1	R2	R3
1	None	15	23.6	29.2	32.0	0.96	0.97	0.97
2	Licking	20	0.0	0.0	0.0	0.97	0.97	0.98
3	None	15	26.6	30.6	37.6	0.97	0.97	0.97
4	Lever pressing	20	20.6	—	39.6	0.93	—	0.90
5	None	15	20.0	33.0	37.2	0.97	0.98	0.98
6	Licking	20	1.0	0.0	0.0	0.97	0.97	0.97

utes) into the total numbers of lever presses and licks made during the session.

Phase 1 established a baseline for rates of lever pressing and licking under the fixed-interval schedule. Lever-pressing rates were approximately 18 per minute for Rat 1; 11 for Rat 2, and 15 per minute for Rat 3. Lick rates were approximately 70 per minute for Rat 1, 115 for Rat 2, and 150 for Rat 3.

In Phase 2, each lick was followed by shock. With all subjects, licking was suppressed almost immediately, with no recovery over the following sessions. A few licks did occur; for example, during the last session of Phase 2, Rat 1 made 32 licks, Rat 2 made 33 licks, and Rat 3 made 19 licks. These results replicate those of Dunham (1971) in indicating that schedule-induced licking is sensitive to punishment by shock. The lever-pressing rates of Rats 1 and 2 initially decreased when licking was shocked, but then recovered to rates similar to the baseline rates in Phase 1. However, Rat 3 initially increased its rate of lever pressing to approximately 27 per minute, and sustained the higher rate throughout Phase 2.

In Phase 3, the punishment schedule was removed, which reinstated the conditions of Phase 1. All subjects showed rapid recovery of their pre-punishment licking rates. Rat 1 increased its rate of licking to a value greater than the baseline rate in Phase 1; Rats 2 and 3 recovered their pre-punishment baseline rates. With no subject did licking show any evidence of a punishment contrast effect, *i.e.*, a transient increase above baseline when punishment was discontinued (Azrin, 1960). This may be due to the fact that the previous punishment phase continued for many sessions (*c.f.* Azrin and Holz, 1966).

In Phase 4, shock followed each lever press. The lever-pressing rates of both rats were immediately suppressed, but in contrast to when licking was punished, they partially recovered over succeeding sessions, finally stabilizing at approximately seven per minute for Rat 1, and two per minute for Rat 3. A partial recovery of the punished response as the procedure is continued is a typical occurrence under mild punishment schedules (Azrin and Holz, 1966). With both subjects, the rate of licking showed a sharp decrease, which was associated with few reinforcements during these early sessions of Phase 4. As the rates of lever pressing recovered partially, both subjects obtained all scheduled reinforcers again (*c.f.* Table 1) and, concurrently, the rate of licking recovered its baseline level.

In Phase 5, shock was again discontinued. Rats 2 and 3 recovered their baseline lever-pressing rates. Rat 1 showed some recovery from the previous suppression, but not to its baseline rate. As with licking, no subject's lever-pressing rate showed a punishment contrast effect. The licking rates of all subjects remained steady at values similar to those in the identical Phases 1 and 3.

In Phase 6, the shock followed each lick as in Phase 2. Again, all subjects showed an immediate suppression of licking. In later sessions, Rat 1 showed some recovery of licking to approximately 10 licks per minute. The other subjects made only occasional licks, two by Rat 2 and four by Rat 3 in their last sessions. The lever-pressing rates of Rats 1 and 2 did not change from their baseline values, but the rate of Rat 3 increased slightly to approximately 30 lever presses per minute, replicating its previous behavior in these conditions.

Fig. 1. Lever-press response rates (continuous lines) and licking rates (unconnected points) in each session of six phases of Experiment 1 for all three subjects.

Note that punishment of one response led to little sustained change in the rate of the unpunished response, in contrast to a recent report by Dunham (1972). Indeed, only one of the subjects, Rat 3, showed any evidence of such an effect. When licking by Rat 3 was suppressed by punishment, lever pressing was sus-

tained at a rate higher than the baseline rate. In all other cases, after initial disruption at the onset of punishment, the unpunished response recovered to its baseline level. Table 1 shows the mean water intakes per session and the mean reinforcement rates during each phase of the experiment for all three

subjects. Except for Phases 2 and 6, when licking was punished, all animals exhibited polydipsic levels of water intake comparable to those reported previously (Stein, 1964; Falk, 1967). The reinforcement rates of all three subjects remained approximately constant across the various phases of the experiment.

EXPERIMENT II

This experiment investigated the effects of a conditioned suppression procedure on the lever pressing and polydipsic licking generated by a variable-interval schedule of food reinforcement. With the traditional conditioned suppression procedure, the stimulus paired with shock is of fixed duration and terminates with a single shock. Such a procedure may result in changes in the degree of response suppression within the pre-shock stimulus due to some form of temporal discrimination (Millenson and Hendry, 1967). Since such changes might make the results of this experiment more difficult to interpret, an alternative procedure was used. Fixed periods of a warning signal were presented in the presence of which unavoidable shocks were delivered at irregular intervals independently of the subject's behavior.

METHOD

Subjects

Two experimentally naive male hooded Lister rats, 120 days old at the start of the experiment, were housed individually and maintained at 85% of their free-feeding weights, which were approximately 300 g. Water was always available in their home cages.

Apparatus

The apparatus was the same as in Experiment 1. The white noise was used as the stimulus correlated with the shocks.

Procedure

The rats were adapted to the chamber, magazine trained, and given five sessions during which each lever press was reinforced. Then, responses on the lever were reinforced under a VI 30-sec schedule. After six 1-hr sessions, the schedule was changed to VI 1-min (range 4 sec to 104 sec), which was in effect throughout the experiment. After 30 sessions

under this schedule, the following procedures were implemented.

Phase 1. Each 1-hr experimental session was considered as 30 consecutive 2-min periods, 10 of which were accompanied by white noise. These noise periods were scheduled in a pseudo-random sequence such that no more than two occurred consecutively and no more than four 2-min periods passed in the absence of noise. The first noise period never occurred within the first 4 min of the session. The VI schedule operated continuously throughout the session, unaffected by changes from one 2-min period to another. There were 15 sessions in this phase.

Phase 2. The procedure was the same as in Phase 1 except that a scrambled shock pulse (0.3 mA, 0.5 sec) was delivered at irregular intervals averaging 1 min (range 4 sec to 104 sec) during the noise periods. There were 20 sessions in this phase.

Phase 3. Electric shock was scheduled for 20 sessions as in Phase 2, but at a higher intensity (0.5 mA, 0.5 sec).

Phase 4. Shock was discontinued for 20 sessions. This condition was identical with Phase 1.

RESULTS AND DISCUSSION

Figure 2 shows for each subject the mean lever-press and lick rates in the presence and absence of noise.

The data for control (no noise) and noise periods in Phase 1 show no effect of noise periods on either licking or lever-pressing rates.

In Phase 2, when periods of noise were correlated with the lower shock intensity, both subjects showed mild suppression of both lever pressing and licking in the presence of noise compared to the control periods. The behaviors of both subjects in control periods of Phases 1 and 2 were similar.

In Phase 3, which had a higher intensity of shock, the lever pressing of both subjects showed more suppression during periods of noise than in Phase 2. The lever-pressing rates of both subjects during both control periods were also slightly lower than the previous control periods. Both subjects showed virtually complete suppression of licking during the periods of noise in Phase 3, and the licking in control periods was less frequent than in the previous control periods.

Fig. 2. Mean lever-press response rates and licking rates during control and noise periods in each of four phases of Experiment 2. Vertical lines indicate standard deviations of the mean scores. The data are taken from the last five sessions of Phase 1 (no shocks) and the last 10 sessions of Phase 2 (0.3-mA shocks), Phase 3 (0.5-mA shocks), and Phase 4 (no shocks).

In Phase 4, when the shock was discontinued, the lever-pressing rates during the noise were similar to those in the control periods, indicating a recovery from the previous conditioned suppression of this behavior. However, the rates of lever pressing were higher than under the identical conditions of Phase 1. In Phase 4, the licking behavior also recovered during the noise periods to the level of licking during the periods without noise. These recovered licking baselines were similar to the original ones in Phase 1.

Table 2 shows the mean water intakes per session and the mean reinforcement rates during both the noise and control periods for each phase of the experiment for both subjects. During Phases 1 and 4 (no shock), both animals exhibited drinking at polydipsic levels

similar to those observed previously (Stein, 1964; Falk, 1967; Experiment 1). In both subjects, water intake fell when the shock was first introduced (Phase 2) and then fell further when its intensity was increased (Phase 3). These decreases were associated with the fact that licking was suppressed during the noise periods when these were correlated with shock. Table 2 also shows that there was little difference in the reinforcement rates obtained during the noise and control periods and that the rates remained approximately constant across the various phases of the experiment.

Figure 3 shows representative segments of the cumulative records of lever pressing and licking by Rat 5 obtained in the final sessions of Phases 2 and 3. The records obtained from Rat 4 were similar. The lever-pressing rates

Table 2

Mean water intake per session and mean reinforcement rate for both the noise and control periods during each phase of Experiment 2 for both subjects. The data are taken from the last five sessions of Phase 1 and the last 10 sessions of the subsequent phases.

Phase	Condition	Sessions	Mean Water Intake (ml)		Mean Reinforcements per Min			
			R4	R5	R4		R5	
					Control	Noise	Control	Noise
1	No shock	15	29.4	25.0	0.88	1.00	0.94	1.00
2	Low shock	20	19.6	22.3	1.00	0.83	0.91	0.94
3	High shock	20	15.2	8.1	0.96	0.92	0.99	0.92
4	No shock	20	28.7	26.6	1.02	1.03	1.05	1.03

are not as regular as is usually reported for variable-interval schedules, *e.g.*, by Ferster and Skinner (1957), due to the intermittent bouts of licking after a reinforcement. The records show that lower rates of lever pressing occurred during the noise periods. It is important to note that even with the more marked suppression of lever pressing obtained in Phase 3, no overall reductions in reinforcement frequency could be detected during the noise periods. The licking record from Phase 2 suggests that suppression of licking during the noise periods took two forms. On some occasions, there was a decrease in the number of

licks in any bout of drinking after reinforcement (marked "A" on record); on other occasions, the rat did not lick after reinforcement (marked "B" on record). The licking records from Phase 3 (higher shock) show that few reinforcements during the noise periods were followed by any licking. This absence of licking after reinforcement also occurred on a number of occasions during the control periods in Phase 3. This finding is of interest because duration of polydipsic licking after reinforcement has typically been altered by changes in the nature of the reinforcing stimulus or by the frequency of occurrence of that

Fig. 3. Representative segments from cumulative records of Rat 5 showing lever-press responses and licks in Phase 2 (low shock) and Phase 3 (high shock) conditions. With the lever-press records, the pen was offset during periods of noise (N); reinforcements are shown by a hatchmark. With lick records, which were taken at the same time, the stepping pen was reset by delivery of food reinforcement, which is also denoted by a hatchmark. The event pen was offset during the periods of noise and delivery of shock is denoted by the hatchmarks. In both conditions, "A" marks occasions when licking after reinforcement was reduced but not eliminated during the noise; "B" marks occasions when the licking was eliminated.

stimulus (Falk, 1967). The present finding suggests that the amount of licking after reinforcement may also be controlled by factors other than those directly involving the primary schedule.

GENERAL DISCUSSION

We have shown that lever pressing (operant behavior) and schedule-induced licking (adjunctive behavior) exhibit similar changes when exposed to punishment by shock or to a conditioned suppression procedure. This similarity between the two behavioral classes has been noted in some other contexts. For example, Hawkins *et al.* (1972) showed that the rate of ingestion associated with schedule-induced polydipsia decreases as the time between reinforcements increases, and that licking increases as the magnitude of the reinforcer increases. These functions are similar to those relating operant behavior to the frequency and amount of reinforcement (Ferster and Skinner, 1957). It may be suggested that under certain conditions the degree of adjunctive behavior, like operant behavior, is a function of the reinforcement rate. This view is supported by the recent finding that the relative frequency of licks in a constant component of various multiple schedules matches the relative frequency of reinforcement in that component (Jacquet, 1972). The matching of operant response rate to relative reinforcement frequency is a well-known finding (Herrnstein, 1970). However, the present results also point out that reinforcement frequency is not the sole factor controlling the two behavioral classes. For example, during Experiment 1, despite no reduction in reinforcement frequency, both licking (Phases 2 and 6) and lever pressing (Phase 4) were suppressed by punishment. Similarly, during the noise periods of Phases 2 and 3 of Experiment 2, both lever pressing and licking were suppressed, despite the fact that there was no reduction in reinforcement frequency. Also, during Phase 3 few of the reinforcers delivered during the noise periods were followed by licking, thereby indicating that the delivery of food-pellets to food-deprived rats is not sufficient for the occurrence of schedule-induced polydipsia.

While it may be the case that operant and adjunctive behaviors are *initiated* by different conditions (Falk, 1969), there is now ample evidence that both behaviors show similar

changes with respect both to variations in reinforcement rate and to response suppression procedures such as punishment and conditioned suppression. Such findings suggest that the two types of behavior may be *maintained* by similar factors. The resistance of polydipsic drinking to suppression by lick-dependent delays in reinforcement remains an anomaly in this respect. However, it should be noted that such a procedure will prohibit the *development* of schedule-induced drinking (Hawkins *et al.*, 1972). The failure to disrupt well-established polydipsia may be due to the fact that there is no discrete aversive event associated with such a procedure.

The present results also point out certain differences between the two classes of behavior. In both experiments, it appears that licking was more sensitive to the suppression procedures than was lever pressing. In Experiment 1, when licking was punished, complete suppression of licking occurred with no recovery during punishment on five of six occasions, whereas when lever pressing was punished (Phase 4), both subjects (Rats 1 and 3) showed eventual partial recovery of lever pressing during the punishment phase. Similarly in Phase 3 of Experiment 2, there was more suppression of licking than of lever pressing, although conditions were identical. This might suggest that the licking (adjunctive behavior) is the more fragile. However, it could also be due to the fact that the two behaviors differed in their rates of occurrence (see Figures 1 and 2). For example, Blackman (1968) showed that the degree of suppression of operant behavior is a function of its rate of occurrence, higher response rates being more easily suppressed. Further investigations, perhaps of a parametric nature, will be needed to identify the variables controlling these differences in the disruption of operant and adjunctive behaviors in the present experiments. However, the present results certainly do not support the suggestion that schedule-induced polydipsia might be relatively insensitive to disruption by punishment contingencies (Falk, 1969). Nor is it resistant to disruption by aversive stimuli scheduled independently of behavior in a conditioned suppression procedure.

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