The Function of Schedule-induced Polydipsia in Establishing Ethanol as a Positive Reinforcer*

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INTERMITTENT presentation of food pellets to food-deprived animals with access to a liquid results in schedule-induced polydipsia, *i.e.*, in excessive drinking (2, 3). After rats or rhesus monkeys have been exposed to a schedule of intermittent food-pellet presentation which results in high levels of intake of either water or ethanol, terminating the schedule of food-pellet presentation results in a decrease of water intake to normal levels, but high levels of ethanol intake may persist (4, 5, 9, 10, 13). When availability of ethanol is made contingent on lever-press responding, characteristic patterns of fixed-interval and fixed-ratio responding can then be engendered and maintained by ethanol presentation (1, 12, 15). Thus, schedule-induced ethanol drinking can be used to establish ethanol as a positive reinforcer which is significant because many procedures are ineffective in generating substantial ethanol drinking (see refs. 16 and 17 for reviews). Is there something unique about the use of schedule-induced polydipsia to establish ethanol as a reinforcer? Several experiments were done to try to answer this question. Each experiment involved an initial phase in which food was used to induce the rats to drink water or ethanol and a second phase in which the efficacy of ethanol as a reinforcer was assessed. Results of the experiments described in this paper show that schedule-induced polydipsia is not unique; other procedures can be used to establish ethanol as a rein forcer. Moreover, patterns of ethanol intake that occur once responding is main-tained by ethanol do not seem to vary as a function of the acquisition procedure.

In the initial phase of the first experiment ethanol drinking occurred when food pellets were intermittently presented; that is, ethanol drinking occurred under conditions of schedule-induced polydipsia. In the initial phase of the second experiment a fixed quantity of food was placed in the operant-conditioning chamber. This procedure was used to increase both water and ethanol drinking. In the initial phase of the third experiment, a limited quantity of food was again placed in the operant-conditioning chamber, but the food was available in the chamber only when water but not ethanol was present. Subsequently, the rats were presented with ethanol in the absence of concurrently available food to determine whether under these conditions ethanol could be established as a reinforcer.

In the second phase of all three experiments the main features were identical: Ethanol concentration was varied and food was never available in the operant-conditioning chamber. Thus, the reinforcing efficacy of ethanol was evaluated in the absence of concurrent food, and ethanol intake and its time course were studied as a function of ethanol concentration.

Experiment 1: Initiation of Ethanol Drinking by Schedule-Induced Polydipsia

In this experiment substitution of 8% (w/v) ethanol for water during schedule-

induced polydipsia established ethanol as a reinforcer (13).

Seven male albino rats, approximately 9 months old at the beginning of the experiment, were maintained at 70% of their free-feeding weight during the experiment. The rats, specific pathogen-free Sprague-Dawley descendent (Hilltop Lab. Animals, Inc., Scottdale, Pa.) were housed individually in a continuously-illuminated room with the temperature controlled at 24 °C. Water was always available in the rats' home cages except during initial training, as explained below.

Two identical operant-conditioning chambers (Foringer, #1107L, Rockville, Md.) were used; each was equipped with two levers, a food-pellet dispenser connected to a receptacle, and a dipper (0.25 ml) for presenting liquid. With each operation of the pellet dispenser, a single 45-mg Noyes food pellet was delivered to the receptacle and two lights located above the levers blinked for 1 sec. Each press on the right-hand lever turned on a light above the dipper and activated the dipper, which made available 0.25 ml of liquid for 4 sec. Presses on the left-hand lever had no consequences.

The ethanol concentrations, expressed in grams percent, were prepared at least 20 hr before use with absolute ethanol in tap water and were kept in stoppered flasks at room temperature. The volume consumed was measured at the end of each session by subtracting the volume remaining from the volume added to the reservoir, corrected for evaporation. Evaporation corrections were determined for each concentration by measuring the volume lost from a second reservoir which, during experimental sessions, was placed adjacent to the reservoir used with the liquid dipper.

Each rat was placed in the operant-conditioning chamber for 6 hr a day at a regular starting time. Initially the rats were deprived of water for 24 hr and the dipper, containing water, was automatically presented on the average once each minute, with the time between water presentations varying randomly. During all sessions preceeding instatement of the final contingencies described below, the rats' supplementary feedings of Purina laboratory chow were placed in the operant-conditioning chamber before the start of the session. This procedure was used to increase the frequency of water responding, since the rat usually drinks after eating. Within one to two sessions the rats approached and drank from the dipper when it was in the up position. After rats reliably drank from the dipper, automatic water presentations were discontinued and the rats were trained to press a lever for water; each lever press resulted in a dipper presentation. Within one to two sessions, the rats began pressing the lever and, during the next two sessions, the rats were water deprived (i.e., without access to water in their home cages). Water was again made available in the home cages before one additional session.

During subsequent sessions, final contingencies of the initial phase were in effect. Throughout each 6-hr session, water or ethanol was available briefly after each lever press. Concurrently, food pellets were delivered automatically during the last 4 hr of each session at the rate of one pellet per minute. No stimulus change other than the presentation of food pellets indicated the change from the first 2 hr to the last 4 hr of the session. After approximately 10 sessions with water available, a stable pattern of lever-press responding was achieved. Little or no water-reinforced responding occurred during the first 2 hr of the session; mean reinforcements per hour were 1.5 (n = 35; seven rats × five sessions each). High rates of water-reinforced responding (i.e., schedule-induced polydipsia) occurred during the subsequent 4 hr of the session; mean reinforcements per hour were 95.

After five sessions in which the pattern of water-reinforced responding was stable (water baseline sessions), 8% (w/v) ethanol was presented during sessions that alter-

nated with sessions of water presentation (water control) sessions. Ethanol was presented for five sessions. Thus, 15 consecutive sessions occurred in the following sequence: WB (water baseline), WB, WB, WB, WB, E (ethanol), WC (water control), E, WC, E, WC, E, WC. After the fifth water control session, concurrent food presentation was permanently discontinued so that ethanol and water responding could be studied in the absence of concurrent food delivery.

Consumption of 8% (w/v) ethanol during just one 6-hr session was sufficient to establish ethanol as a reinforcer for each of the seven rats. The number of ethanol reinforcers obtained during the first 2 hr of the second ethanol session (viz., 29, mean for seven rats) was substantially higher than the number of water reinforcers obtained during the first 2 hr of the second water control (6 reinforcements) or baseline sessions (three reinforcements). Ethanol reinforcers during the first 2 hr were also greater than water reinforcers during the first 2 hr of the third, fourth and fifth sessions for each liquid.

After the fifth water control session, rats no longer received food pellets during the last 4 hr of each session. Consequently, during this phase of the study conditions remained the same within any one particular 6-hr session: Ethanol or water (on the intervening control days) was always available contingent on a single lever press. Ethanol concentrations of 8, 16, and 32% were presented to each rat in an ascending order with at least one water control day separating ethanol sessions. Each rat was presented with each concentration for at least five sessions and was not switched to the next concentration until responding had stabilized. In figure 1 is shown the group mean cumulated reinforcements for the 6-hr session. The temporal pattern of ethanol-reinforced responding was negatively accelerated; most reinforcements occurred at the beginning of the session. In this experiment the number of reinforcements at each concentration occurred in the rank order of 8% > 16% > 32% > 0% (cf. ref. 14). Although number of reinforcements decreased as the concentration was increased, the decreases were not below one-half the value obtained at the adjacent lower concentration. Thus, rate of ethanol intake increased with concentration. For example, during the first hour, mean in-
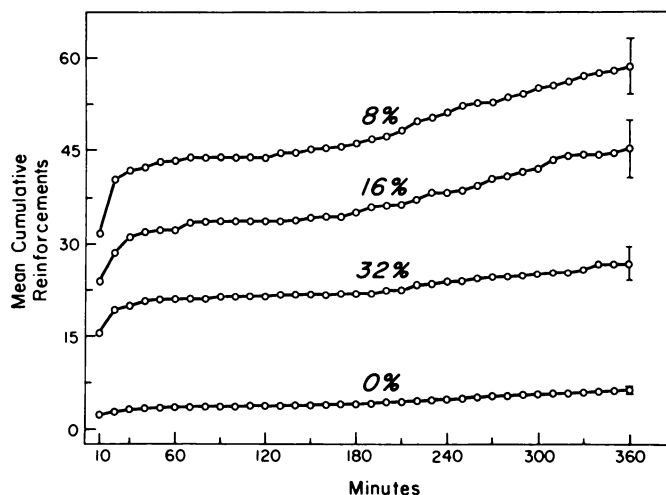

FIG. 1. Mean number of cumulative reinforcements over 6-hr sessions for each ethanol concentration. Each point is based on 35 observations (seven rats × five values), except for the points at 0% (water) where each point is based on 105 observations (seven rats × 15 values). Brackets indicate the mean standard error of the mean total reinforcements for the seven rats.

take rates at 8, 16, and 32% were 177, 242, and 330 mg/100 g of body weight per hour, respectively (n = 35; seven rats × five sessions each). Similar results were obtained in the maintenance phase of the following two experiments.

Experiment 2. Initiation of Ethanol Drinking by Access to Solid Food

In this experiment, ethanol was established as a reinforcer by being substituted for water during sessions in which the daily maintenance feeding of Purina laboratory chow occurred in the operant-conditioning chamber.

Four male albino rats, approximately 4 months old at the beginning of the experiment, were maintained at 75% of their free-feeding weights for the duration of the experiment. The rats, specific pathogen-free Sprague-Dawley descendents (Hilltop Lab. Animals, Inc., Chatsworth, Calif.,) were housed individually in a continuously-illuminated room with the temperature controlled at 24°C. Water was always available in the rats' home cages except during initial training, as explained below.

A sound-attenuated operant-conditioning chamber (Lehigh Valley Electronics, #1417, Fogelsville, Pa.) was equipped with two levers and a solenoid-driven liquid dipper (Lehigh Valley Electronics, #1351, Fogelsville, Pa.). The dipper cup was constantly available in the up position, except during the 0.8-sec refilling operation when it was lowered into the reservoir. The ethanol concentrations, expressed in grams percent, were prepared with 95% (v/v) ethanol in tap water. For example, the 8% solution was made by adding 10.6 ml of ethanol to a volumetric flask with sufficient tap water to make a total volume of 100 ml.

Each rat was placed in the operant-conditioning chamber for 6 hr a day at a regular starting time. Initially rats were deprived of water in their home cages and, to further increase the probability of drinking, the daily feedings of Purina laboratory chow were placed in a wire food hopper in

the operant-conditioning chamber. During the first daily session, water was automatically presented on the average once each minute, with the time between water presentations varying randomly. After the rats reliably drank from the dipper, automatic water presentations were discontinued and the rats were trained to press a lever for water. Each press on the right-hand lever resulted in a refilling operation, during which a tone sounded (Sonalert, 2900 Hz, Mallory & Co.) and the light above the dipper was turned off. The volume delivered per reinforcement was 0.09 ml. After the rats initiated lever-press responding, three more sessions were conducted before water bottles were restored to their home cages.

During the subsequent 14 sessions, the rats received their daily feedings of Purina laboratory chow in the operant-conditioning chamber. During the first five sessions, water was the available liquid, then 2% ethanol for two sessions, 4% ethanol for three sessions, and 8% ethanol for four sessions. The in-session feedings were then discontinued, and the food was given to the rats only in their home cages after each session. After in-session feedings were discontinued, five more 6-hr sessions were run with 8% ethanol available. Session length was then decreased to 1 hr for 10 or more sessions with 8% ethanol available.

The mean number of reinforcements occurring in each session at each step of the acquisition procedure is shown in figure 2. When the Purina laboratory chow was no longer available in the operant-conditioning chamber, the number of reinforcements declined. That ethanol had been established as a reinforcer was shown by the results of following experimental manipulations.

The session length was decreased from 6 hr to 1 hr, and concentrations of 8, 16, 32, 8, 0 (water) and 8% ethanol were each presented in that order to each rat for at least 10 sessions. The mean number of reinforcements during the three phases when 8% was available and when 0% was available is
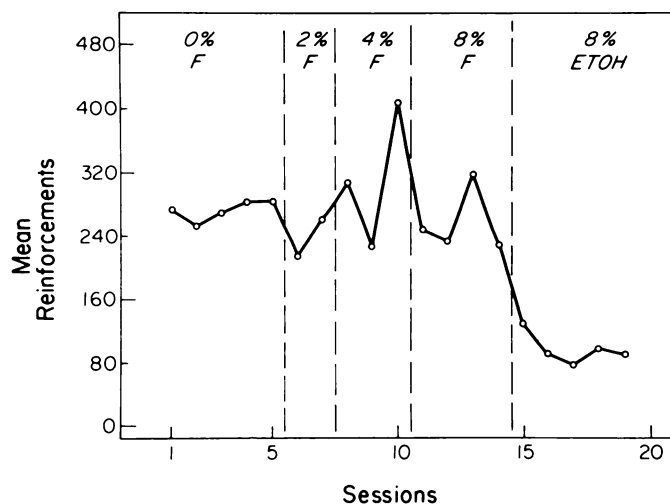
Fig. 2. Mean number of reinforcements at each 6-hr session during the acquisition procedure. Each point is a mean of four observations (four rats × one session). "F" indicates that the daily maintenance feeding of Purina laboratory chow was available in the operant conditioning chamber.

shown in table 1. The greater number of reinforcements when 8% was available than when water was available indicates that ethanol was functioning as a positive reinforcer.

The time course of ethanol intake is shown in figure 3. As in the previous experiment, the highest rate of reinforcement was at the beginning of the session. Lever pressing usually occurred in short bursts (fig. 4).

Mean intake rates at 8, 16, and 32% were 94, 170, and 165 mg per 100 g of body weight per hour, respectively (n = 20; four rats × five sessions each).

Experiment 3. Initiation of Ethanol Drinking by Exposure to Ethanol

In this experiment, ethanol was established as a reinforcer by replacing water with ethanol in the liquid reservoir.

Four male albino rats, approximately 8 months old at the beginning of the experiment, were maintained at 80% of their free-feeding weights during the experiment. The rats, Wistar descendents (Bio-Lab Corporation, St. Paul, Minn.), were housed individually in a continuously-illuminated room with the temperature controlled at 24°C. Water was always

available in the rats' home cages except during initial training, as explained below. The apparatus was the same as that used in experiment 1, except that the volume delivered per reinforcement was 0.22 ml.

Each rat was placed in the operant-conditioning chamber for 6 hr a day at a regular starting time. Initially rats were deprived of water in their home cages and, to further increase the probability of drinking, the daily feedings of Purina laboratory chow were placed in a wire food hopper in the operant-conditioning chamber. During the first daily session, water was automatically presented on the average once each minute, with the time between water presentations varying randomly. After the rats reliably drank from the dipper, automatic water presentations were discontinued, and the rats were trained to press a lever for water. After the rats initiated lever-press responding, three more sessions were conducted before water bottles were restored to the home cages.

After water bottles were restored to the home cages, in-session feedings of Purina laboratory chow continued for a series of five daily 6-hr sessions (i.e., sessions 4 to 8) with water available during the session. After the eighth session, the in-session

TABLE 1

Number of reinforcements at 8% ethanol and 0% water

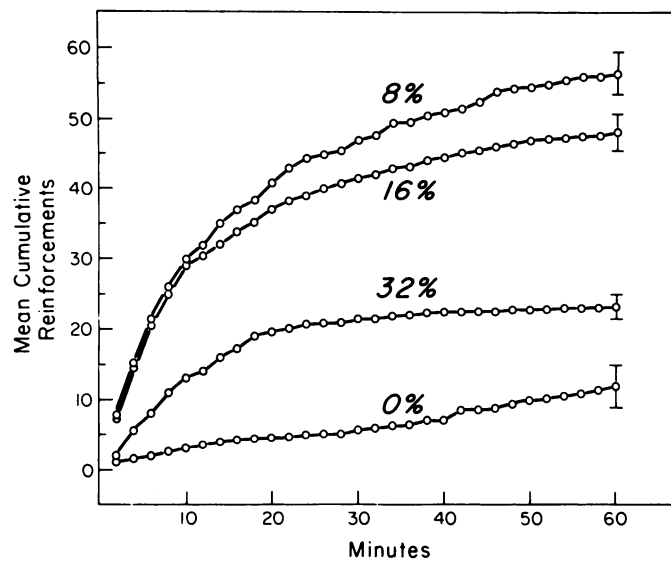| Rats	0% Before 8% 7 Sessions $\bar{x} \pm$ (S.E.)	8% Before 16% 10 Sessions $\bar{x} \pm$ (S.E.)	8% After 32% 10 Sessions $\bar{x} \pm$ (S.E.)	0% Between 8% 10 Sessions $\bar{x} \pm$ (S.E.)	8% Retest 10 Sessions $\bar{x} \pm$ (S.E.)
H1	4.3 (1.5)	49.6 (2.1)	37.7 (2.6)	5.6 (1.1)	51.3 (2.8)
H2	3.3 (1.1)	50.7 (3.2)	54.0 (3.2)	12.8 (3.8)	75.1 (3.9)
H3	—[1]	56.1 (1.4)	53.0 (2.1)	7.1 (2.0)	48.1 (3.2)
H4	34.4 (8.5)	64.7 (3.9)	102.8 (8.8)	25.5 (4.3)	127.8 (11.7)
Group means	10.5	55.3	61.9	12.8	75.6

[1] No 0% (water) sessions were run.

FIG. 3. Mean number of cumulative reinforcements over 1-hr sessions for each ethanol concentration. Each point is based on 40 observations (four rats × 10 values). Brackets indicate the mean standard error for the four rats.

feedings were discontinued and only water was available during the next five sessions. Subsequently, 2% ethanol was substituted for water for two sessions, followed by three sessions at 4%, nine sessions at 8%, and nine sessions at 0% (water). After in-session feedings were discontinued, sufficient food was placed in the rats' home cages to maintain them at 80% of their free-feeding weights.

In figure 5 is shown the mean number of reinforcements per session for the four rats at each step of the acquisition procedure. The number of reinforcements at 2% was approximately the same as the number at 0% (fig. 5). However, the number at 4% was slightly elevated, and the number at 8% was clearly in excess of the number at 0%. That 8% ethanol was serving as a reinforcer is shown by the decrease in the number of reinforcements when water replaced 8% ethanol (fig. 5).

After completion of the acquisition phase, the session length was decreased from 6 hr to 1 hr, and concentrations of 8, 16, and 32% were presented in that order to each rat. Each concentration was present for at least seven sessions and until responding showed no upward or downward trend. That the temporal distribution of reinforcements was negatively accelerated and that the rank order of the number of
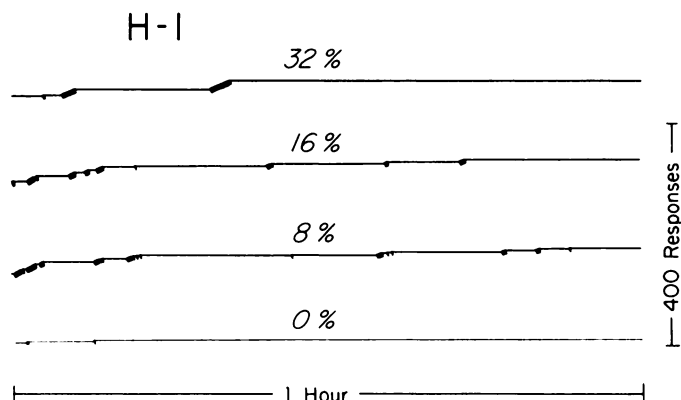
FIG. 4. Representative cumulative records for rat H-1 at each concentration. Numbers above each record indicate the concentration. Each record was selected on the basis of being closest to the mean value at a particular concentration. Time is indicated along the abscissae, and responses are cumulated along the ordinates. Thus, the slope of the line represents the rate of responding. Slash marks indicate the 0.8-sec intervals when the dipper cup was lowered into the reservoir and refilled with liquid.
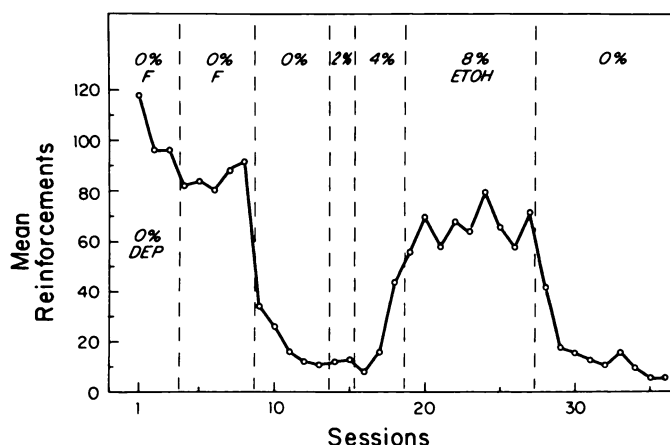

FIG. 5. Mean number of reinforcements at each 6-hr session during the acquisition procedure. Each point is a mean of four observations (four rats × one session). "0% DEP" indicates that the rats did not have access to water in their home cages. "F" indicates that the daily maintenance feeding of Purina laboratory chow was available in the operant conditioning chamber.

reinforcements obtained was 8 > 16 > 32 > 0 are shown in figure 6. These results are similar to those obtained in the first two experiments. Mean intake rates at 8, 16, and 32% were 116, 171, and 197 mg/100 g of body weight per hour, respectively (four rats × five sessions each).

Discussion

Polydipsia procedures reliably function to induce animals to drink ethanol. However, schedule-induced polydipsia is but one of several methods that can be used to establish ethanol as a reinforcer. Since maintenance patterns of ethanol drinking are similar to those occurring after other acquisition histories, schedule-induced polydipsia is not unique. Similar results in temporal pattern of intake and in rank order of concentration (*i.e.*, 8 > 16 > 32 > 0) were obtained despite the following differences: rat strain, session duration, type of ethanol (absolute *vs.* 95%), dipper cup position (*i.e.*, in the up or down position between reinforcements), dipper cup size, commercial dipper type, and type of
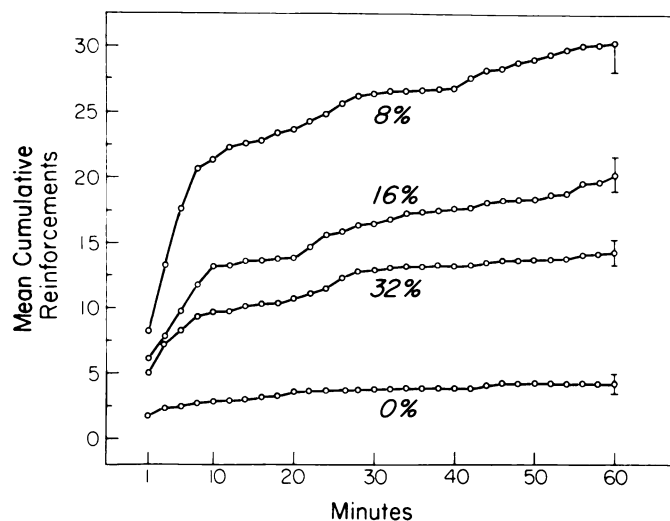
FIG. 6. Mean number of cumulative reinforcements over 1-hr sessions for each ethanol concentration. Each point is based on 20 observations (four rats × five values). Brackets indicate the mean standard error for the four rats. Note that the results at 0% represent the values obtained during the first hour of the last five 6-hr sessions run at 0%.

operant-conditioning chamber. Thus, the generality of the present results does not seem sharply limited.

That different acquisition procedures with rats result in similar ethanol-maintained patterns of responding is consistent with the findings of Winger and Woods (18). These investigators initiated intravenous ethanol self-administration in 14 rhesus monkeys. Six of the 14 monkeys began responding when each response produced an infusion of 0.1 g of ethanol per kg. Of the remaining eight monkeys, two began responding when the ethanol dose was increased to 0.2 g/kg. With the other six monkeys, four began responding when given access to 0.5 mg of cocaine per kg per injection and two monkeys initiated responding when given access to 0.5 mg of sobium methohexital per kg per injection. After responding was established, all eight monkeys were switched to ethanol to a dose of 0.1 g/kg per injection, and with all monkeys response-contingent injections of ethanol at this dose maintained responding. Winger and Wood (18) note that "... regardless of the method used to initiate ethanol-reinforced responding, the final rate of responding became stable under 3-hr/day access conditions, and the ethanol intake was much the same for all animals" (p. 169).

In the present experiments observations were not made to determine whether any gross behavioral changes occurred as a consequence of ethanol drinking. However, in an earlier study similar quantities of ethanol were consumed as in the present experiments (i.e., approximately 100 to 300 mg of ethanol per 100 g of body weight per hour), and in the earlier study, it was noted that the rats were ataxic (14). No withdrawal signs were noted after substitution of water for ethanol in the operant-conditioning chamber. Withdrawal signs were not expected since access to ethanol was limited to 6 hr or less per day. In the present experiments few presses occurred on the second lever. These lever presses produced no programmed consequences, and the number of presses on the second lever did not vary with any experimental manipulation. Similar findings concerning responding on a second lever were reported previously (11).

In experiments conducted in our laboratory in 1975 (6, 8), the procedure described in experiment 2 has been used to establish

ethanol as a reinforcer. This procedure consists of placing Purina laboratory chow in the operant-conditioning chamber to increase the volume of water and ethanol consumed. This procedure is reliable for with different rat strains and under a range of conditions ethanol-reinforced lever pressing is initiated. Also, this procedure is rapid in that counting from the session when the rat is first placed in the operant-conditioning chamber, approximately 20 sessions are required to establish ethanol-maintained lever pressing.

After ethanol has been established as a reinforcer, responding by rhesus monkeys is maintained under fixed-ratio schedules at levels exceeding water control values (7). Additionally, lever pressing by rats is maintained by ethanol presentations under fixed-ratio and fixed-interval schedules (1, 12, 15). With rats, ethanol-reinforced lever pressing is not limited to conditions of food deprivation; lever pressing under fixed-ratio schedules is maintained by 8 and 32% (w/v) ethanol even when rats are food satiated (12, 14).

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