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Ethanol Intake as a Function of Concentration During Food Deprivation and Satiation[1]

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MEISCH, R. A. AND T. THOMPSON. *Ethanol intake as a function of concentration during food deprivation and satiation.* PHARMAC. BIOCHEM. BEHAV. 2(5) 589–596, 1974. – Ethanol intake and responding of 6 male albino rats were measured at concentrations of 0 (water control) 2, 4, 8, 16, and 32% (W/V) during daily 1-hr sessions in operant conditioning chambers. The rats were run first food deprived (80% of free-feeding weight) and then food satiated (free access to food in home cages). Ethanol intake was greater when the rats were food deprived, but under both food conditions: (1) ethanol intake exceeded that of water at all concentrations, (2) quantity (mg) consumed increased with the concentration, and (3) the highest rate of responding occurred at the beginning of the session. In a second experiment, fixed-ratio responding maintained by contingent presentation of 32% (W/V) ethanol exceeded water control responding. This finding strengthened the conclusion that this concentration can serve as a reinforcer for the food-satiated rat.

Rats Ethanol drinking Ethanol reinforcement Food deprivation Food satiation Ethanol concentration Fixed-ratio schedule

RICHTER and Campbell [25] reported that rats would drink greater volumes of an ethanol solution than water if the concentration was between 1.8 and 6% (W/V). This occurred when rats were given 24-hour concurrent access in their home cages to two drinking bottles: one containing water and the other containing an ethanol solution. Subsequent studies have confirmed these results [6, 8, 12, 17, 18, 20, 26]. Similar results were obtained during 1-hour sessions when liquid dippers activated by lever-press were used [19].

Recently, two procedures have been reported which resulted in rats' consuming concentrations of ethanol above 6% (W/V) in greater volumes than water [7,28]. One procedure involved repeatedly presenting an ascending series of ethanol concentrations [28], and the other, genetically selecting rats for predisposition to drink ethanol [7]. Male rats exposed to these procedures drank concentrations as high as 9.6% (W/V) [28] or 12% (W/V) [7] in volumes in excess of water. In none of the above studies was intoxication observed.

In other studies, in which rats were deprived of food, concentrations as high as 32% (W/V) were consumed in volumes far exceeding water control volumes during both one and 6-hour sessions [13,16]. In another study, employing only 8% (W/V) ethanol, food-satiating the food-deprived rats resulted in an immediate decrease in ethanol intake to 30% of the food-deprivation levels [15]. However, intake rose to 70% of food-deprivation values when these rats were repeatedly exposed to ethanol while food satiated.

The present study compared ethanol intake during food deprivation with ethanol intake during food satiation over a range of concentrations from 2 to 32% (W/V). In addition, the time course of intake and the quantity (mg) of ethanol consumed were studied as a function of concentration.

EXPERIMENT 1: ETHANOL INTAKE AS A FUNCTION OF CONCENTRATION DURING FOOD DEPRIVATION AND SATIATION

The rats were presented with an ascending series of ethanol concentrations when food deprived. Subsequently the rats were food satiated and presented twice with the ascending series of ethanol concentrations. The repetition of the series during food satiation was done to determine whether ethanol intake would increase within the food-satiation phase as it had with 8% (W/V) ethanol in a previous study [15].

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METHOD

Animals

Six male albino Sprague-Dawley rats, about 300 days old, were individually housed in a constantly illuminated room with the temperature controlled at 24°C. When maintained at 80% of their free-feeding weights, they weighed 354 g, R-10; 397 g, R-11; 392 g, R-12; 408 g, R-13; 421 g, R-14; and 384 g, R-15. Water was always available in the home cages. These rats had experience drinking ethanol in an earlier study where under conditions of food-deprivation they were presented with a series of ascending ethanol concentrations [14].

Apparatus

Six identical rat operant conditioning chambers (Gerbrands) were used, each equipped with two levers, a food magazine, and a dipper for presenting liquid. The levers were separated by the food magazine, which was directly above the dipper. Each operation of the dipper made available 0.25 ml of liquid for 4 sec. The liquid was contained in a reservoir partially covered to minimize evaporation.

The operant conditioning chambers were housed in ventilated, sound attenuating enclosures. Masking white noise was constantly present. Programming and data recording were automatically controlled by standard electromechanical equipment in an adjacent room.

Procedure

Training the rats to press the right-hand lever was not necessary because of their past history of ethanol-reinforced responding [14]. No consequence was programmed for pressing the left lever. One-hour experimental sessions were conducted daily at a constant starting time. The order of presentation of the ethanol concentrations was as follows: 0 (water control), 2, 4, 8, 16, 32 and 0% (W/V). The series of increasing ethanol concentrations was presented 3 times, once when rats were maintained at 80% of their free-feeding weights (Food-Deprived) and twice when they had free access to food in their home cages (Food-Satiated: Series I and II). Between the completion of food-deprivation phase and the beginning of the food-satiation series, the rats remained in their home cages for 18 to 23 days and had free access to food. Changes from one concentration to the next were made after 5 sessions if the number of reinforcements showed no systematic trend; when there was a trend, additional sessions were conducted until it was eliminated. After each session during the food-deprivation phase the rats were given sufficient Purina Laboratory chow to maintain their weights at 80% of their free-feeding values.

At least 20 hr prior to use absolute ethanol was diluted in tap water to the desired concentration; all concentrations are expressed in grams percent (W/V). Solutions were kept in capped flasks.

The volume of liquid consumed was measured at the end of each session by subtracting the volume remaining from the volume added to the reservoir, corrected for evaporation. The temporal pattern of the responses and reinforcements was continuously recorded by cumulative recorders, and every 2 min a counter printed out the number of responses and reinforcements.

RESULTS

The number of reinforcements was an inverted U-shaped function of ethanol concentration for both the food-deprived and food-satiated conditions (Fig. 1). Since the volume of liquid consumed was directly related to the number of reinforcements, a similar function was found between volume consumed and ethanol concentration. At all concentrations ethanol reinforcements exceeded water control values (Fig. 1). Comparisons between the water values and the ethanol values at each concentration for the Food-Deprivation Series and the Food-Satiation Series II, using the paired t statistic and the mean values for each rat, revealed a significance level of at least 0.05 ($df = 5$), except for the comparison at 2% (W/V) during food deprivation ($t = 2.13$, $df = 5$, $p<0.1$.) Figure 2 shows that even at 32% (W/V) and under food-satiated conditions, five of the six rats obtained significantly more ethanol than water reinforcements ($t \geq 2.68$, $df = 8$, p at least <0.05). Only Rat R-11's ethanol reinforcements did not significantly exceed its water reinforcements ($t = 1.71$, $df = 8$, $p<0.1$).

Food-satiating the rats by giving them unlimited access to food in their home cages resulted in a marked decrease in ethanol reinforcements, but little change in water reinforcements (Fig. 1). The absolute difference in ethanol reinforcements between the food-deprivation and satiation values decreased with increasing concentration. Other studies, similarly, have found ethanol intake to be greater when rats are food deprived [2, 3, 4, 5, 11, 15, 24, 27, 30, 31].

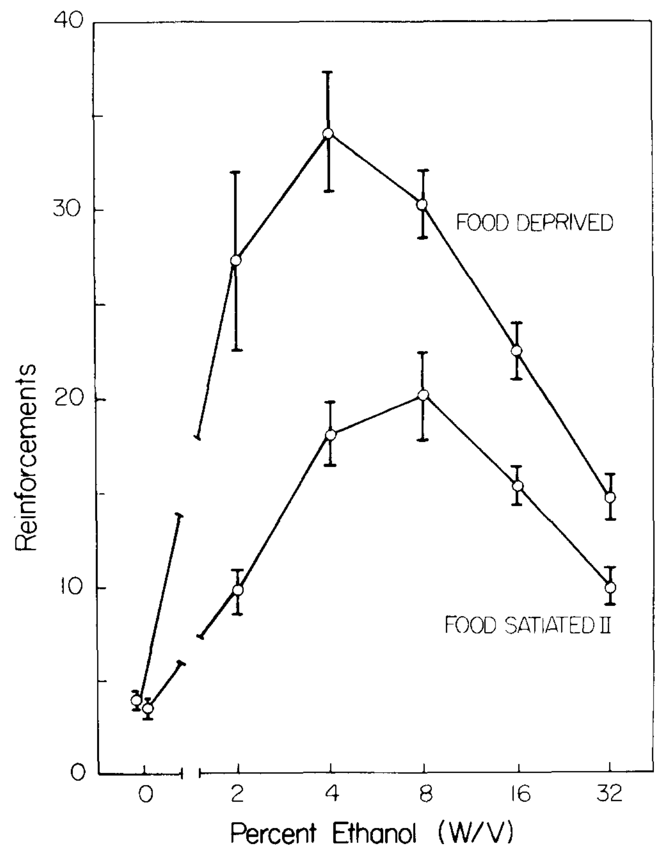

FIG. 1. Number of reinforcements as a function of ethanol concentration during food deprivation and satiation. Each point is the mean of 30 1-hour sessions: the 5 terminal sessions at each concentration for each of 6 rats. Brackets indicate the standard error of the mean.

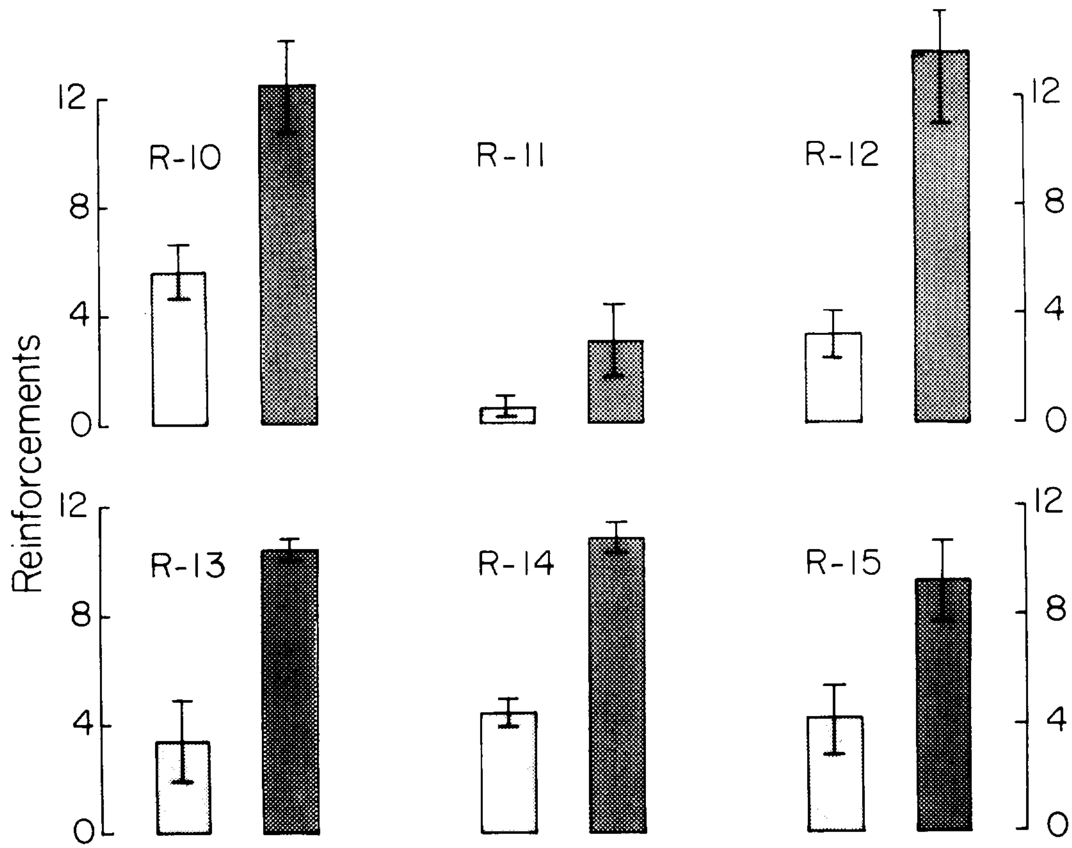

FIG. 2. Number of reinforcements for individual rats at 0% (water control) and 32% (W/V). Results are for the second series of ethanol presentations during food satiation (Series II). Zero percent results are represented by the light-shaded bars, and 32% results are represented by the dark-shaded bars. For each bar, N = 5. Brackets indicate the standard error of the mean.

The results for Food-Satiation Series I differed from Series II in that more reinforcements were obtained in Series II at concentrations 4 through 32% (W/V) ($t = 3.44$, $df = 23$, $p<0.01$) and fewer reinforcements at 2 and 0% ($t = 3.33$, $df = 11$, $p<0.01$) (Fig. 3). Since water reinforcements decreased from the first to the second series, the increase in ethanol reinforcements cannot be attributed to a non-specific increase in liquid intake.

At concentrations above 4% (W/V), ethanol reinforcements decreased to a value not below one-half the number obtained at the adjacent lower concentration (Fig. 1), so that quantity of ethanol consumed increased with increases in the concentration (Fig. 4). In most cases the rate of ethanol intake substantially exceeded the rat's rate of ethanol metabolism of 30 mg per 100 g of body weight per hour [29]. When the rats were food deprived their motor behavior was impaired following intake of concentrations above 4% (W/V). For example, after rearing up on their hind legs, the rats frequently fell backwards or on to one side, and they also occasionally fell off the weighing scale. These behaviors never occurred after control sessions or after the rats received low concentrations of ethanol.

The time course of ethanol-reinforced lever pressing under both food conditions was characterized by a high rate at the beginning of the session, followed by periods of no responding which were occasionally interrupted by responses. A typical time course of lever pressing by a representative subject is illustrated in Fig. 5. Figure 6 shows that when the rats were food deprived the percent of reinforcements received early in the session increased as a function of the concentration. When the rats were food satiated, the percent of reinforcements received early in the session did not vary with the concentration: At all concentrations at least 80% of the reinforcements were received in the first 6 min. Table 1 presents the estimated quantity that was consumed per unit body weight during the first 6 min. Rats' intakes (mg/100 g body wt) over this initial 6-min period, were similar at any particular concentration under both food conditions. These results may be compared with the finding that a dose of 90 mg per 100 g of body weight, administered by stomach tube, produced a significant decrease in the angle at which rats would slide down a tilted plane [1], presumably indicating a behaviorally intoxicating dose of ethanol.

DISCUSSION

These data indicate that rats with a past history of ethanol drinking when food deprived will, when food satiated, rapidly consume ethanol in concentrations as high as 32% (W/V) in volumes substantially in excess of water. We are not aware of any previous reports of food-satiated rats' consuming concentrations as high as 32% (W/V) at levels exceeding water control values. The intake of concen-

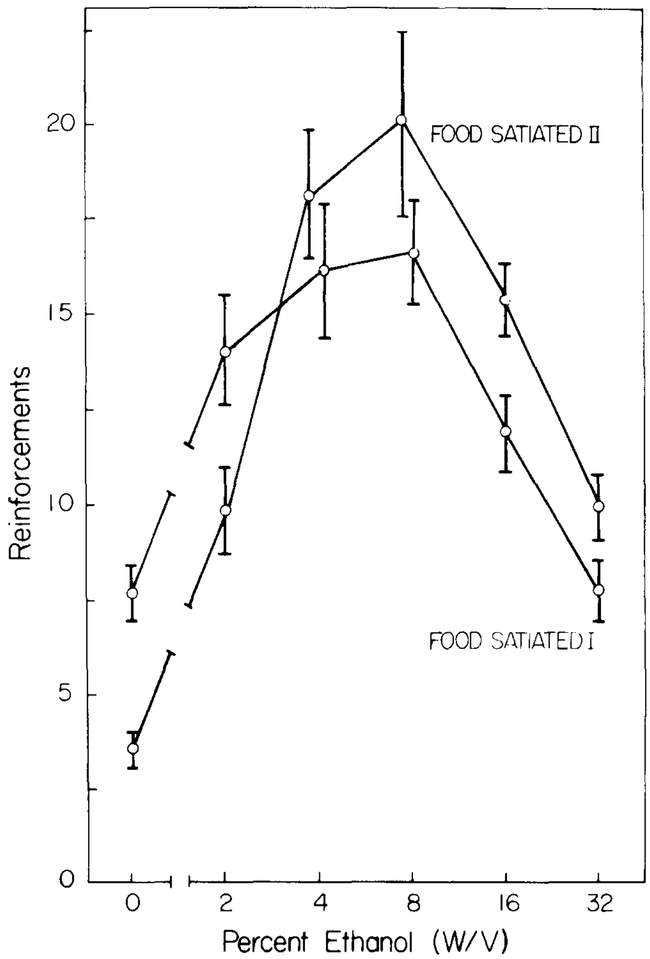

FIG. 3. Number of reinforcements as a function of ethanol concentration during food satiation. Each point is the mean of 30 1-hour sessions: the 5 terminal sessions at each concentration for each of 6 rats. Brackets indicate the standard error of the mean.

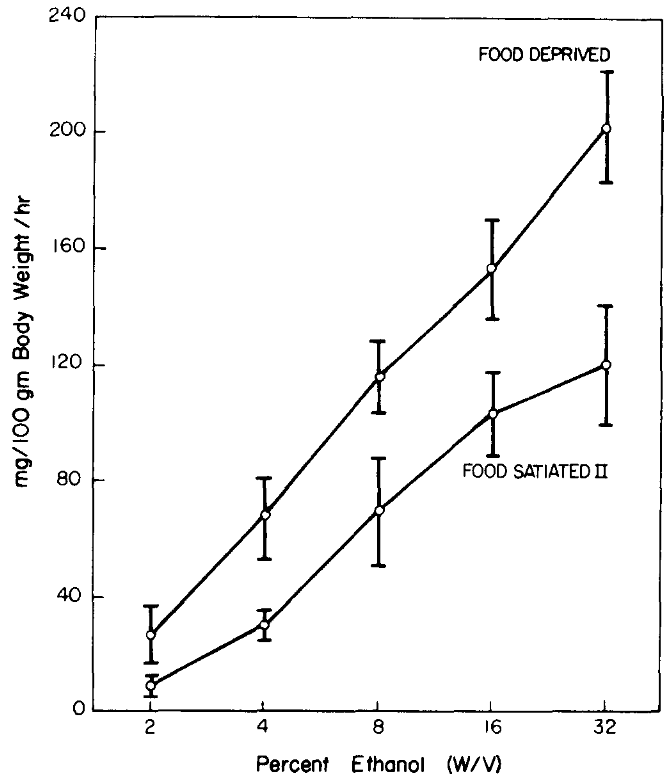

FIG. 4. Ethanol intake (mg/100 g body weight/hr) as a function of ethanol concentration during food deprivation and satiation. Each point is the mean of 30 sessions: the 5 terminal sessions at each concentration for each of 6 rats. Brackets indicate the standard error of the mean.

trations of 16 and 32% (W/V) makes it unlikely that this behavior is maintained by local taste factors, since many studies have shown that such concentrations are rejected [6, 8, 12, 17, 18, 19, 20, 25, 26]. Thus, the present data are not easily accounted for by a presumed taste preference.

The pattern of responding was characterized by a high rate at the beginning of the session followed by prolonged pauses. This pattern has been noted in previous studies with food-deprived rats [13, 15, 16]; the present study indicates that it also occurs with food-satiated rats. Since each response was reinforced and the volume consumed was directly proportional to the number of reinforcements, the time course of intake paralleled the pattern of responding. The behavioral effects of a given quantity of ethanol depend in part upon how rapidly it is consumed [10], and the time course of intake observed in this investigation was that which should produce maximum behavioral effects.

An additional finding was that the quantity (mg) of ethanol consumed increased as a function of concentration during both food deprivation and food satiation (Fig. 4). This function has been previously found with food-deprived rats [13,16].

The persistence of ethanol drinking during food satiation might be attributed to ethanol-related stimuli which have become conditioned reinforcers by association with a reduction in hunger during food deprivation. If this explanation were correct, ethanol intake during food satiation should decrease over time. However, ethanol drinking actually increased within the food-satiation phase. This increase in ethanol intake from the first to the second series during food satiation confirms similar findings made in another study with 8% (W/V) ethanol [15], and extends these findings to include other concentrations. This increase in intake within the food satiation phase is in contrast to the absence of change within the food deprivation phase: A comparison of the food-deprivation results of this study with those obtained earlier with these rats [14] revealed no difference.

Lester and Freed [9] have argued that ethanol's caloric value is a major factor in its consumption by food-deprived rats. The present findings are consistent with this argument, in that food-satiating the rats resulted in an immediate and marked decrease in ethanol intake. However, since substantial intake still occurred when rats had unlimited access to food in their home cages, the present data strongly suggest that there are factors other than ethanol's caloric value which act to determine its consumption. That ethanol intake under food-deprivation conditions, likewise, cannot

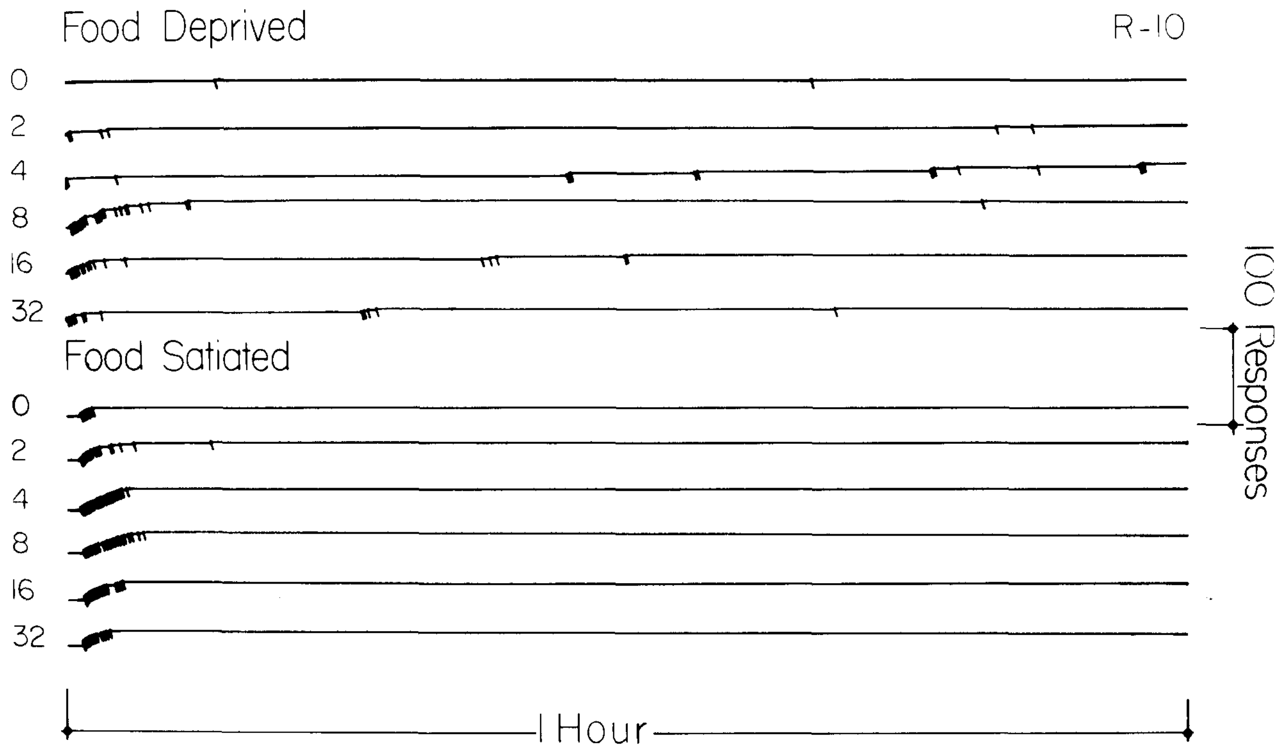

FIG. 5. Representative cumulative records for Rat 10 showing patterns of responding as a function of ethanol concentration during food deprivation and satiation. Numbers along the left side indicate the ethanol concentration. Each record was selected on the basis of being closest to the mean performance measured over the last 5 sessions at each concentration during food deprivation and food satiation (Series II). Time is indicated along the abscissa, and responses are cumulated along the ordinate. Thus, the slope of the line represents the rate of responding. Slash marks indicate 4-sec dipper presentations of 0.25 ml of the labeled concentration. Rat 10's decrease in ethanol responding during food satiation was less than the mean decrease for the 6 rats.

TABLE 1

MEAN ETHANOL QUANTITY (MG/100 G BODY WEIGHT) CONSUMED DURING THE FIRST SIX MINUTES OF ONE HOUR SESSIONS

Concentration	Food Deprived	Food Satiated II
2	7.8*	7.3
4	22.0	25.4
8	56.8	63.2
16	79.3	91.5
32	112.0	109.4

*n = 30 (6 rats X 5 observations each)

be accounted for entirely on a caloric basis is suggested by the finding that rats' intake of a morphine solution – which has no caloric value – was approximately doubled by food deprivation [22].

EXPERIMENT 2: ETHANOL INTAKE AT 32% (W/V) AS A FUNCTION OF FIXED-RATIO SIZE

In Experiment 1 it was found that food-satiated rats would drink ethanol concentrations as high as 32% (W/V) at values significantly exceeding water control intake. This result is contrary to findings of other investigators (for reviews see references nos. 21 and 29). Consequently, a second experiment was performed in which the rats were required to respond on a fixed-ratio (FR) schedule for the opportunity to drink 32% (W/V) ethanol. On such a schedule, presentation of the reinforcer is contingent upon the emission of a specified fixed number of responses. If this concentration of ethanol maintains lever pressing under ratio schedules, then the conclusion that it serves as an effective reinforcer would be substantiated.

METHOD

Animals

The same rats used in the previous experiment were used. Water and food were always available in the animals' home cages.

Apparatus

The apparatus was the same as that used in the previous experiment. Again, each operation of the dipper made available 0.25 ml of liquid for 4 sec.

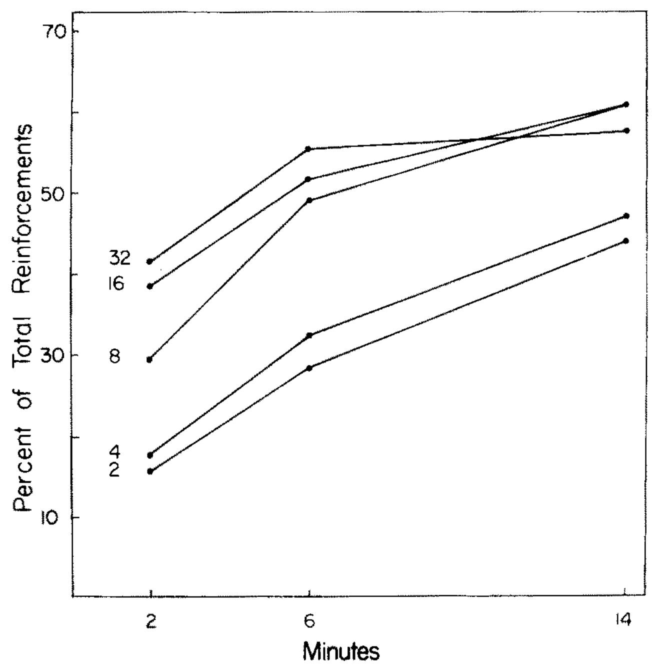

FIG. 6. Percent of total reinforcements obtained at each ethanol concentration during food deprivation as a function of elapsed session time. Numbers above the lines indicate the ethanol concentration. Each point is the mean of 6 percentages (6 rats × 1 percentage), where each percentage was calculated separately for each rat at each concentration using data from 5 sessions. The total number of reinforcements obtained per session was summed across the last 5 sessions at each concentration. This sum was then divided into the sum of the reinforcements obtained during the first 2, 6, or 14 min of the same 5 sessions, and the quotient was multiplied by 100.

Procedure

In general, the procedure was similar to that in the first experiment. Following the completion of Experiment 1, session duration remained at one hour, and on alternate days the rats were presented with either 32% (W/V) ethanol or water. Fixed-ratio sizes of 1, 2, 4 and 8 were studied, in that order. Rats were switched from one fixed-ratio value to the next after 5 ethanol and 5 water sessions, if rate of responding was stable. If responding was not stable, more sessions were run until the rate stabilized.

RESULTS

Responding for 32% (W/V) ethanol exceeded responding for water at all fixed-ratio values for four of the six rats (Fig. 7). In general, differences between ethanol and water values increased with increases in the size of the fixed ratio. At fixed ratios of 4 and 8, for each rat, ethanol-maintained responding was significantly greater than water-maintained responding (p at least <0.05, $df = 8$). For the other two rats rates of responding for both water and ethanol were variable and did not systematically differ from each other. As in the first experiment, the highest rate of responding was at the beginning of the session. When responding occurred, the pattern was similar to that observed when responding on fixed-ratio schedules is maintained by 8% (W/V) ethanol [15] or by other drugs [23] as well as by food or water.

DISCUSSION

In this experiment the mean number of ethanol reinforcements was small, ranging from 14.0 to 2.6. The low numbers may be attributed to the large magnitude of reinforcement which resulted from using a very large dipper volume and a high concentration. For example, when 8% (W/V) was used and the fixed-ratio size was varied, more reinforcements were obtained at the same fixed-ratio values [15]. When the dipper size was systematically decreased from 0.250 ml to 0.017 ml, the number of reinforcements increased and drinking occurred over progressively larger segments of the session [Henningfield and Meisch, manuscript in preparation].

Why was intake of high concentrations in excess of water values observed in the two experiments? The answer may be that acquisition of ethanol responding, like acquisition of responding for other reinforcers, occurs under restricted circumstances relative to the conditions under which responding may later be maintained. For example, when an animal is trained to press a lever for food, initially every lever press is reinforced. After acquisition of lever-pressing behavior, responding may be maintained when

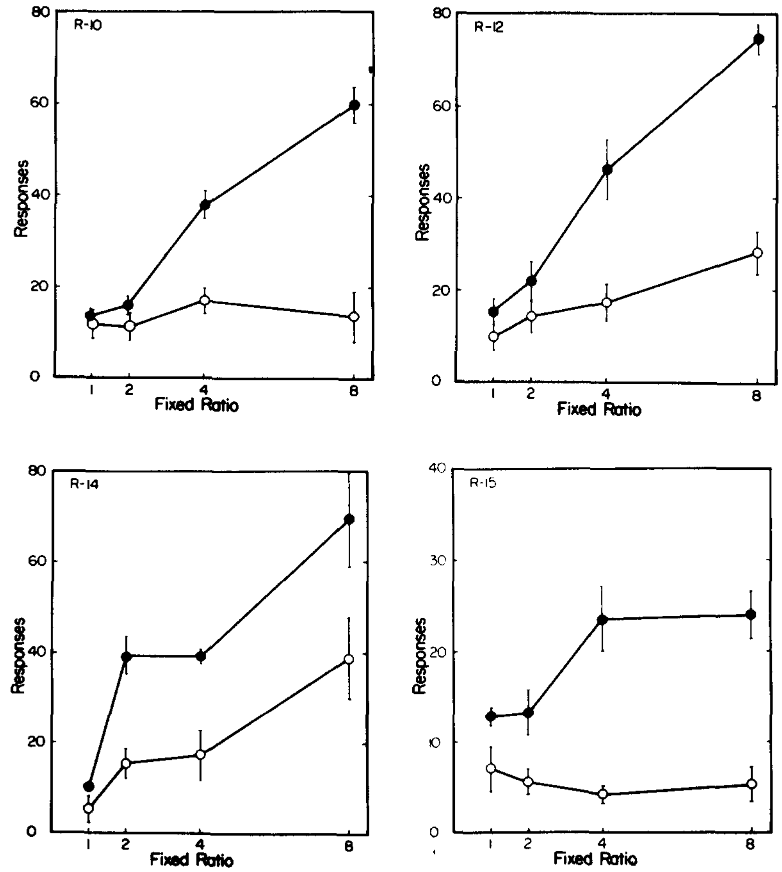

FIG. 7. Responses for 32% (W/V) ethanol (filled circles) or water (empty circles) as a function of fixed-ratio size. Separate results are shown for each rat. Each point is the mean of 5 sessions. Brackets indicate the standard error of the mean.

lever presses are only intermittently reinforced. Similarly, it is possible to obtain ethanol drinking in rats by initially presenting them with concentrations between 4 and 8% (W/V) when they are food deprived. After ethanol has been established as reinforcer during food deprivation, ethanol drinking persists when high concentrations are used and the rats are food satiated. Future research should determine whether a past history of ethanol drinking under food-deprived conditions is necessary for obtaining intake of high concentrations under conditions of food satiation.

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