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Increasing the Rate of Ethanol Consumption in Food- and Water-Satiated Rats

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MACDONALL, J. S. AND H. MARCUCELLA. *Increasing the rate of ethanol consumption in food- and water-satiated rats.* PHARMAC. BIOCHEM. BEHAV. **10**(2) 211–216, 1979.—The effects of food satiation, ethanol concentration, and the schedule of ethanol availability on the rate of ethanol consumption were investigated in rats. In Experiment 1 separate groups were exposed to 6.2 or 12.5% w/v ethanol and unlimited access to food. The food and ethanol were available concurrently for one to three hours daily. After approximately 15 sessions unlimited food was available whenever ethanol was not available. The rate of ethanol consumption was positively related to ethanol concentration and negatively related to duration of ethanol availability. In Experiment 2 similar procedures were followed, except rats had unlimited access to food throughout the experiment. The results were similar to Experiment 1. In Experiment 3 separate groups were exposed to 6.2 and 12.5% w/v ethanol for one hour every other day; unlimited food was available throughout the experiment. The results were similar to the one-hour availability groups in Experiments 1 and 2. In all experiments ethanol consumption rates increased to levels above baseline and above the usual ethanol metabolic rate found in rats. The results demonstrated new combinations of ethanol availability and non-availability durations that were sufficient to significantly increase the rate of ethanol consumption.

Ethanol Food satiation Ethanol consumption Ethanol concentration Periodic availability Ethanol self-administration Water-ethanol choice Rats

WHEN sapid solutions (e.g., ethanol, saccharin, salt, or citric acid) were made periodically available to one group of rats and continuously available to a control group, the rate of consumption by the experimental group was significantly greater than by the control group [7, 14, 15, 16]. Typically, animals were first continuously exposed, for several days, to water and ethanol-water solutions. Then half the animals (experimental group) were placed on a regimen in which ethanol availability periods were alternated with ethanol non-availability periods (water only). Availability and non-availability durations were both equal to 24 or 48 hours. The rate of ethanol consumption by experimental animals was greater than the control animals, who were continuously exposed to water and water-ethanol solutions throughout [1, 7, 14, 15, 16].

There has been little research using availability and non-availability durations shorter than 24 or 48 hours. One investigation [12] made water and 10% ethanol available to water deprived Long-Evans rats for one-hour each day for 35 days. They reported the consumption of absolute ethanol increased from 0.65 ml/kg/hr on the first two availability periods to 1.65 ml/kg/hr on the last two. The ethanol preference ratio (volume of ethanol solution consumed/volume of ethanol solution consumed plus the volume of water consumed) increased from 12 to 22%. From their procedures it is unclear how much of the increase in ethanol consumption was due to the periodic availability of ethanol and how much was due to the 23 hours of water deprivation. A second investigation [5], made ethanol available for six hours each day and found that after six to ten sessions the rate of ethanol drinking increased to a rate considerably greater than the rates established by previous investigators. However, several aspects of this procedure, in addition to the durations of ethanol availability and non-availability, differed from those used by other investigators. The major differences were: (1) the rats were deprived to 80% of ad lib weight; (2) when ethanol was available, water was not available; (3) the daily food ration was only present when ethanol was available (Experiment 2); and (4) the ethanol concentration was increased across sessions.

The purpose of the present series of studies was to examine the effect of several variables on the rate of ethanol consumption, at several combinations of availability and non-availability durations. Experiment 1 examined whether either food or water deprivation was a necessary condition for the periodic ethanol availability procedure to increase the

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TABLE 1
SEQUENCE OF ETHANOL CONCENTRATIONS MADE AVAILABLE DURING EXPERIMENTS 1 AND 3

	6.2% Groups	12.5% Groups
Days 1–4	6.2%	12.5%
Days 5–7	1.6%	1.6%
Days 8–10	3.1%	3.1%
Days 11–13	6.2%	6.2%
Days 14–23	6.2%	12.5%
Days 24–26	—	12.5%

rate of ethanol consumption when ethanol was available for several hours each day.

EXPERIMENT 1

Animals

Sixteen male Sprague-Dawley rats obtained from Holtzman Co. (Madison, WI) were between six to eight months old at the beginning of the experiment.

Apparatus

Animals were housed individually in 22×27×22 cm wire mesh cages in a continuously illuminated room. Ethanol solutions and tap water were made available in 200 ml glass bottles provided with 6.3 cm stainless steel spouts and rubber stoppers. Ethanol solutions, prepared at least 20 hours before scheduled availability periods and kept at room temperature, were mixed from 95% ethanol USP and tap water. All concentrations are expressed as weight/volume (w/v).

Procedure

During baseline (the first four days) while Purina rat chow and tap water were available ad lib, 6.2% ethanol was also available to one half of the animals, and 12.5% ethanol was available to the other half. During the experimental treatment, only an ethanol solution and lab chow were concurrently available for limited periods daily. For one-half the animals of each group (N=4) the availability period was one hour; during the remaining 23 hours only water was continuously available. For the remaining subjects the period of concurrent availability was three hours daily; during the remaining 21 hours only water was continuously available. In order to facilitate acclimation to any possible aversive taste of the ethanol solution, the ethanol concentration was reduced to 1.6% ethanol and then was increased gradually over the next six to nine availability periods. Table 1 presents the sequence of increasing ethanol concentrations. For the last seven periods food was made available when and only when ethanol was unavailable; ethanol continued to be made available once a day for either one or three hours.

Each group will be referred to by the concentration of ethanol made available during baseline and by the duration of ethanol availability. For example, the 6.2%-1-hour group was exposed to 6.2% ethanol during baseline and was exposed to increasing concentrations of ethanol beginning with 1.6% ethanol for 1-hour daily during the experimental treatment.

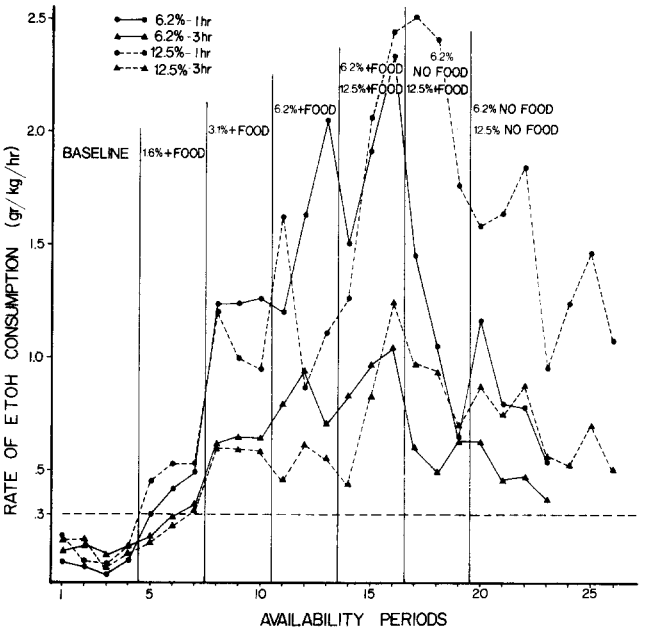

FIG. 1. Rate of ethanol consumption (g/kg/hr) per availability period. The horizontal dashed line at 0.3 g/kg/hr represents the usual ethanol metabolic rate found in rats [13]. Ethanol was available for either one or three hours daily. During food conditions food was available only when ethanol was available. During no food conditions food was available only when ethanol was not available.

RESULTS

Figure 1 shows the mean rate of ethanol consumption (g/kg of body weight/hour) per availability period for each group. There are four results to be seen in Fig. 1. First, the rate of ethanol consumption increased, across availability periods, to a level above the baseline rate (periods 1–4) and above the usual rate at which rats metabolize ethanol. Second, within the one-hr and three-hr availability conditions, the group exposed to a 12.5% ethanol solution consumed at a higher rate than the group exposed to a 6.2% ethanol solution. Third, making food available ad libitum on days 17 and 20 for the 6.2 and 12.5% groups, respectively, reduced the rate of ethanol consumption; yet, the rate was maintained above the usual rate that rats metabolize ethanol. And fourth, within the 6.2 and 12.5% conditions, making ethanol available for one hour resulted in a greater rate of ethanol consumption than making ethanol available for three hours.

Table 2 presents the means and standard deviations of the rates of ethanol consumption for the last five periods of ethanol availability (concurrent food availability—24 hour cycle). The results in Table 2 reflect the effects seen in Fig. 1.

DISCUSSION

The present results clearly indicate that making ethanol available for one or three hours daily to food- and water-satiated rats was sufficient to increase the rate of ethanol consumption. Thus, it is clear that the effect of making solutions periodically available is not limited to availability or non-availability durations of 24 or 48 hours. These results systematically replicate and extend previous findings by

TABLE 2

THE MEAN RATE OF ETHANOL CONSUMPTION (G/KG/HR) FOR ALL CONCURRENT FOOD-ETHANOL AND PERIODIC AVAILABILITY GROUPS DURING THE LAST FIVE DAYS OF EXPOSURE TO EITHER 6.2 OR 12.5% ETHANOL. STANDARD DEVIATIONS ARE IN PARENTHESES. DATA ARE INCLUDED FOR ALL GROUPS IN THE FIRST TWO EXPERIMENTS (24-HR CYCLE) AND THE THIRD EXPERIMENT (48 HR CYCLE)

	6.2%			12.5%		
	1 Hr	3 Hr	24 Hr	1 Hr	3 Hr	24 Hr
24-Hr Cycle						
Concurrent Availability	0.79 (0.24)	0.50 (0.12)		1.37 (0.45)	0.62 (0.16)	
Periodic Availability	0.75 (0.20)	0.34 (0.07)	0.23 (0.04)	1.41 (0.38)	0.64 (0.16)	0.16 (0.01)
48-Hr Cycle						
Periodic Availability	0.72 (0.26)			1.27 (0.48)		

using a different species of older rats [12], a licking instead of a lever press response to obtain ethanol [5], different ethanol concentrations [5,12], and different durations of ethanol availability [5,12].

Of course, it could be argued that limiting food availability to one or three hours daily is, in itself, food deprivation, although not as severe as being deprived to 80% of ad libitum weight. In the second experiment we assessed the effect of making ethanol available for one or three hours daily on the rate of ethanol consumption when both water and lab chow were continuously available throughout the entire experiment.

Two control groups were also included. Each control group was continuously exposed to increasing concentrations of ethanol (ethanol available for 24 hours each day), terminating in 6.2 and 12.5% ethanol concentrations.

EXPERIMENT 2

Animals

Twenty-four male Sprague-Dawley rats obtained from Holtzman Co. (Madison, WI) were between six to eight months old at the beginning of the experiment. Both lab chow and tap water were available ad libitum throughout the experiment.

Apparatus

The same apparatus as was used in Experiment 1.

Procedure

The animals were assigned to one of six groups (N=4). For four groups (the experimental groups) the procedures including the sequence of ethanol concentrations, the durations of ethanol availability and non-availability periods, and the number of sessions were, with the following two exceptions, identical to Experiment 1. First, lab chow and water were available throughout the entire experiment, and second, the locations of the ethanol and water bottles were alternated daily.

The other two groups functioned as controls for exposure to the ethanol solutions. Each group was exposed to ethanol for 24 hours each day. Except for continuous exposure to ethanol, each group was treated identically to the group whose terminal ethanol concentration was either 6.2% or 12.5% (see Table 1).

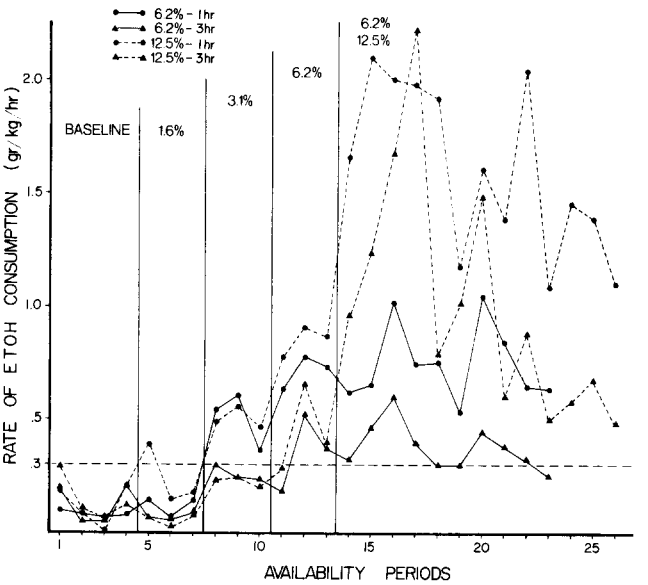

FIG. 2. Rate of ethanol consumption (g/kg/hr) per availability period. The horizontal dashed line at 0.3 g/kg/hr represents the usual metabolic rate found in rats [13]. Ethanol was available for either one or three hours daily.

RESULTS

Figure 2 shows the mean rate of ethanol consumption (g/kg/hr) per availability period for each group. These results were quite similar to the results of Experiment 1 even though both food and water were always available. The rate of ethanol consumption increased, across availability periods, to a level above the baseline rate and above the usual rate at which rats metabolize ethanol. As in Experiment 1, the rate

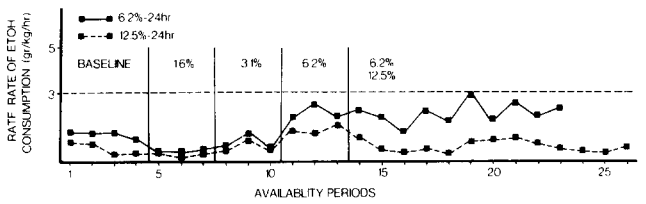

FIG. 3. Rate of ethanol consumption (g/kg/hr) per availability period. The horizontal dashed line at 0.3 g/kg/hr represents the usual ethanol metabolic rate found in rats [13]. Ethanol was available for 24 hours daily.

of ethanol consumption was higher for the one-hour available group than for the three-hour available groups, and the rate of ethanol consumption was higher for the 12.5% ethanol condition than for the 6.2% ethanol condition.

Figure 3 shows the ethanol consumption (g/kg/hr), per availability period for the two control groups with continuous access to ethanol solutions. During baseline the rates of ethanol consumption for each group were approximately equal and the rates were less than the usual rate that rats metabolize ethanol; after continuous exposure to increasing concentrations of ethanol beginning with 1.6% ethanol, the consumption rates were unchanged from the baseline rates.

Figures 2 and 3 reveal that the ethanol consumption rates during baseline were equivalent for the experimental and control groups. However, the rate of ethanol consumption for the experimental groups during the last four availability periods was greater than that of their respective controls. Table 2 also presents the means and standard deviations of the rates of ethanol consumption for the last five periods of ethanol availability for each experimental and control group (periodic availability—24 hour cycle). Table 2 reflects the effects seen in Figure 2. In addition, note that different histories, i.e., concurrent lab chow and ethanol, or periodic ethanol availability resulted in equivalent rates of ethanol consumption.

A 2×3×5 repeated measures analysis of variance (ethanol concentration × availability duration × availability periods) of the last five availability periods was conducted ([17] p. 564). For all statistical tests the α was equal to 0.05. In order to conform to the assumption that the data were normally distributed, the transformation $X^1=k^{-1/2}\sinh^{-1}(100\ kX)^2$, where k=0.05, was employed [2]. The following effects were significant: ethanol availability duration, F(2,18)=110.8, availability periods, F(4,72)=3.83, the interaction of ethanol concentration and ethanol availability duration, F(2,18) =34.8, and the interaction of ethanol availability duration and availability periods, F(8,72)=4.20. The effect of ethanol availability duration was further examined by comparing each group with its control using Dunnett's t statistic ([17] p. 201). For the 6.2% groups, only the one-hour availability group differed significantly from the control group, $t_{1\text{-hr}}$ (9,3)=3.90; for the 12.5% groups both the one- and three-hour groups differed significantly from the control group, $t_{1\text{-hr}}$ (9,3)=19.6; $t_{3\text{-hr}}$ (9,3)=24.4.

Table 3 presents the means and standard deviations of the preference ratios obtained from baseline and from the last four sessions (24-hr cycle). The preference ratio is obtained by dividing the volume of ethanol solution consumed by the volume of ethanol solution plus water consumed. For the experimental groups the preference ratios obtained from the last four sessions were at least double the ratios obtained during baseline. An examination of the preference ratios for individual rats indicated that this relationship was observed in 14 of the 16 rats used in this experiment. For the control groups the change in the preference ratio was inconsistent. The ratio increased slightly for the 6.2% group and remained unchanged for the 12.5% group. However, note the preference ratio for the 6.2% group during baseline was unusually large, and approximately equal to the preference ratios obtained by the experimental groups following periodic ethanol availability.

DISCUSSION

These results confirm and extend previous results [5, 12, 15] to different combinations of ethanol availability and non-availability durations and different ethanol concentrations. The present study demonstrated that making ethanol available for one- or three-hours daily without food or water deprivation increased the rate of ethanol consumption compared to baseline and compared to control subjects exposed continuously to the same series of ethanol concentrations. In addition, these results demonstrated that the concurrent availability of food and ethanol on a periodic basis produced a rate of ethanol consumption equal to that produced when

TABLE 3

THE MEANS OF THE ALCOHOL PREFERENCE RATIOS OBTAINED FROM BASELINE (SESSIONS 1–4) AND LAST FOUR SESSIONS FOR EACH GROUP IN EXPERIMENT 2 (24-HR CYCLE) AND IN EXPERIMENT 3 (48-HR CYCLE). STANDARD DEVIATIONS ARE IN PARENTHESES

	6.2%		12.5%	
	Baseline	Last 4 Sessions	Baseline	Last 4 Sessions
24-Hr Cycle				
1 Hr	0.18 (0.02)	0.52 (0.04)	0.14 (0.10)	0.69 (0.10)
3 Hr	0.21 (0.14)	0.54 (0.09)	0.17 (0.06)	0.46 (0.04)
24 Hr	0.51 (0.13)	0.77 (0.08)	0.14 (0.05)	0.12 (0.02)
48-Hr Cycle				
1 Hr	0.25 (0.09)	0.52 (0.11)	0.18 (0.07)	0.56 (0.11)

TABLE 4

SEQUENCE OF ETHANOL CONCENTRATIONS MADE AVAILABLE DURING EXPERIMENT 3

	6.2% Groups	12.5% Groups
Days 1–4	6.2%	12.5%
Days 5–6	1.6%	1.6%
Day 7	3.1%	3.1%
Days 8–9	6.2%	6.2%
Days 10–18	6.2%	12.5%

only ethanol was made periodically available and food was continuously available, thus, extending Meisch's [5] findings to food satiated rats. Experiments 1 and 2 demonstrated that the duration of the ethanol availability period affected the rate of ethanol consumption.

Experiment 3 examined the influence of the duration of the interval between ethanol availability periods on the rate of ethanol consumption.

EXPERIMENT 3

Animals

Eight male Sprague-Dawley rats, obtained from Holtzman Co. (Madison, WI) were between six to eight months old at the beginning of the experiment. Lab chow and water were available ad libitum throughout the experiment.

Apparatus

The same apparatus as was used in Experiment 1.

Procedure

The animals were assigned to one of two groups (N=4), which differed according to the concentration of ethanol periodically made available, either 6.2 or 12.5%. After four days of continuous ethanol availability, both groups were exposed to an ethanol solution for one hour every 47 hours. Table 4 presents the exact sequence of ethanol concentration used. The locations of the water bottle and the ethanol bottle were alternated daily.

RESULTS

Figure 4 shows the mean rate of ethanol consumption (g/kg/hr) as a function of availability periods. Again, the rate of ethanol consumption increased to a level above the baseline rate and above the usual rate that rats metabolize ethanol, and the rate of ethanol consumption was higher for the 12.5% solution.

The means and standard deviations of the rates of ethanol consumption during the last four periods are included in the lower portion of Table 2 (48-hr cycle). When a 6.2% ethanol solution was made available for one hour, the rate of consumption was similar whether rats were deprived of the ethanol solution for 23 or 47 hours. A similar effect was observed for the animals consuming a 12.5% ethanol solution for one hour. Table 3 presents the means and standard deviations of the preference ratios obtained from baseline (sessions 1–4) and from the last four sessions (48-hr cycle).

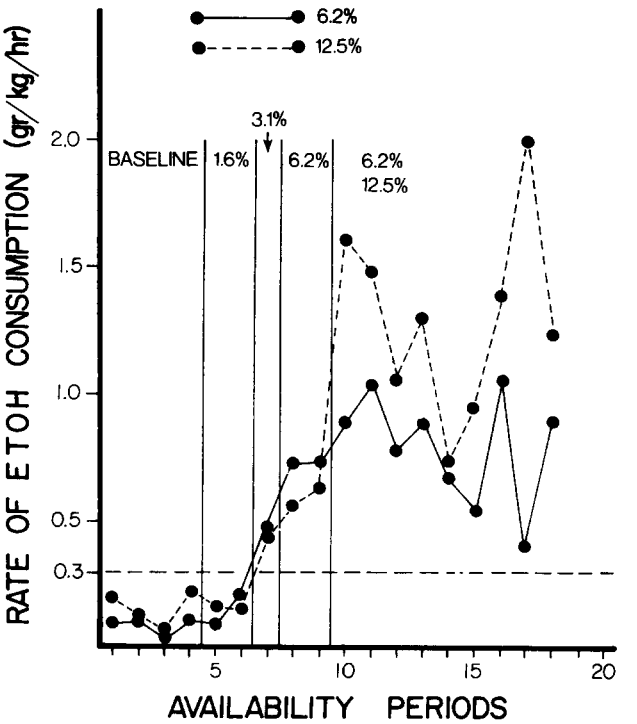

FIG. 4. Rate of ethanol consumption (g/kg/hr) per availability period. The horizontal dashed line at 0.3 g/kg/hr represents the usual ethanol metabolic rate found in rats [13]. Ethanol was available for one hour every two days.

As in Experiment 2 the preference ratios had at least doubled by the end of the periodic availability procedure. An examination of preference ratios for individual rats indicated that this relationship was observed for five of eight rats in this experiment.

DISCUSSION

The results of this experiment confirm and extend the results of Experiment 2. Making ethanol available for one hour every two days to rats receiving ad libitum lab chow and water was sufficient to increase the rate of ethanol consumption to levels above both the baseline rate and the usual rate at which rats metabolize ethanol. It is unlikely that the equivalent effects for 23 and 47 hours of ethanol non-availability could be accounted for by the different number of ethanol availability periods (the rats with 23-hour non-availability periods received two or four additional ethanol availability periods). Rather, it appears that increasing the duration of the non-availability period from 23 to 47 hours had no appreciable effect on the rate of ethanol consumption.

GENERAL DISCUSSION

The results of the present series of experiments clearly demonstrate that when ethanol is made available to food-satiated rats for one or three hours every day or two, the rate of ethanol consumption increases to levels above the baseline and above the usual metabolic rate found in rats.

These results are consistent with and extend to new strains [12], to new combinations of ethanol available/non-available durations [6,12] and to new concentrations [5,12] the effect of periodic ethanol availability on ethanol consumption. There are two other alternative accounts of these data. One maintains that the increase in ethanol consumption is not specific to ethanol, e.g., the increase may be a result of increased thirst. The second maintains that the amount of ethanol measured as consumption actually may not have been consumed but instead was spillage from the drinking tubes. Based on either of these alternatives, one would predict that the preference ratios for the experimental groups would remain unchanged following periodic availability. Instead, the preference ratios increased, at least doubling, indicating that the volume of ethanol solution was becoming a larger proportion of the rat's fluid consumption. Thus, neither argument is supported by the data.

Two points suggest caution when interpreting these data. First, the ethanol metabolic rates were not measured in this report, instead, the rates were obtained from published reports. The actual rate obtained from these subjects could vary as a function of several variables, e.g., strain or age. Second, comparisons with prior baselines require unchanging baselines. Baselines obtained in this report were stable: the ethanol consumption rate for the control groups in Experiment 2 did not increase significantly. Other investigators have found increases as a function of continuous exposure. Slight procedural variations could result in non-stable baselines, limiting the usefulness of within-subject comparisons of baseline and post-experimental treatment rates.

There is considerable evidence suggesting that the frequency of any response increases following a period (usually about 24 hours) in which that response cannot be emitted. In addition to the increased rate of consumption of sapid solutions produced by periodic availability [1, 5, 7, 12, 14, 15, 16], Premack [8] has shown that the frequency of wheel running can be increased by temporarily depriving the animal of the opportunity to wheel run. In addition, there was a positive relationship between the rate of wheel running by rats [4], lever pressing by rats [10,11], lever pressing by monkeys [9] or light contingent lever pressing by rats [10] and the duration that animals were deprived of the opportunity to engage in each behavior. Butler [3] has demonstrated that visual contingent responding was positively related to the duration of deprivation from visual stimuli.

The procedure used in the present experiment was quite similar to these response deprivation studies, i.e., rats were periodically deprived of the opportunity to consume ethanol. Thus, it is consistent with the above studies that periods of ethanol deprivation of 21, 23, or 47 hours alternating with periods of ethanol availability of 3, 1, or 1 hours, respectively, temporarily increased the rate of ethanol consumption.

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