

# Influence of Increasing Concentrations of Ethanol on Food and Water Intake, Body Weight, and Wheel-Running of Male Sprague-Dawley Rats

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Received 20 August 1985

BARR, S. I. *Influence of increasing concentrations of ethanol on food and water intake, body weight, and wheel-running of male Sprague-Dawley rats.* PHARMACOL BIOCHEM BEHAV 29(4) 667-673, 1988.—Male Sprague-Dawley rats were used to study the influence of increasing concentrations of ethanol on wheel-running, food and water intake and body weight. Animals were housed individually in screen-bottom cages ( $n=12$ ) or in activity wheel cages ( $n=12$ ). Half the animals in each activity condition received an ethanol-free liquid diet, and the remainder received liquid diet in which the concentration of ethanol was increased by 5% of energy intake per week to a maximum of 35%, at the expense of dextrin. Ethanol did not significantly affect total wheel-running, but was associated with decreased total food intake when it represented  $\geq 20\%$  of energy ( $p < 0.001$ ). The decreased intake was restricted to the dark cycle, while light cycle intake was unaffected. Neither water intake nor body weight (with food intake as a covariate) were affected by ethanol. In contrast, wheel-running was associated with increased water intake and decreased body weight, but did not affect food intake. No interactions between activity and ethanol were detected. It is concluded that ethanol in the concentrations tested does not affect wheel-running in male rats, but does reduce food intake and may disrupt circadian food intake patterns.

Ethanol    Food intake    Activity    Rat

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THE influences of ethanol on body weight gain and on various aspects of physical activity have been studied separately in rats. Ethanol-fed animals generally gain weight at a slower rate than nonalcohol controls, whether the ethanol is administered in drinking water [5, 20, 23] or as part of a liquid diet [10, 13, 23]. For the most part, the decreased body weight is mediated by reduced food intake [10, 13, 20, 23], although reduced caloric efficiency has also been reported at high ethanol intakes [18,23]. The possibility that the level of physical activity may have differed between animals receiving ethanol and those not receiving ethanol, and thus had an influence on weight gain, does not appear to have been addressed.

Various aspects of physical activity in rats have been found to be affected by ethanol. Locomotor activity of animals tested in an open field was reduced following intraperitoneal injection of ethanol [12]; acute intake resulted in loss of coordination as measured by tilting plane test [11]; and performance on a moving belt apparatus was impaired in animals chronically receiving ethanol at 35% of energy intake [13]. However, the effect of chronic exposure to ethanol on spontaneous daily activity has not been reported, and is of potential significance in relation to ethanol's effect on energy balance. A moderate reduction in caloric efficiency (and therefore, an increase in energy expenditure) could be

missed if ethanol simultaneously decreased spontaneous activity and its associated energy expenditure. Ethanol-fed animals could thus gain weight at the same rate as controls not receiving ethanol, yet the components of energy expenditure would have been altered.

In this study, the effects of increasing concentrations of ethanol on body weight, voluntary activity as monitored by wheel-running, and food and water intake were studied in male rats. Exercise, in addition to being studied as a dependent variable, was also examined as an independent variable: food and water intake and body weight gain of wheel-running animals were compared to those of animals without access to activity wheels.

## METHOD

### *Animals*

Male weanling Sprague-Dawley rats (obtained from Charles River, Hull, Quebec) 50-60 g in weight, were kept in an animal room maintained at  $21 \pm 1^\circ\text{C}$  with a 12 hour light/dark cycle. Following a three-day acclimatization period during which animals were housed communally and offered water and Purina lab chow ad lib, they were transferred to individual stainless steel hanging cages or activity wheel cages (Wahmann Co., Timonium, MD) as appropriate. The

TABLE 1  
MEAN DAILY CALORIC INTAKES AS INFLUENCED BY ETHANOL AND WHEEL-RUNNING

Week	% EtOH*	No Wheel Access		Wheel Access	
		No Ethanol	Ethanol	No Ethanol	Ethanol
1	0	47.4 ± 11.4†	40.0 ± 6.3	40.8 ± 11.0	41.8 ± 9.2
2	5	73.8 ± 6.9	71.8 ± 6.3	71.7 ± 8.6	71.0 ± 4.4
3	10	92.5 ± 9.3	87.8 ± 9.5	87.2 ± 9.8	85.7 ± 7.6
4	15	94.1 ± 8.8	88.4 ± 10.1	93.3 ± 6.8	89.1 ± 8.6
5	20	101.3 ± 4.2	87.7 ± 9.0	98.0 ± 5.0	91.7 ± 9.0
6	25	98.8 ± 5.6	93.9 ± 9.0	102.0 ± 4.4	90.8 ± 10.8
7	30	100.1 ± 6.1	85.2 ± 8.1	104.2 ± 5.9	85.8 ± 7.4
8	35	97.9 ± 9.2	81.2 ± 8.6	103.0 ± 8.3	72.8 ± 10.8

\*% Energy intake contributed by ethanol in ethanol-fed groups.

†Mean ± standard deviation, kcal/day.

activity wheels were one meter in circumference, and were connected to side cages to which diet and water bottles were attached.

#### Diets

The liquid diet employed was identical to that of Miller *et al.* [13], except that the suspending agent used was Suspending Agent K (Bio-Serv, Frenchtown, NJ). The ethanol-free liquid diet contained (in g/kg final formulation) 42.0 g micropulverized casein, 0.6 g L-methionine, 10.5 g corn oil, 2.1 g A.I.N. Vitamin Mix 76, 7.3 g A.I.N. Mineral Mix 76, 25.0 g sucrose, 110.0 g white dextrin, 1.0 g Suspending Agent K, 0.4 g choline bitartrate, and 801.1 g water. Ingredients other than Suspending Agent K were obtained from ICN Nutritional Biochemicals (Cleveland, OH) with the exception of corn oil and sucrose, which were purchased locally. As appropriate, ethanol (95% v/v) was added to the diet at the expense of dextrin, and the volume of water adjusted so the diets were isocaloric. When ethanol was present in amounts exceeding 25% of the energy content of the diet, the amount of suspending agent was increased to 1.5 g/kg to ensure that the diet remained in suspension.

The diet was freshly prepared each day from premixed dry ingredients. The water and ethanol (if included) specified in the formula were initially mixed for 20 seconds at low speed in a Waring blender with half the suspending agent. The dry ingredients and corn oil were then added, and blended for an additional 20 seconds. Finally, the remaining suspending agent was added and the mixture blended for 25 seconds. The diet was portioned into glass bottles equipped with rubber stoppers and ball-point feeding tubes that almost eliminated spillage.

#### Protocol

Four groups of animals (n=6/group) were included in the experiment: ethanol-fed, wheel access; ethanol-fed, no wheel access; no ethanol, wheel access; and no ethanol, no wheel access. Animals with wheel access were housed in the activity wheel cages and animals without wheel access in rectangular hanging cages. Following three days during which animals had access to both lab chow and the ethanol-free liquid diet, chow was removed and the experiment begun. For the first week, all animals received the ethanol-free liquid diet. Thereafter, the concentration of ethanol in the diet

received by the ethanol-fed groups was increased by 5% of the energy content of the diet per week to a maximum of 35% during the eighth week of the experiment, after which time the experiment was terminated.

The following variables were recorded throughout the experiment at the intervals specified: food intake (by weight) every day; wheel-running (as revolutions) every day; water intake (by weight) every second day; and body weight every fourth day. During the final two weeks of the study, wheel-running and food intake were recorded twice daily, at the start of the light cycle and of the dark cycle. Tail blood samples, approximately 250  $\mu$ l in volume, were obtained at the start of the light cycle at weekly intervals for evaluation of blood ethanol by the alcohol dehydrogenase method, using reagents obtained from Sigma, St. Louis, MO.

#### Statistical Analysis

Statistical analyses were performed using programs available in SPSS:x [16]. Analysis of variance (ANOVA) was used to test for main effects of diet (ethanol or no ethanol) and wheel-running (wheel access or no wheel access) on body weight, food intake, water intake, and the light/dark cycle pattern of food intake. *t*-Tests were employed to test for differences in mean wheel-running levels with the presence or absence of ethanol. When testing for differences in patterns of wheel-running or food intake associated with the light/dark cycle, arcsin square root transformations of the proportion of total wheel-running or food intake occurring in the light cycle were used to equalize variances [24]. The level of statistical significance was set at  $p=0.05$ , although results are reported at the highest level of significance.

#### RESULTS

##### Food Intake

The average daily caloric intakes of the four groups of animals are presented in Table 1. No significant effects of wheel-running on caloric intakes were detected by ANOVA, but the inclusion of ethanol in the diet was associated with decreased intake when it represented 20% or more of total energy,  $F(1,20)=19.4$ ,  $p<0.001$ . No two-way interactions between ethanol and wheel-running were detected.

##### Ethanol Intake

As ethanol in the diet increased in increments of 5% of

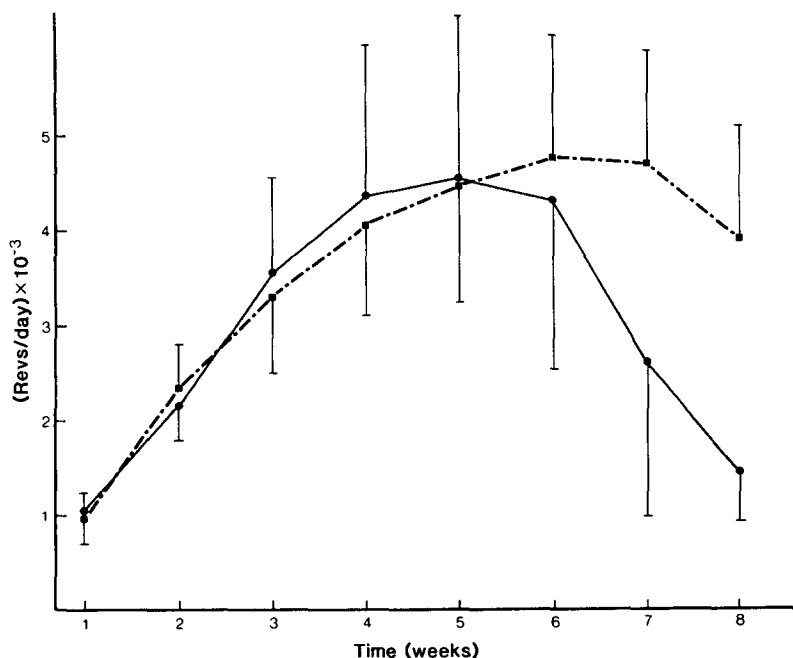


FIG. 1. Mean activity levels of rats not receiving ethanol (■) or receiving ethanol in amounts increasing by 5% of energy intake per week from 0% in week 1 to 35% in week 8 (●). Error bars represent standard error of the mean.

energy intake per week from 5% to 35%, corresponding group mean ethanol intakes of the wheel-running animals for each of the seven weeks (expressed in g EtOH/kg body weight/day) were:  $2.7 \pm 0.4$ ,  $6.1 \pm 0.5$ ,  $7.8 \pm 0.6$ ,  $9.4 \pm 0.8$ ,  $10.4 \pm 1.0$ ,  $11.5 \pm 0.8$  and  $11.0 \pm 1.5$ . For animals with no wheel access, group intakes averaged  $2.6 \pm 0.3$ ,  $5.7 \pm 0.4$ ,  $7.0 \pm 0.6$ ,  $7.9 \pm 0.5$ ,  $8.8 \pm 0.7$ ,  $9.0 \pm 0.8$  and  $9.3 \pm 0.3$  g/kg/day for each of the seven weeks. The relative intakes of wheel-running animals were significantly greater than those of the animals with no wheel access when ethanol made up  $\geq 15\%$  of energy intake, due to the lower body weight of the wheel-running animals. Absolute ethanol intake, expressed as g EtOH/animal/day, did not differ between groups.

#### Water Intake

In contrast to food intake results, wheel-running was associated with an increase in water intake that was significant by the second week of the experiment,  $F(1,20)=10.8$ ,  $p < 0.01$ , and remained so for its duration. During the final week of the study, water intakes averaged  $14.0 \pm 12.9$  and  $9.8 \pm 3.6$  g/day for nonethanol and ethanol-fed animals without wheel access respectively, and  $27.1 \pm 6.2$  and  $39.7 \pm 20.7$  g/day for wheel-running animals not receiving and receiving ethanol. The presence of increasing concentrations of ethanol in the diet did not influence water consumption, and no two-way interactions between wheel-running and ethanol were detected.

#### Wheel-Running

The mean activity levels of wheel-running animals receiving or not receiving ethanol are illustrated in Fig. 1. In both groups of animals, wheel-running increased during the first five weeks of the study, and then appeared to plateau in the animals receiving control diet. The activity level of the

ethanol-fed animals declined from an average of 4562 rev/day during week five to an average of 2417 rev/day during week eight ( $p < 0.02$ ). Due to a high degree of variability in individual activity levels, differences between the two groups were not statistically significant at any point.

#### Body Weight

Average weights of the animals are shown in Fig. 2. ANOVA revealed that wheel-running significantly affected body weight by the end of the second week of the study,  $F(1,20)=7.4$ ,  $p < 0.05$ , and this effect was highly significant,  $F(1,20)=15.2$ ,  $p < 0.001$ , from the fifth week through to the end of the study. The presence of ethanol in the diet was also associated with lower body weight, and this became significant when ethanol was included at levels  $> 20\%$  of energy intake. However, because ethanol-fed animals consumed less of the diet than did their controls (Table 1), ANOVA was also performed with food intake as co-variate. When the influence of ethanol on food intake was controlled, its effect on body weight was not significant at any point.

#### Light/Dark Cycle Caloric Intake and Activity

Food intakes of the animals during the light and dark cycle were recorded during the final two weeks of the experiment (Table 2). Although total caloric intake of the ethanol-fed animals was lower than that of animals not receiving ethanol (Table 1), this difference was confined to the dark cycle: Light cycle intake was not affected by ethanol or wheel-running, but ANOVA revealed a significant effect of ethanol on dark cycle intake,  $F(1,20)=59.5$ ,  $p < 0.001$ . The proportion of the total intake consumed during the light cycle was thus significantly higher in the ethanol-fed animals ( $p < 0.05$ ).

Likewise, wheel-running patterns during the light and

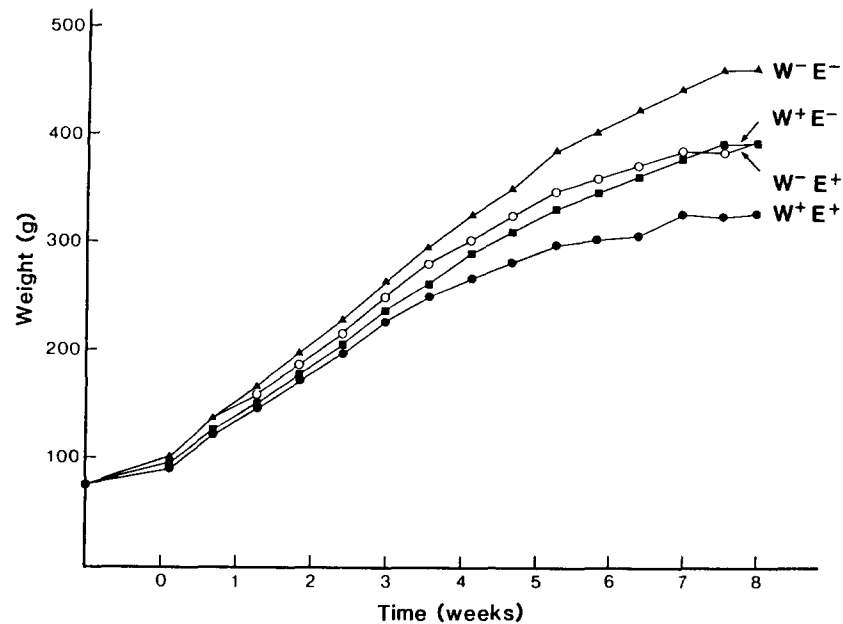


FIG. 2. Mean body weights of rats. W<sup>-</sup>E<sup>-</sup>=no wheel access, no ethanol; W<sup>+</sup>E<sup>-</sup>=wheel access, no ethanol; W<sup>-</sup>E<sup>+</sup>=no wheel access, ethanol in amounts increasing by 5% of energy intake per week from 0% in week 1 to 35% in week 8; W<sup>+</sup>E<sup>+</sup>=wheel access, ethanol in amounts as described above.

dark cycle were examined during the final two weeks of the experiment (Table 2). Animals not receiving ethanol completed approximately four times more revolutions during the dark cycle than during the light cycle. Ethanol-fed animals had light cycle wheel-running levels that were similar to those of animals on control diet, but dark cycle wheel-running appeared to be comparatively reduced, particularly during the final week of the study. This difference was not statistically significant.

#### Blood Ethanol Levels

As the concentration of ethanol in the liquid diet increased from 5% to 35% of energy intake, average blood ethanol levels progressively increased from  $2.3 \pm 0.1$  mg/dl to  $87.6 \pm 12.3$  mg/dl, and did not differ between animals with and without access to running wheels. Average blood levels were positively correlated with the concentration of ethanol in the diet ( $r = .91, p < 0.01$ ).

#### DISCUSSION

In this study, increasing amounts of ethanol were added to a liquid diet fed to weanling male Sprague-Dawley rats with or without access to activity wheels. When ethanol was present in amounts up to and including 15% of energy intake, it had no detectable effects on either caloric intake or body weight. However, at 20% or more of energy intake, both caloric intake and weight gain were inhibited. At 35% of energy, the highest level tested in this study, caloric intake was inhibited by approximately 23%, less than the 39% inhibition at 30% of energy intake reported by Shorey *et al.* [23] or the 35% inhibition at 30–35% of energy reported by Miller *et al.* [13] in animals fed similar liquid diets. These differences may be due to the fact that animals in the present study built up to this level of intake over a period of seven weeks,

as compared to three days or less in the other studies [13,23]. The deficit in weight gain experienced by these animals could be accounted for by their reduced caloric intake; thus, these data did not provide evidence for inefficient use of ethanol calories as observed elsewhere [18,23]. It is possible that the ethanol intake in this study was not high enough for a long enough time period for this to occur. In the animals studied by Shorey *et al.* [23], ethanol at 20% and 30% of energy intake inhibited food intake and weight gain, but only when ethanol was fed at 40% of total energy could the reduced weight gain not be completely ascribed to decreased food intake.

Water intake of the animals was increased by exercise as reported previously [15,22], but was not affected by ethanol. Although ethanol can act as a diuretic, its lack of effect on water intake by these animals is not surprising, given the high concentration of water in the liquid diet itself. The free water intakes of the animals in this study were lower than those reported for animals consuming solid diets [15,21], suggesting that the water content of the liquid diet was adequate.

Somewhat surprising was the failure of ethanol to significantly affect voluntary activity as monitored by wheel running. Ethanol is known to act as a central nervous system depressant, and acute intake by rats has been reported to result in decreased gross motor activity [12], loss of coordination as measured by tilting-plane test [11], and decreased performance on a moving belt [13]. In the present study, the wheel-running level of rats fed ethanol did tend to be less than that of animals receiving control diet during the final week of the study. However, there was a high degree of individual variability in activity level, and differences between ethanol-fed and control groups were not statistically significant. Thus, no evidence was obtained to suggest that a reduction in physical activity may have prevented the detec-

TABLE 2  
LIGHT AND DARK CYCLE CALORIC INTAKE AND ACTIVITY

Week	% EtOH*	Variable	No Wheel Access		Wheel Access	
			No Ethanol	Ethanol	No Ethanol	Ethanol
Light cycle						
7	30	Caloric intake (kcal/12 hr)	26.8 ± 4.6†	33.4 ± 3.5	31.4 ± 10.4	33.8 ± 5.3
		Wheel-running (rev/12 hr)	—	—	877 ± 1702	328 ± 306
8	35	Caloric intake (kcal/12 hr)	25.8 ± 4.3	30.9 ± 2.2	28.2 ± 10.1	31.6 ± 4.0
		Wheel-running (rev/12 hr)	—	—	836 ± 1653	624 ± 811
Dark cycle						
7	30	Caloric intake (kcal/12 hr)	73.4 ± 7.3	48.9 ± 7.0	72.8 ± 11.1	46.7 ± 4.2
		Wheel-running (rev/12 hr)	—	—	3822 ± 2836	2303 ± 4034
8	35	Caloric intake (kcal/12 hr)	72.2 ± 9.3	42.1 ± 7.3	74.2 ± 11.4	42.2 ± 10.6
		Wheel-running (rev/12 hr)	—	—	3063 ± 2462	867 ± 879

\*% Energy intake contributed by ethanol in ethanol-fed groups.

†Mean ± standard deviation.

tion of ethanol-induced caloric inefficiency at the levels of ethanol tested in this study. It could be asked whether a more accurate measure of activity might have detected a difference between ethanol-fed animals and controls. It is true that wheel-running does not represent the animals' total activity, as they were also able to move in the side cages attached to the wheels. However, it is unlikely that this obscured a true difference in activity level: if this were indeed to be the case, it would be necessary to speculate that ethanol differentially affected movement in the wheel as opposed to movement in the cage, having no significant effect on the former and reducing the latter to such an extent that the total activity level was reduced. This is not a likely explanation, as the side cages were smaller than typical hanging cages, and the amount of activity that could be performed in them was thus limited.

Aside from variability, another possible explanation for the failure of ethanol to significantly affect activity level may be related to its apparent effect on the circadian food intake pattern. Although the level of ethanol attained in this study was comparable to that achieved in studies in which physical dependence was demonstrated [6,10], the ethanol-fed animals generally did not appear to be intoxicated. This may have been due to their pattern of food intake: ethanol-fed animals consumed only 58% of total energy intake during the dark cycle, as compared to an average of 72% by animals not receiving ethanol ( $p < 0.001$ ). By distributing total intake more evenly throughout the day, the ethanol-fed groups likely avoided acutely elevated blood ethanol levels, and were able to continue activities such as wheel-running. This suggestion is also supported by the finding that average blood ethanol levels of the animals in this study were not as high as those reported in animals whose access to ethanol-containing diet was restricted during the light cycle [13].

An effect on circadian food intake has previously been reported in ethanol-fed pregnant rats on day 13 of gestation [17], and the behavioral and biological sensitivity of rats to acute doses of ethanol has been observed to exhibit circadian variation [4]. Motor activity, body temperature and blood corticosterone responses following ethanol injection were found to vary in relation to what time of day the ethanol was administered, despite similar blood ethanol levels [4]. Brick *et al.* speculate that their findings may be due to differences in brain neurotransmitter levels, several of which have circadian rhythms themselves [8,9]. Since many of ethanol's effects are felt to be mediated through neurotransmitters [25], it is not unexpected that chronic ethanol intake, as in the present study, could affect the circadian distribution of certain behaviors.

While the primary purpose of this study was to examine ethanol's effects on wheel-running level, weight gain, and food and water intake, the study design also permitted analysis of the effects of wheel-running on weight gain and food intake. Animals running in activity wheels in this study gained significantly less weight than controls, whether or not ethanol was consumed, yet had similar food intakes (Table 1). Many other studies of wheel-running male rats also report a decrease in body weight relative to sedentary controls [7, 14, 19, 22, 26], although no difference [3] or increased body weight [2] have also been reported. The results of the latter study may be explained by the fact that animals had access to activity wheels only one day in three, and rats 'retiring' from physical activity have been found to have rapid increases in food intake and body weight [1]. Thus, the body weight results of the present study are consistent with those of most other studies of voluntarily exercising males consuming ad lib diets, and support the generalization that exercise is associated with decreased body weight in male rats.

The effect of exercise on food intake does not appear to be as reproducible from one study to another. Even among studies of voluntarily exercising male rats who experienced decreased body weight relative to controls, little consistency is found. Food intake of exercising rats relative to controls was found to be increased [2,14]; not different [3,22]; decreased [7]; decreased for the first ten days and increased thereafter [26]; or increased at 50–75 days of age and similar at 148–160 days [19]. The present study, in which food intake was recorded daily, found that intake was not affected by activity at any point during the study. It is difficult, if not impossible, to rationalize the discrepancies amongst these studies, particularly given their similarities in terms of exercise modality and sex of the animals. However, it is probable that the age of the animals when activity was initiated played a role, as old rats exercise less than young rats [17,19]. Another factor could be when food intake was evaluated, if this wasn't done continuously. Animals exercising in activity wheels typically increase their activity levels over the first two to four weeks, after which activity tends to plateau or decrease [19, 22, 26]. If one wishes to investigate the hypothesis that energy intake is regulated by or reflects energy expenditure in some way, it is obviously necessary to evaluate food intake when activity levels are high.

An issue which should be addressed relates to whether the use of growing rats affected the conclusions drawn from this study. Briefly, these were: (1) ethanol did not affect wheel-running in the concentrations used; (2) at concentrations greater than 20% of energy intake, ethanol was associated with decreased energy intake, particularly during the dark cycle; (3) ethanol did not affect free water intakes of animals receiving liquid diets; and (4) no evidence was obtained to suggest that caloric efficiency was influenced by ethanol in the concentrations used (that is, diminished physical activity did not obscure decreased efficiency in ethanol-fed rats). These conclusions could have been affected if exposure of rats to ethanol at a young age induces a permanent change in the way that it is metabolized, such that animals initially exposed during this critical time period do not re-

spond in the same way at a later age as animals initially exposed at a later age. Should this be the case, I am not aware of the evidence. There is some evidence in the literature to suggest that young animals may respond differently to acute doses of ethanol than older animals: for example, Hollstedt reported that rats 25–100 g in weight responded somewhat differently than rats 150–250 g in weight [11]. The rats used in the present study, however, averaged 125 g in weight upon initial exposure to ethanol, and were thus heavier than the young animals studied by Hollstedt. Finally, it is true that the animals in this study were growing rapidly, and that their energy intakes were not constant throughout the experiment. Thus, although the proportion of dietary energy derived from ethanol increased seven-fold (from 5% to 35%), the dosage level (in g/kg body weight) increased only four-fold. However, if one examines only the data obtained during the final four weeks of the study, when energy intakes of the rats had stabilized and their growth rate had decreased, the conclusions do not appear to be altered.

In summary, the results of this study indicate that in growing male rats, ethanol at up to 15% of energy intake had no demonstrable effects on food intake, weight gain or wheel-running. Higher concentrations inhibited both food intake and weight gain proportionally, and also disrupted the circadian food intake pattern. No evidence was obtained to suggest that a decrease in physical activity prevented the detection of ethanol-associated caloric inefficiency at the levels of ethanol tested in this study.

#### ACKNOWLEDGEMENTS

The author extends sincere thanks to Roberta Crosby and Marcia Pedersen for typing the manuscript, and to Diana Vos for invaluable technical assistance. A preliminary report of these data was presented at the annual meeting of the Federation of American Societies for Experimental Biology, Anaheim, CA, April 1985. This research was supported by Operating Grant A0019 from the Natural Sciences and Engineering Research Council of Canada.

#### REFERENCES

- Applegate, E. A., D. E. Upton and J. S. Stern. Exercise and detraining: effect on food intake, adiposity and lipogenesis in Osborne-Mendel rats made obese by a high fat diet. *J Nutr* 114: 447–459, 1984.
- Bazzarre, T. L. The effects of diet and exercise on feed intake, body weight, body fat and growth hormone in male weanling rats. *Nutr Rep Int* 29: 997–1004, 1984.
- Bowering, J. and G. F. Norton. Relationships between iron status and exercise in male and female growing rats. *J Nutr* 111: 1648–1657, 1981.
- Brick, J., L. A. Pohorecky, W. Faulkner and M. N. Adams. Circadian variations in behavioral and biological sensitivity to ethanol. *Alcohol: Clin Exp Res* 8: 204–211, 1984.
- Cascales, C., M. Benito, M. Cascales, T. Caldes and A. Santos-Ruiz. The effect of chronic ethanol administration on lipogenesis in liver and adipose tissue in the rat. *Br J Nutr* 50: 549–553, 1983.
- Cicero, T. J., S. R. Snider, V. J. Perez and L. W. Swanson. Physical dependence on and tolerance to alcohol in the rat. *Physiol Behav* 6: 191–198, 1971.
- Collier, G., E. Hirsch and A. I. Leshner. The metabolic cost of activity in activity-naive rats. *Physiol Behav* 8: 881–884, 1972.
- Eriksson, E., S. Eden, K. Modigh and J. Haggendal. Ultradian rhythm in rat hypothalamic dopamine levels. *J Neural Transm* 48: 305–310, 1980.
- Friedman, A. H. and C. A. Walker. Circadian rhythms in rat mid-brain and caudate nucleus biogenic amine levels. *J Physiol* 197: 77–85, 1968.
- Goldman, M. E., S. S. Miller, R. L. Shorey and C. K. Erickson. Ethanol dependence produced in rats by nutritionally complete diets. *Pharmacol Biochem Behav* 12: 503–507, 1980.
- Hollstedt, C., O. Olsson and U. Rydberg. Effects of ethanol on the developing rat. II. Coordination as measured by the tilting-plane test. *Med Biol* 58: 164–168, 1980.
- Lamble, R. and U. Rydberg. Effects of ethanol on locomotor activity in rats of different ages. *Acta Pharmacol Toxicol* 50: 246–250, 1982.
- Miller, S. S., M. E. Goldman, C. K. Erickson and R. L. Shorey. Induction of physical dependence on and tolerance to ethanol in rats fed a new nutritionally complete and balanced liquid diet. *Psychopharmacology (Berlin)* 68: 55–59, 1980.
- Mondon, C. E., C. B. Dolkas and G. M. Reaven. Site of enhanced insulin sensitivity in exercise-trained rats at rest. *Am J Physiol* 239: E169–E177, 1980.
- Nance, D. M., B. Bromley, R. J. Barnard and R. A. Gorski. Sexually dimorphic effects of forced exercise on food intake and body weight in the rat. *Physiol Behav* 19: 155–158, 1977.
- Nie, N. H. *SPSS<sup>x</sup> User's Guide*. New York: McGraw-Hill Book Company, 1983.

17. Peng, M. T. and M. Kang. Circadian rhythms and patterns of running-wheel activity, feeding and drinking behaviors of old male rats. *Physiol Behav* 33: 615-620, 1984.
18. Pirola, R. C. and C. S. Lieber. Energy wastage in rats given drugs to induce microsomal enzymes. *J Nutr* 105: 1544-1548, 1975.
19. Pitts, G. C. Body composition in the rat: interactions of exercise, age, sex, and diet. *Am J Physiol* 246: R495-R501, 1984.
20. Porta, E. A. and C. L. A. Gomez-Dumm. A new experimental approach in the study of chronic alcoholism. I. Effects of high alcohol intake in rats fed commercial laboratory diets. *Lab Invest* 18: 352-364, 1968.
21. Rick, J. T. and C. W. M. Wilson. Alcohol preference in the rat: its relationship to total fluid consumption. *Q J Stud Alcohol* 27: 447-458, 1966.
22. Rolls, B. J. and E. A. Rowe. Exercise and the development and persistence of dietary obesity in male and female rats. *Physiol Behav* 23: 241-247, 1979.
23. Shorey, R. L., P. A. Terranella and W. Shive. Effects of ethanol on growth, consumption of food, and body composition of weanling rats. *J Nutr* 107: 614-620, 1977.
24. Snedecor, G. W. and W. G. Cochran. *Statistical Methods*, 6th edition. Ames: Iowa State University Press, 1967.
25. Tabakoff, B. and P. L. Hoffman. Alcohol and neurotransmitters. In: *Alcohol Tolerance and Dependence*, edited by H. Rigger and J. C. Crabbe, Jr. Amsterdam: Elsevier/North-Holland Biomedical Press, 1980, pp. 201-226.
26. Tokuyama, K., M. Saito and H. Okuda. Effects of wheel running on food intake and weight gain of male and female rats. *Physiol Behav* 28: 899-903, 1982.