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Shock Induced Ethanol Consumption in Rats

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MILLS, K. C., J. W. BEAN AND J. S. HUTCHESON. *Shock induced ethanol consumption in rats.* PHARMAC. BIOCHEM. BEHAV. 6(1) 107–115, 1977. – Two experiments are presented which describe the temporal and volumetric changes in ethanol consumption by rats exposed to recurring schedules of inescapable random shock. The animals in Experiment 1, which had a choice between ethanol and water, increased their voluntary ethanol consumption immediately after the shock schedule. The postshock changes occurred with both 5% and 10% V/V ethanol, were specific to the presence of shock and were not reflected by measures of total daily ethanol intake. Experiment 2 exposed rats to extended 22 hr stress sessions, during which each animal had four simultaneous fluid choices available: water, saccharin 0.1% W/V, ethanol 5% V/V, and ethanol 10% V/V. Temporal intake patterns for both 5% and 10% ethanol showed pronounced peaks for the interval immediately following the shock schedule. A shift of intake from 5% to 10% ethanol was also demonstrated with increasing time under shock, while saccharin and water intake decreased. The results are interpreted as a relationship between voluntary ethanol intake and escape from the consequences of stress.

Stress and drinking Voluntary ethanol consumption Animal models of alcoholism
Temporal patterns of fluid intake Escape drinking Shock induced ethanol consumption

THIS paper describes a temporal relationship between stress and free-choice alcohol consumption in rats. The focus is upon the short term changes in fluid intake which occur as a function of periodic shock stress. Previous experiments have attempted to isolate the variables involved with stress and drinking and the designs have usually centered on the type or amount of stressor effecting a change in measures of daily home cage ethanol consumption [4, 10, 12, 26, 27, 35]. The range of stress manipulations has been extensive, and this literature has received review in several reports [8, 23, 24].

We assumed that measures of daily ethanol intake might not reflect changes of shorter duration which could be occurring as the result of stress. Rather than expose the animals to stress in one environment and measure daily consumption in the home cage, our animals were housed in the test environment 24 hr daily. This arrangement allowed us to quantify fluid selection over smaller units of time by measuring licking with drinkometers as described by a number of investigators [1, 2, 20, 29, 31]. Freund [18] and Eriksson [13] have also used drinkometer records to describe the diurnal distribution of ethanol intake in rats and mice, and the continuous monitoring procedures provide an ideal method to measure the temporal components of ethanol intake under stress.

Experiment 1 describes ethanol intake relative to recurring stress for rats housed continuously in the test environment for 50 days with a two fluid choice of ethanol and water. Exposure to different concentrations of ethanol was sequential. Experiment 2 describes the temporal patterns of fluid intake for a group of animals given simultaneous multiple fluid choices and ethanol concentrations during extended stress and non stress exposure.

EXPERIMENT 1

Method

Animals. The animals were 12 male Long-Evans hooded rats from Blue Spruce Farms, Altamont, New York. They had a mean weight of 533.8 g with a range from 455–644 g at the start of the Basline I.

Apparatus. The animals were individually housed in sound attenuated chambers which also allowed control of diurnal light cycles (12 hr light, 12 hr dark). Each cage had a grid floor, a lever and two drinkometers, spaced 5 cm apart. The living space measured 30 × 24 × 26 cm high. The drinkometers, described in detail elsewhere, used a Richter drinking spout and were designed around an infrared light emitting diode so that the possibility of tongue shock and visual cue problems in contact and photocell designs could be eliminated [21]. Footshock was provided by constant current scrambled shock sources and was set at 1.5 ma for all shock procedures. Temporal schedules were controlled with solid state logic.

Procedure. Alcohol solutions were prepared from 95%

ethanol in distilled water [11]. The animals were housed in the closed environments 24 hr daily, with one 20 min interruption for weighing and recording of daily fluid intake. Food was provided ad lib in hoppers suspended from the wall of the cage.

Baselines were defined as intervals in which licking distributions over time were sampled for ethanol and water. The position of each fluid changed every 48 hr. Estimates of fluid intake for a cumulative time interval were derived from the lick count for that interval relative to the total cumulative number of licks in a 24 hr session. The ratio was then multiplied by the total quantity of fluid delivered to provide an estimate of the fluid consumed in the interval [see 21].

Licking data for Experiment 1 were obtained by accumulating lick counts from five separate 12 min segments of each hour over 24 hr. After baseline, the same 12 min segment in each hr was designated as the shock interval and the assignment of pre- and postshock intervals was arbitrary. Using a digital printer, lick counts on both ethanol and water were also sampled to a 3 min resolution during selected sessions from individual animals.

Shock sessions were defined by delivering randomly spaced 1 sec footshocks for the same 12 min of each hr around the clock. The schedule during the 12 min was VI 1 min, so that each animal received on the average 12 inescapable shocks per hr, or 288 shocks per 24 hr session.

When shock occurs for 12 min of each hr, a randomly distributed drinking pattern would show 40% of drinking during the preshock interval (24 min), 20% during the shock interval and 40% during the post shock interval (24). A post interval ratio of 0.40 would reflect this pattern and is typically very close to that observed under baseline conditions. Changes in the post interval ratio are used as one measure of the effects of shock. However, a large change in a ratio may mean little on a daily basis if the amount of fluid consumed is not taken into account. A shift of a post interval ratio from 0.40–0.80 could be applied to a daily decrease in fluid consumption from 20–10 ml resulting in no change in post interval fluid intake. Drinkometer estimates of postinterval volumetric intake are also taken as an index of the effects of shock.

Following a 20 session (24 hr) baseline (Baseline I), all animals were exposed to the 12 min recurring hourly random shock schedule for five daily sessions (21–25 Shock I) and a five session after shock baseline (sessions 26–30). The entire cycle was repeated with a different concentration of ethanol as a fluid choice for a 10 day baseline (sessions 31–40 Baseline II), 5 days of random shock (sessions 41–45 Shock II), and 5 days of after shock baseline (sessions 46–50). Half of the animals (N = 6) received a 5% V/V ethanol choice and water for the first baseline-shock cycle and a 10% V/V ethanol choice for the second cycle. The other half received the 10% V/V ethanol as their initial choice and 5% V/V with the second cycle. In essence, two independent groups of six rats received alternate orders of exposure to 5 and 10% ethanol and four treatment combinations occurred under each Baseline-Shock-Baseline cycle: Shock I-5%, Shock II-10%, Shock I-10%, and Shock II-5%. The number of animals in Group II-5% was five due to equipment failure.

Results

Figure 1 displays the overall results of repeated baseline and shock exposures with 12 animals. The data are plotted separately for each group representing a treatment combination under each of the two criteria for evaluating fluid intake. The total interval criterion is the cumulative daily intake of ethanol and water in the 24 hr session. The post interval criterion is the cumulative daily intake of ethanol and water for the 24 min following shock and the same 24 min interval during preshock and after shock baseline. To reiterate, shock schedules are not in effect during baselines and the selection of a similar 24 min segment is arbitrary under nonshock conditions. It should be noted that the body weights for the animals dropped an average of 5.5% from mean baseline weights with the introduction of shock sessions, and fluid intakes are expressed relative to the observed weights for each procedure. It is apparent from

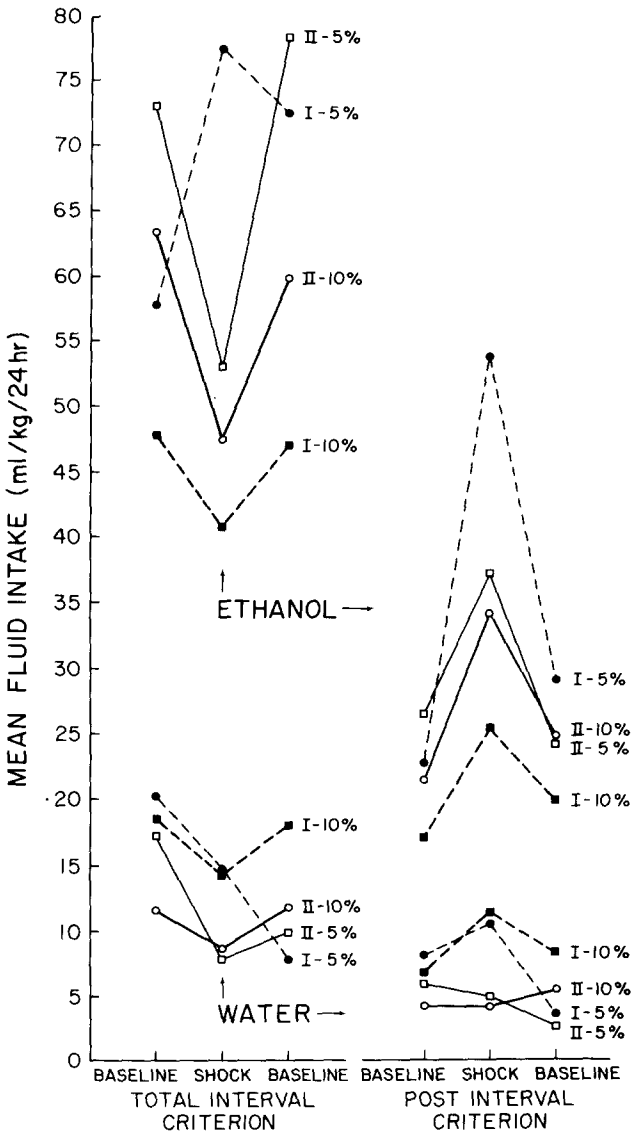

FIG. 1. Mean daily ethanol and water intake expressed as cumulative hourly intake (total interval criterion) and as cumulative intake during a 24 min schedule segment (postinterval criterion). During the five shock sessions (24 hr) the shock schedule recurs hourly for 12 min followed by the 24 min postinterval.

Fig. 1 that modulation of ethanol intake in terms of total daily fluid intake was typical of many studies looking at the effects of shock on drinking. With the exception of the 5% animals on their first shock exposure, all groups seemed to show a decrease in their ethanol intake following shock. The post interval criterion, however, indicated that the intake of ethanol increased for all four groups during the shock schedule exposure. Modulation of water intake as reflected by both criteria was not apparent.

In order to evaluate the effects of shock on ethanol consumption separate but identical analyses of variance were carried out for both total interval and post interval scores. Water scores were not included in the analyses because of the disparate intake volumes indicated in Fig. 1. Each analysis was a two by two by two factorial design as described by Winer [36]. The two levels of Factor A were Order I (5%–10%) and Order II (10%–5%). This was the factor on which repeated measures were not taken. Repeated measures were taken on the two levels of Factor B which were 5% and 10% ethanol intake and the two levels of Factor C which were defined by baseline and shock procedures. The consumption scores for each after shock baseline are shown in Fig. 1, but were not included in the analyses.

The analysis of variance of the total interval scores showed no significant main effects for either the baseline to shock mean differences or the order of exposure to 5 and 10% ethanol. A significant main effect was detected for the difference between 5 and 10% intake, $F(1,10) = 28.66$, $p<0.05$. A significant interaction was also observed between the concentration factor and order of exposure, $F(1,10) = 10.07$, $p<0.05$.

The analysis of the post interval scores, however, yielded significant main effects for both baseline to shock differences, $F(1,10) = 16.24$, $p<0.05$. and 5 and 10% ethanol intake scores, $F(1,10) = 18.80$, $p<0.05$. Again, significant main effects for the order of exposure factor were not evident. All interactions for the postinterval analysis were nonsignificant.

The statistical analyses implied that ethanol intake immediately after the shock was a more sensitive index of consumption than the amount of ethanol selected during the total interval which is often expressed as daily ethanol intake. Upon inspection of the data it was evident that the last two shock sessions contained proportionately more postinterval increases in ethanol intake than the first two shock sessions, suggesting a gradually emerging effect of shock on drinking. Figure 2 shows the postinterval ratio changing as a function of shock exposure over all animals at both concentrations for the first and second shock cycles. The increasing peak with increasing time in shock and the abrupt return to baseline levels indicate that ethanol intake was specific to the shock schedule.

The postinterval ratio as opposed to postinterval intake (ml × ratio) does not take into account the absolute amount of fluid consumed, and the measure does not differentiate those animals which showed absolute increases in ethanol intake with shock from those which did not. The consistency of the data across both treatments and animals implies that the postshock ratio is sensitive to shock effects regardless of whether or not this leads to increases in postshock ethanol intake. Because of the high incidence of shock sessions in which water intake was zero, comparable postinterval data for water intake were not reliable.

To illustrate an individual temporal pattern of shock

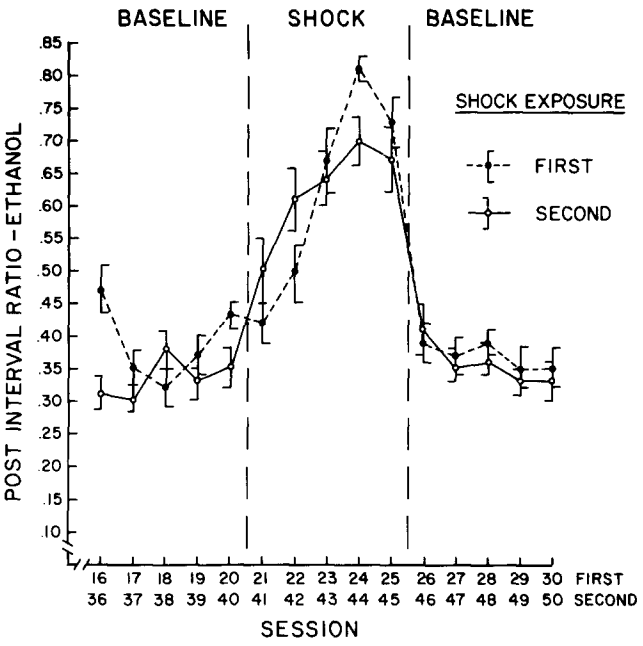

FIG. 2. Postinterval ethanol licking as a proportion of total ethanol licking for shock and nonshock conditions on consecutive exposures. Each vertical hash mark represents the standard error of the mean.

induced consumption, Fig. 3 presents the records of the animal showing the largest increases in ethanol intake following shock. Because of equipment restrictions, intake records resolved to 3 min resolution around the clock were not available for all sessions.

Animal 8 showed both overall and postinterval increases in ethanol intake at both concentrations. This is illustrated by intake peaks for ethanol immediately following shock and by total increases in ethanol intake over baseline of 62.5 ml/kg/24 hr for Shock I and 14 ml/kg/24 hr for Shock II. Postinterval increases reflected the peak intakes more closely and were respectively 60 ml/kg/24 hr for Shock I and 48.4 ml/kg/24 hr for Shock II. Total interval water intake for both shock exposures was 7.2 ml/kg/24 hr for Shock I and 0.7 ml/kg/24 hr for Shock II.

Discussion

The animals in Experiment 1 displayed temporal shifts in ethanol intake relative to recurring inescapable shock. Specifically, the distribution of licking reflected fluid intake increases specific to ethanol in the interval immediately following the shock. The data demonstrated that the daily intake criterion was inadequate to describe the changes in ethanol consumption, and that with some animals the postshock increases in ethanol intake were quite dramatic.

The central issue, however, is whether or not the animals were using the intoxicating properties of the ethanol to somehow alter the consequences of shock. The continuous isolation procedures make it difficult to extract blood ethanol samples without disturbing the animals therefore blood samples were not taken. Nevertheless, it would seem necessary to display circulating blood ethanol levels which are in excess of the rat's metabolic capacity in order to

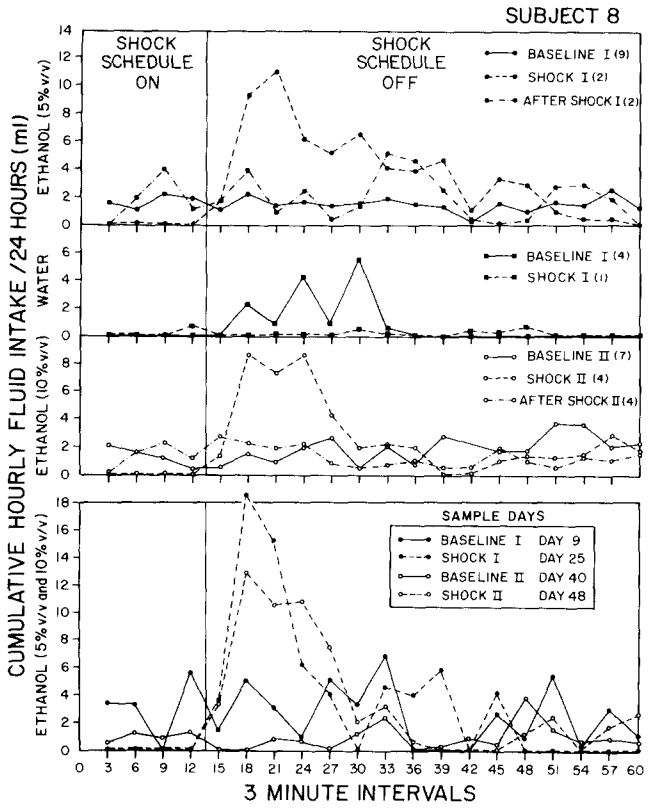

FIG. 3. Cumulative ethanol and water intake for subject 8 summarized over grouped and single sample sessions (24 hr) of baseline and shock exposure at 5 and 10% ethanol-water choice. The value in parentheses adjacent to the procedure represents the number of 24 hr sessions sampled to a 3 min resolution.

state that the animals are using the intoxicating properties of ethanol to achieve some measure of stress relief.

Collateral studies in our lab on rats exposed to the same shock paradigm have indicated that when blood samples are taken at random times during the 24 hr session, circulating blood ethanol levels are often in excess of 150 mg/100 ml. Baseline blood ethanol levels average around 10 mg/100 ml with a range from 1–25 mg/100 ml and shock blood levels average 35 mg/100 ml ranging from 5–160 mg/100 ml. Although the increase from baseline to shock is statistically significant, it is difficult to interpret the data in that the metabolic rate is confounded with the animal having continuous access to the ethanol and a temporary elevation of blood ethanol would not necessarily be evidence for continuous intoxication. One problem may be that in order to consistently produce a distribution of blood levels above 50 mg/100 ml, which would indicate sustained intoxication during a 24 hr session, the animal would have to consume at least 8.4 g/kg of ethanol/day. This would be approximately 212 ml/kg of 5% ethanol or 106 ml/kg of 10%. If we assume that the animal is accumulating some blood ethanol from hour to hour the intake requirement might be reduced somewhat to maintain the blood level at or above 50 mg/100 ml, but the requirement is high in that the total daily fluid intake for our animals in the test environment is typically around 80 ml/kg over all procedures.

With this information in mind, it can be argued that the temporal correlation of shock and increased ethanol intake might be due to some property of the ethanol other than the intoxicating effect, such as a simple taste preference, which is amplified by the shock schedule. If the animal is sampling anything novel as an attempt to alter the shock, then momentary intoxication from ethanol might be a by-product of drinking induced by the novel taste of ethanol relative to water.

The animals in Experiment 1 also show an unusually high preference for ethanol in the test cages as reflected by Fig. 1. These animals were not given home cage preference tests so that the distribution obtained during the test cage baseline would not be confounded with exposure and acclimation effects [9, 25, 34, 37]. The test chambers were isolated in comparison with home cages and this restriction might also have been strong enough to induce a high ethanol preference over water [28]. Taken together the taste, preference and isolation factors could be operating to produce the exaggerated ethanol consumption patterns attributed to the shock stress and replication with additional controls was warranted.

EXPERIMENT 2

Experiment 2 was an attempt to further define the functional relationship between stress and drinking by describing the temporal properties of fluid intake in rats. The animals were offered four fluid choices of water, sodium saccharin, ethanol at 5% V/V (preferred) and 10% V/V (nonpreferred) to control for taste and preference variables. Simultaneous rather than sequential exposure to multiple concentrations of ethanol allowed examination of the shifting patterns of ethanol intake in response to stress. In addition, home cage preferences were taken prior to test cage exposure to determine the extent to which test cage isolation altered fluid intake.

Experiment 1 limited the animals to five days of stress exposure at each ethanol concentration, and a longer shock exposure was used in the second study. An extended shock exposure permitted us to examine whether the animals adapted to the effects of shock and increased their selection of non intoxicating fluids or whether persisting shock would continue to influence ethanol intake as suggested by Experiment 1.

Method

Animals. The animals for Experiment 2 were 12 male Long-Evans hooded rats from Blue Spruce Farms, Altamont, New York. The mean weight for all animals during the first test cage baseline was 522 g with a range from 454–589 g. The final mean weight for the animals during the last 10 sessions of the study was 519 g with a range of 426–614 g. One animal showed several indices of poor health during the initial phases of the study and was removed from the test environment with the onset of shock stress. His data are not included in the group data for test cage preferences.

Apparatus. The animals' environment was similar to the system used in Experiment 1, but the test cages and data facilities were redesigned to accommodate inputs from four simultaneous fluid choices with a 2-min resolution. The animals were housed in similar sound attenuated chambers, but each cage (28 × 21 × 21 cm) had four bottles mounted behind one wall of the cage. Each bottle was calibrated to 2 ml and was mounted behind an 8 mm diameter access hole. The cages had grid floors, an inoperative lever and internal

house lights. The diurnal cycle was 11 hr light and 11 hr dark with 2 hr daily for a service break. Footshock was provided by constant current shock sources, and the shock level was set at 1.5 ma for all procedures.

The drinkometers in each cage consisted of four optical couplers with an infrared light emitting diode (LED) and photo-transistor. The infrared beam of light passed directly across the access hole to the drinking tube.

The data collection system consisted of an 8K, PDP-8F (Digital Equipment Corporation) computer. The software was written in PAL III and was designed to process and count licks occurring at each of the 48 individual inputs over a specified block of time (2 min). Following each time block, the software switched to another bank of 48 counters for the duration of the next block. The system continued this operation for the total number of blocks specified, or 30 for the 1 hr timebase of Experiment 2. After twenty-two 1 hr cycles the cumulative data was outputed.

Procedure. Home cage fluid preferences were determined for the 12 rats during a 24 day pretest exposure. The animals were housed in wire mesh home cages with ad lib rat chow and two fluid choices continuously available throughout the day. Each cage had one drinking bottle for water and one bottle for a choice sloution of ethanol at 5% V/V, 7.5% V/V, 10%V/V 12.5% V/V or sodium saccharin at 0.1% W/V. The animals were given eight days of ethanol exposure or two days at each choice. As part of another study, the animals were also given sucrose solutions and water for an additional eight days. The order of presentation of the four ethanol concentrations was random across animals. Bottle positions were reversed daily and solution concentrations were changed daily. The animals were weighed every other day.

After a two week break without alcohol in the home cage, the subjects were transferred to the test environments. They were housed continuously in the test environments for 55 consecutive 22 hr sessions. Baseline and shock session schedules were defined as in Experiment 1 with the exception that the session length was shortened to 22 hr to allow for cage servicing and data collection.

Four drinking solutions were always available in the test environment: water, 0.1% W/V sodium saccharin, 5% V/V ethanol, and 10% V/V ethanol. Ethanol solutions were prepared from 95% ethanol and distilled water. Saccharin solutions were prepared from commercial saccharin tablets and distilled water. Ad lib rat chow was provided in hoppers suspended from the opposite wall of the cage on which the drinkers were mounted.

During the service interval the animals were transferred to individual holding cages without access to food or water and the positions of the drinking bottles were rotated in a cyclical fashion. The sequence of the four bottles never changed and their positions repeated every four days. The drinking tubes were rinsed and drinking solutions were replenished with fresh solutions once daily.

The baseline was extended to 25 sessions for the first exposure in Experiment 2 to allow the animals to accommodate to the four drinker situation and produce stable drinking patterns. Baseline 1 refers to the last 10 sessions of the 25 session baseline exposure. Following Baseline I, all animals were given 20 consecutive sesions of shock. As in the first study, shock occurred for the same 12 min of each hr on a VI one min schedule.

For convenience in looking at the extended effects of shock, the first 10 shock sessions are called Shock I, and the second 10 sessions are called Shock II. Ten 22 hr sessions of postshock baseline (Baseline II) followed the shock sessions.

Results

The total mean daily fluid intake during the home cage pretest exposure was 126.3 ml/kg with the two bottle choice. When the rats were transferred to the test environments with the four bottle choice, the total mean volume of daily fluid decreased in Baseline I to 80.4 ml/kg. The reasons for the decrease were not clear, but the changes were reflected in measures of water intake rather than intake on saccharin, 5% or 10% ethanol. A t-test for correlated means indicated that daily water intake dropped significantly from 48 ml/kg to 21.4 ml/kg ($t = 6.81$; $p<0.05$). Saccharin intake decreased from 48.2 ml/kg to 37.3 ml/kg but the difference was not significant ($t = 1.11$; $p>0.05$). Ethanol intake at both concentrations dropped slightly but home cage to test cage mean differences were not significant (5%, $t = 1.03$; 10%, $t = 0.92$). Five percent home cage intake was 21.4 ml/kg and test cage intake was 14.8 ml/kg. Similarly 10% ethanol intake showed a mean daily level of 8.7 ml/kg in the home cages and 6.9 ml/kg in the test cages. Both the home cage and test cage data showed moderate consumption of 5% and low consumption of 10% ethanol. These results were more consistent than the data of Experiment 1 with previous reports of the rats' aversion for higher concentrations of ethanol.

The test cage data for the 11 animals in Experiment 2 are shown in Figs. 4, 5, and 6. The mean intake records during each of the 10 sessions of Shock I, Shock II and postshock Baseline II are expressed as departures from the intake records for the last 10 sessions of Baseline I. The net change in daily fluid intake (ml/kg/22 hr) is plotted for each of the fluid choices of 5% V/V ethanol, 10% V/V ethanol, distilled water and saccharin. The X-axis shows each hour of the 22 hr session broken into successive two min intervals. Each data point represents the mean of 2420 samples of licking during a specific two min interval (11 animals $\times$ 22 hr $\times$ 10 sessions = 2420). For example, the sum of all points along one line would represent the total change from baseline intake on a specific fluid, and the plot represents the temporal and volumetric shift in drinking relative to the recurring one hr cycle.

It can be seen in Fig. 4 that ethanol intake at both 5 and 10% increases during shock sessions and the peaks occur 8–12 min after shock, with continued intake for up to 26 min after shock. A peak is also noted for saccharin intake corresponding to the initial segments of both ethanol peaks, but consumption does not continue after the initial burst. Water intake shows negligible changes during and after shock.

Figure 5 shows the baseline to shock difference for the second 10 sessions of shock (Shock II) and also indicates a shift away from 5% ethanol intake to increased peaking on 10%. Post shock saccharin intake dropped off sharply with increased shock exposure during Shock II. These data are consistent with Experiment 1 in that fluid intake under shock was suppressed and post shock drinking was characterized by sharp peaks in ethanol intake.

Figure 6 shows the four fluid intake patterns for the 10 sessions of postshock Baseline II as a difference from the 10 sessions of preshock Baseline I. Shock was not in effect and peak intake patterns were not observed. However, a

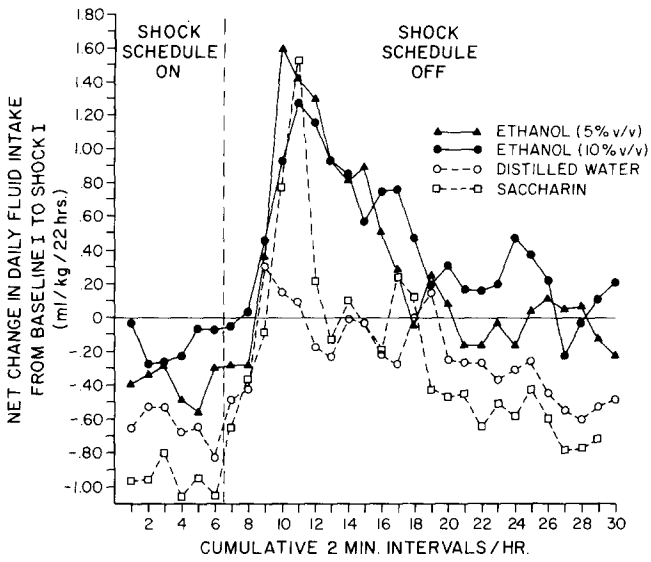

FIG. 4. The net change in daily fluid intake for 11 animals as a difference from Baseline I to the first 10 sessions of shock (Shock I) cumulated over the 22 hr cycle for each 2 min interval in an hr. The VI 1 min shock schedule was in effect for the first 12 min of each hr during Shock I.

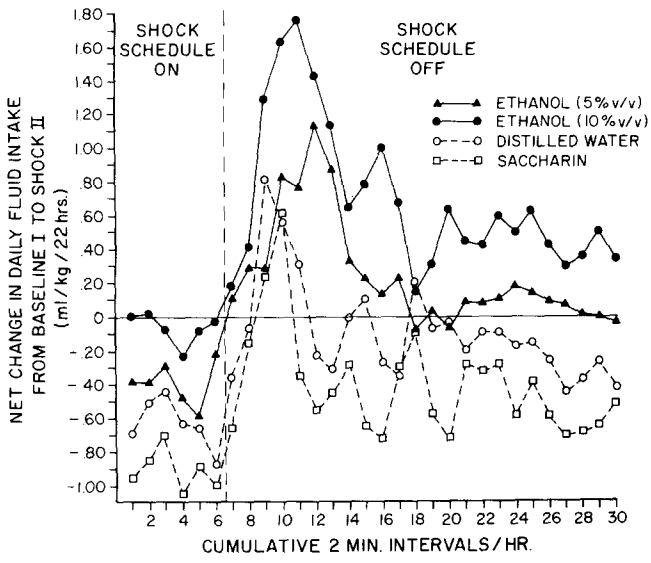

FIG. 5. The net change in daily fluid intake for 11 animals as a difference from Baseline I to the second 10 sessions of shock (Shock II) cumulated over the 22 hr cycle for each 2 min interval in an hr. The VI 1 min shock schedule was in effect for the first 12 min of each hr during Shock II.

preference for both 5 and 10% ethanol above water and saccharin is reflected by the four curves. The pattern of saccharin intake shows a mirror like negative pattern to that observed under shock and could suggest that the animals had learned to respond to the hourly temporal properties of the shock schedule.

Whereas Figs. 4, 5 and 6 illustrate the cumulative hourly fluid intake relative to the first baseline, the net change

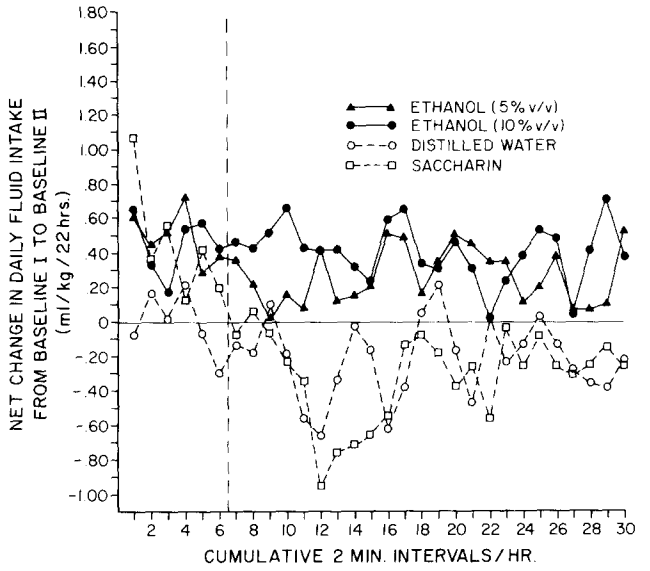

FIG. 6. The net change in daily fluid intake for 11 animals as a difference from Baseline I to the 10 sessions of baseline (Baseline II) which followed the 20 sessions of shock exposure. Shock was not in effect for Baseline I or Baseline II.

scores could be sensitive to distortion from the initial high preferences for saccharin and low preferences for ethanol at 10% V/V. The distortion could be reflected by a temporal modulation of all fluid consumption to the postshock interval without corresponding absolute volumetric changes. Figure 7 therefore represents the absolute changes in both total interval and postinterval (24 min) fluid intake over baseline and shock sessions. The ethanol intake is combined for the 5 and 10% solutions and expressed as g/kg intake. The absolute increase in ethanol intake as a function of shock is seen for both the total and post interval criteria and is consistent with the temporal data.

Two one-way repeated measures analyses of variance were carried out to evaluate the changes in ethanol intake observed for both the total and postinterval measures. When ethanol intakes (g/kg) were collapsed over sessions and summarized for Baseline I, Shock I, Shock II and Baseline II, significant main effects were evident for the total interval scores, $F(3,30) = 5.57$, $p<0.05$, and the postinterval scores, $F(3,30) = 4.98$, $p<0.05$. Posthoc comparisons were obtained with Dunnets t statistic and compared each treatment with the Baseline I control [36]. Using the total interval scores, ethanol intake for Shock I ($t = 2.74$, $p<0.05$), Shock II ($t = 3.70$, $p<0.05$) and Baseline II ($t = 3.33$, $p<0.05$) was significantly increased over Baseline I intake levels. With the postinterval scores, ethanol intake for Shock I ($t = 3.06$, $p<0.05$) and Shock II ($t = 3.44$, $p<0.05$) increased significantly over Baseline I. As might be expected from the data in Fig. 7, postinterval ethanol intake for Baseline II did not differ significantly from Baseline I ($t = 1.47$, $p<0.05$). The absolute changes in the volume of ethanol consumed coincident with shock sessions indicate that the relative temporal peaks shown in Figs. 4 and 5 also represent a volumetric modulation of ethanol intake. The total interval saccharin and water intake changes from Baseline to shock were also evaluated with Dunnets t-test. As might be expected from the

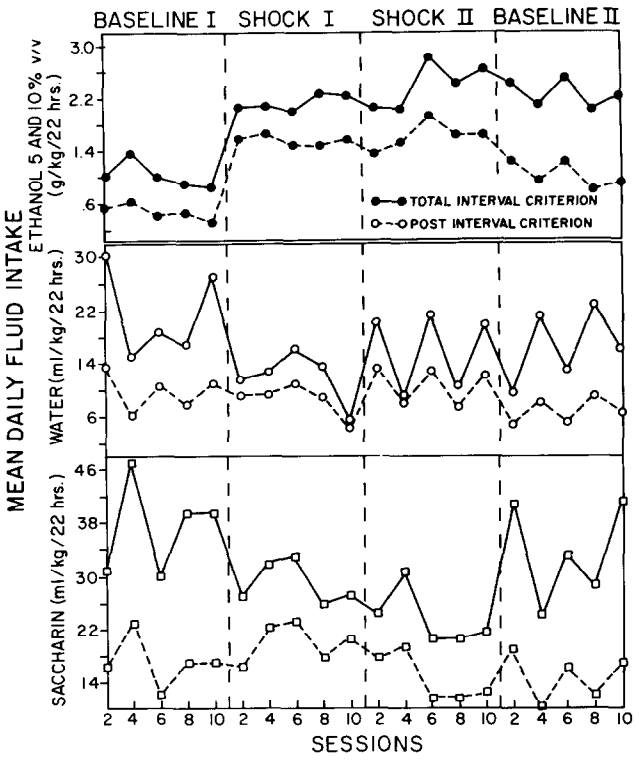

FIG. 7. Absolute daily fluid intake of ethanol, saccharin and water across sessions and procedures for the 11 animals in Experiment 2. Ethanol intakes on 5 and 10% V/V are combined to give the total ethanol intake in g/k/22 hr. The postinerval criterion represents the cumulative amount of fluid consumed daily in the 24 min interval during the nonshock baselines. The total interval criterion represents the total daily fluid intake cumulated over twenty-four 1 hr segments.

temporal data in Figs. 4 and 5, saccharin intake during Shock I did not show a significant decrease from baseline (t = 1.40, $p>0.05$), but did show a significant mean decrease during the second ten sessions of Shock II (t = 2.21, $p<0.05$). This suggests that with increasing exposure to stress, taste played a less important role in fluid selection. Total interval water intake showed an immediate significant decrease from baseline to Shock I (t = 2.97, $p<0.05$), but the difference between Baseline and Shock II water intake was nonsignificant (t = 1.47, $p>0.05$).

The mean daily ethanol intake for all animals in Baseline I was 1.14 g/kg with a range from 0.14–2.49 g/kg. With the first 10 shock sessions, the mean increased to 2.18 g/kg and the range was from 0.15–6.81 g/kg. The second 10 shock sessions showed an additional mean increase to 2.54 g/kg with the range extending from 0.17–4.96 g/kg. Finally, Baseline II intake was relatively constant at 2.41 g/kg, and the range was from 0.19–5.78 g/kg. The largest individual daily intake under shock was 9.20 g/kg.

Interestingly, consumption of 10% ethanol accounted for 47.5% of the total ethanol intake (g/kg) during Baseline I, but 62.3% of the total intake under Shock I, 73.2% under Shock II and 61.2% under Baseline II. The shift of preference toward 10% corresponds to the temporal peaks shown in Fig. 5 and may suggest that 10% intake is a more sensitive indicator of the prolonged effects of stress than measures of intake on the previously preferred 5% solution. When the postinterval intake of 10% ethanol was examined with Dunnets test, the mean difference between Baseline I and Shock I intake was nonsignificant (t = 2.07, $p>0.05$). However, the difference between Baseline I and Shock II postinterval 10% (intake) was statistically significant (t = 2.55, $p<0.05$). The gradual increase in postshock selection of 10% ethanol is also evidence that the animals were using increasing doses of ethanol to alter the consequences of shock.

Although the temporal distribution of 5% ethanol intake changed during the early shock sessions, the volumetric data indicated that the 5% intake patterns were limited by the amount of fluid that an animal was able to consume, even when decreases in saccharin and water intake were taken into account. Often some animals would drink copious amounts of 5% ethanol during daily shock sessions (90–100 ml), but the intake was not sustained over days, and these animals would begin to include increasing doses of 10% ethanol as time under shock increased.

It should be noted that the total interval increases in ethanol intake coincident with the onset of shock shown in Fig. 7 were not reflected by the same measure in Experiment 1 (Fig. 1). Although comparisons between the two and four fluid choice procedures are limited, the animals in the second study which gradually increased their 10% intake effectively doubled their dose of ethanol with the same volume and the combination of both 5 and 10% fluid intake as a single drug dose might account for the significant total interval increases. The animals in the first study did not have simultaneous access to both concentrations and again suggests that sensitivity to the effects of shock is gained by measuring the change in preference rather than absolute daily intake on a single fluid choice. When only a two fluid choice is available, however, the postinterval criterion seems to be the more sensitive measure of ethanol intake as an index of the effects of stress.

Discussion

A simple explanation of the data is that some animals in Experiment 1 were capable of learning to drink alcohol as a specific response to short duration random shock stress. In effect, ethanol intake seemed to become a quickly acquired escape response. The escape may be functionally similar to that provided by moving the animals to the home cage in other designs, but this comparison was not directly tested. Following extended stress exposure, the animals in Experiment 2 continued to increase their quantity of absolute ethanol intake and continued to restrict their consumption primarily to the interval immediately after shock. The increasing dose intake could indicate that the stress became move aversive over time or that the animals showed some low dose tolerance to the initial choice of 5% ethanol. Both possibilities are consistent with the explanation that ethanol selection somehow modified the consequences of shock stress.

Several experiments have pointed to a possible relationship between extended shock stress and drinking. An increase in ethanol consumption specific to the onset of inescapable shock was reported by Anisman and Waller [5]. Their animals were housed in the shock compartment with ethanol and water choices available throughout the daily cycle and animals receiving shock on both alternating six and twelve hr schedules increased their alcohol intake

approximately double the control animals receiving no shock. It is possible that cumulative temporal patterns of ethanol consumption were occurring as a specific response to shock. Similarly, Hatton and Vieth [19] report pilot data for three animals which increased their ethanol intake following, but not before or during shock avoidance sessions. These data again suggest that patterns of postshock ethanol consumption may have been emerging but temporal data were not gathered.

In both Experiments 1 and 2 we arbitrarily used the recurring hourly shock schedule and shock termination always predicted 48 min which were free of shock, or an interval of relative safety. In that drinking was suppressed during the shock schedule, licking in the postshock interval could represent consumption in the most stress free interval. With this view shock becomes a discriminative stimulus for the onset of the stress free interval and serves to signal drinking; a contrast to a stress reduction interpretation of the data. Although our design did not test for this possibility, several factors argue against a purely nonaversive discriminative function for the shock. First, some animals show postshock patterns almost immediately after shock exposure and the short exposure time involved would not seem adequate for the animals to learn about the temporal nature of the shock schedule. In addition, pilot data from a separate set of 18 rats which were given shock only once daily clearly indicated that increasing postshock ethanol ratios were appearing as a function of shock but not in the cumulative proportions evidenced with the recurring 24 hr schedule. With the shock occurring only once daily, it is unlikely that the animals were learning to use the shock as a discriminative stimulus which predicted periods of relative safety.

We do not know the hourly distribution of the blood ethanol concentrations in the present experiments and there is a possibility that the animals were achieving the highest levels of intoxication just prior to, or even during, the 12 min of shock. The postshock drinking could, therefore, be conceived as an avoidance response in anticipation of upcoming shock in the next hour. This seems unlikely because the rats would have to not only learn the temporal discrimination which enabled them to predict shock, but also adjust their drinking patterns to accommodate for the delays in achieving intoxicating blood ethanol levels which would be coincident with shock onset. One animal in the second study, however, showed some moderate peaking on 10% ethanol just prior to the onset of shock; an indication that learning to use the ethanol in an avoidance rather than an escape fashion may not be an impossible task for the rat.

There is also a possibility that the consumption patterns observed were generated by the recurring nature of the shock schedule and that any recurring event, stressful or nonstressful, would produce a similar pattern of drinking. Although the data do not test this, we would expect the ethanol patterns to persist with saccharin or water if the phenomenon were due to schedule induction [14, 15, 17].

The present studies have not ruled out the possibility that the animals were consuming greater amounts of ethanol, and lesser amounts of saccharin, because of the calories which the alcohol provided during extended stress. The weight loss observed under stress could indicate that the animals were attempting caloric replacement through ethanol intake. The data from Experiment 1 indicated that the overall daily intake of ethanol showed a decrease while the distribution of ethanol consumption shifted to the postshock pattern. The net result, relative to baseline, is shock induced consumption with lower daily caloric intake from ethanol. However, the animals which received extended stress in Experiment 2 increased their daily ethanol intake and could have been drinking ethanol for its caloric properties as a means to alleviate the stress [6,17].

Alcohol is high in calories (7 Kcal/g) and increased ethanol intake is always likely to be confounded with increased caloric intake. The ideal free choice experimental design would be to provide a nonintoxicating choice solution, such as sucrose or dextrose, as a caloric equivalent to ethanol. However, when our rats are given isocaloric solutions of dextrose or even a minimally sweet commercial product at approximately 4 Kcal/g (Polycose, Ross Laboratories) equivalent to 5% ethanol as a free choice, virtually all fluid selection is restricted to the sweet-calorie choice. Several other investigations have attested to the rat's overwhelming preference for sweet-calorie combinations [7, 16, 22, 30, 33]. Our animals will select sugar solutions predominantly over water, saccharin and ethanol both during baseline and shock procedures. There is a need for research which will offer the animal an isocaloric and nonintoxicating control solution which would also produce similar baseline selection rates to that observed with ethanol. The extreme sugar preferences prevent meaningful comparisons to be made between the separate caloric and intoxicating components of fluid selection as they function relative to stress.

One persistent feature of the data is the relatively rapid appearance of the postshock drinking in response to shock. Apparently an animal will try a number of responses when faced with an inescapable stressor [3, 4, 32], and one hypothesis concerning the existing data would be that postshock ethanol and saccharin comsumption are both subsets of postshock novel fluid intake. In the present study, the distinctive taste properties of the fluid may be the more important variable when attempting to explain the origin of the animal's response. The data indicate that the animals progressively shifted from saccharin to 5% ethanol to 10% ethanol with increasing exposure to shock. This would argue toward a two component process based on taste and the secondary or more delayed properties of fluid intake to respectively intitiate and maintain ethanol intake in response to stress. In conclusion, shock induced ethanol consumption is a cumulative effect and the data demonstrate that the relationship between stress and drinking is amenable to temporal measurement. The relation apparently depends to a large extent on the continuous nature of the inescapable stress and the continuously available alcohol supply appearing together.

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