Alcohol, respiration, skin and body temperature during cold water immersion

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MARTIN, SHEILAGH, R. J. DIEWOLD, AND K. E. COOPER. *Alcohol, respiration, skin and body temperature during cold water immersion*. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 43(2): 211–215, 1977. —Subjects who had not been exercising, were immersed for 20 min in water at 13°C after ingestion of alcohol. During the immersion period, total ventilation, end-tidal P_{CO_2}, rectal temperature, aural temperature, and mean skin temperature were recorded. Control experiments were carried out at the same water temperature. Blood samples (3 ml), taken immediately before the immersion period, were analyzed by gas liquid chromatography. The mean blood alcohol level was 90 ± 11.2 mg·(100 ml)$^{-1}$. There was no significant difference in ventilatory responses, rectal temperatures, aural temperatures, or mean skin temperatures achieved during the two cold water immersions. It would appear that for a 20-min immersion at 13°C, relatively high blood alcohol levels do not affect ventilatory responses or increase body heat losses.

cold water; ventilatory responses; mean skin temperature

ALTHOUGH ALCOHOL DRINKING has occurred from early recorded history, some of its precise physiological effects have been defined only in more recent times. Alcohol is a central nervous system depressant and, in moderate doses, is said to cause cutaneous blood vessel vasodilatation (10). This latter effect is thought to be mediated via the central nervous system, since there is an insignificant direct action of alcohol on blood vessels (10). It is generally believed that alcohol increases heat loss during cold exposure.

One investigation showed that no deleterious effects were observed in resting subjects exposed to 20°C ambient temperature after alcohol ingestion. At 15°C ambient temperature only one subject showed a difference in body heat loss as a result of alcohol consumption (1). No blood alcohol levels were measured. However, in subjects who had exercised severely and were exposed to cold (14.5°C) alcohol increased the rate of body heat loss (6), and this effect appeared not to be related to changes in skin circulation.

Because the thermal conductance of water is approximately one thousand times greater than that of air at a comparable temperature, it might be expected that alcohol ingestion and cold water immersion would produce significant changes in body temperature. One study (6) on the possible additive effects of cold water and alcohol consumption showed that there was no significant difference in the rate of body heat loss whether or not alcohol was consumed. However, blood alcohol levels were not measured.

Since alcohol is frequently ingested by people engaged in recreational activities in water, it was considered of interest to see if a correlation existed between blood alcohol concentrations and skin temperatures, core temperatures, and respiratory responses during immersion in cold water.

METHODS

Thirteen subjects, eight males and five females, were used in the experiments. Each subject had received a medical examination before participating in the study, and each gave informed consent after being told of possible risks during the experimental procedure. The subjects' heights and weights are given in Table 1.

All experiments were carried out in a laboratory area in which a tank measuring 2.7 x 1.22 x 1.22 m (vol: 2,161 liters) was filled with water at the desired temperature and continuously and vigorously stirred. The subject breathed through a mouthpiece, attached to a low dead-space, two-way, respiratory valve. A continuous stream of gas, taken from the respiratory valve in the mouth region, at 500 ml·min^{-1}, was passed through an infrared CO_2 analyzer (Beckman Instruments LB2). Total expired volume ($\dot{V}_E$) was measured by an integrating pneumotachograph placed on the expiratory side of the valve. This summated expired volume gave the total ventilation over a specific time period. Calibrations for total expired volumes and the CO_2 analyzer, as well as the calibration for the end-tidal P_{CO_2} measurement, were achieved as reported previously (4).

Body temperature was monitored continuously by two methods. Rectal temperature (T_{re}) was measured with an indwelling rectal thermistor probe (Yellow Springs Instruments, Yellow Springs, Ohio) to an accuracy of ±0.05°C. Aural temperature (T_e) was monitored using the zero gradient aural thermometer (7). Mean surface skin temperature (T_{sk}) was measured by means of skin thermistors (no. 709, Yellow Springs Instruments) placed in six locations: right lower leg, right midthigh, right upper arm, right chest, abdomen, and back. Measurements were made continuously on each subject at rest out of the water. The subject then entered the tank and measurements were continued in water at 13.59 ± 0.13°C for the control immersion and 13.58 ± 0.11°C

TABLE 1. *Height and weight of subjects for alcohol protocol*

Subj	Ht, cm	Wt, kg
AB	193	84
RD	187	76
GS	180	74
KEC	179	81
VD	178	66
JJ	173	65
RT	173	62
SM	171	67
SH	170	60
JW	170	53
DS	169	65
MS	163	55
HM	157	43
$\bar{X}$ ± SE	174.0 ± 2.63	65.46 ± 3.18

TABLE 2. *Blood alcohol levels*

Subj	Sample I, mg (100 ml)$^{-1}$ (45 min after starting to drink)	Sample II, mg (100 ml)$^{-1}$ (~80 min)
RT	175	158
KEC	130	131
GS	128	146
JJ	111	106
VD	110	108
HM	106	99
SH	97	86
DS	70	124
SM	67	78
RD	66	59
JW	63	81
MS	61	75
AB	30	47
$\bar{X}$ ± SE	90 ± 11.2	99 ± 9.2

following alcohol consumption. The immersion time was 20 min.

The subjects were given varying volumes of pure ethanol (dependent on body weight) mixed with 200 ml fruit juice. They consumed the alcohol over a 20-min period and 45 min after beginning ingestion were immersed in the water. Subjects had been fasting for 2 h before the experiment. Blood samples were taken from an antecubital vein before immersion and after the subject came out of the tank (about 1 h after drinking the alcohol). These 3-ml samples were stored on ice and analyzed in the Foothills Hospital, Department of Laboratories, by the gas-liquid chromatography technique for determination of blood alcohol levels. Ventilatory, mean skin temperature, and body temperature data were analyzed using the Student *t*-test for paired samples.

RESULTS

An attempt was made to have the subjects attain a blood alcohol level of approximately 80 mg. (100 ml)$^{-1}$ but as illustrated in Table 2 a wide range (30–175 mg. (100 ml)$^{-1}$) was found in the first sample, which was taken before entry into the cold water. The second sample, taken 1 h after drinking the alcohol, again showed a wide range (47–158 mg. (100 ml)$^{-1}$). Six subjects had a lower and seven subjects had a higher blood alcohol content than that found in the initial sample.

The ventilatory responses measured during the cold water immersion with and without alcohol consumption were compared. Figure 1 shows the mean percentage changes in total expired volume. Although there appeared to be a slightly attenuated response during the first 3.5 min, the differences were not statistically significant ($P > 0.10$). Similarly, the degree of hyperventilation shown in Fig. 2 seemed to be attenuated but again the differences were not statistically significant ($P > 0.10$).

Body temperature was measured both rectally (T_{re}) and aurally (T_e). The changes during the immersion without alcohol consumption show that T_{re} was significantly higher ($P < 0.001$) than T_e in the preimmersion period and for the first 2 min of the immersion. The T_e remained constant for most of the cold water immersion

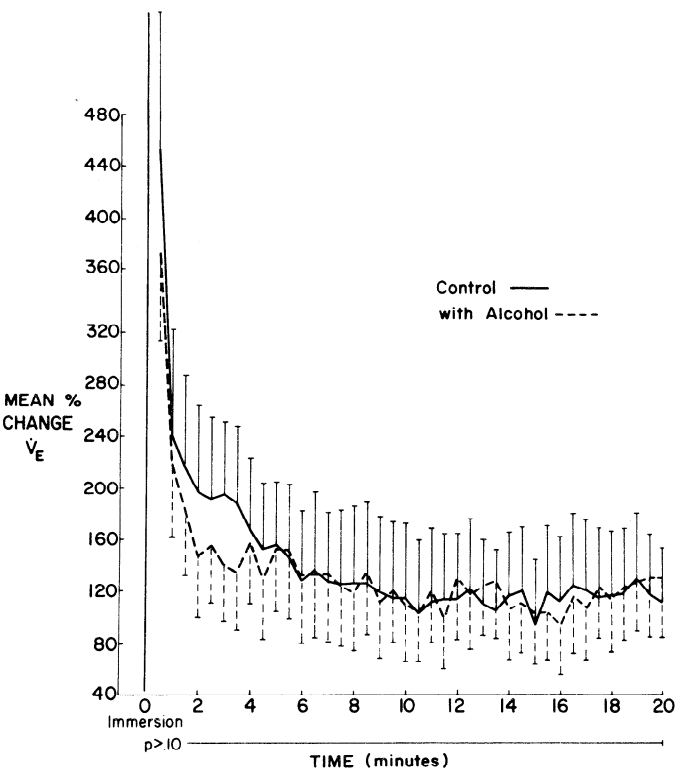

FIG. 1. Mean percentage change in ventilation during 10-min immersion in cold water. $N = 13$.

period and a decline was not seen until *minute 16*. In contrast, the T_{re} showed a steady decline during the time in the cold water, but after the third minute of immersion the difference between the two temperatures was no longer statistically significant ($P > 0.10$). The overall changes in the two measurements were decreases of 0.92°C and 0.11°C for T_{re} and T_e, respectively.

A similar pattern in body temperature changes during cold water immersion was seen after the subjects had ingested alcohol. The differences between the T_{re} and T_e during the preimmersion period and for the first 3 min of the immersion were statistically significant ($P < 0.001$). The T_e was constant until *minute 16* when a decrease was evident. A continuous decline in the T_{re} was seen during the 20 min, but after *minute 4* the differences between the two body temperatures were no

longer statistically significant ($P > 0.10$). A decline of 1.15°C was seen for the T_{re} and a decrease of 0.22°C for the T_e.

A comparison of the rectal temperature during the immersions with and without alcohol ingestion is seen in Fig. 3*A*. A steady decline in T_{re} was evident during both immersions, and the T_{re} after alcohol consumption declined more quickly than the T_{re} obtained without alcohol consumption. The difference was not statistically significant ($P > 0.10$). The overall change in T_{re} was a decrease of 0.92°C for the procedure without and 1.15°C for the procedure with alcohol consumption.

Figure 3*B* shows the changes in aural temperature (T_e) during both immersion periods. A slightly faster decline in T_e was seen after alcohol consumption, and although the T_e was lower in this procedure than without alcohol consumption the difference was not statistically significant ($P > 0.10$). The change in the T_e was a decrease of 0.11°C for the immersion without alcohol and 0.22°C for the immersion following alcohol ingestion.

Mean skin temperature ($\bar{T}_{sk}$) changes during the two cold water immersions are seen in Fig. 4. The $\bar{T}_{sk}$ after alcohol consumption was lower than the $\bar{T}_{sk}$ without alcohol consumption during the preimmersion period but was slightly higher during the first two minutes of immersion. These differences were not statistically significant ($P > 0.10$). The rate of change in the $\bar{T}_{sk}$ for both immersion times is similar and no statistically significant differences were noted. The $\bar{T}_{sk}$ at the end of each experimental procedure was 2.3°C above the prevailing water temperature.

A variable pattern (mild, vigorous, or intermittent) in the shivering response was observed in the subjects during the immersion periods. The average time for shivering to occur following immersion without alcohol was 2.7 min, and after alcohol consumption, the latency was 3.3 min. Three subjects did not shiver during the control nor the alcohol experiments. Subjectively, the

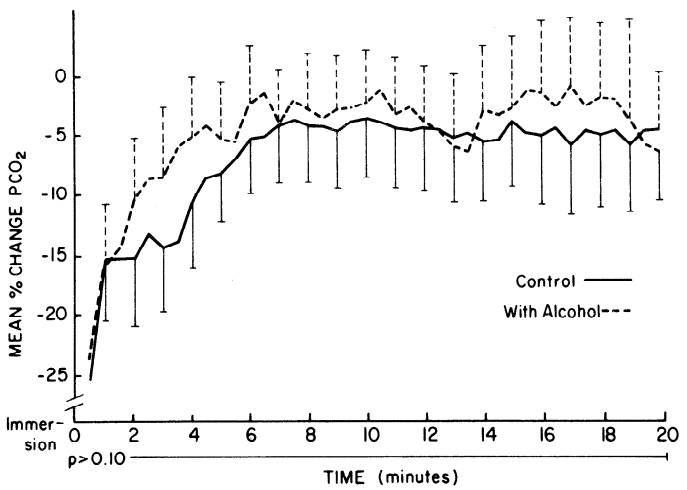

FIG. 2. Mean percentage change in end-tidal P_{CO_2} during 20-min immersion in cold water. $N = 13$.

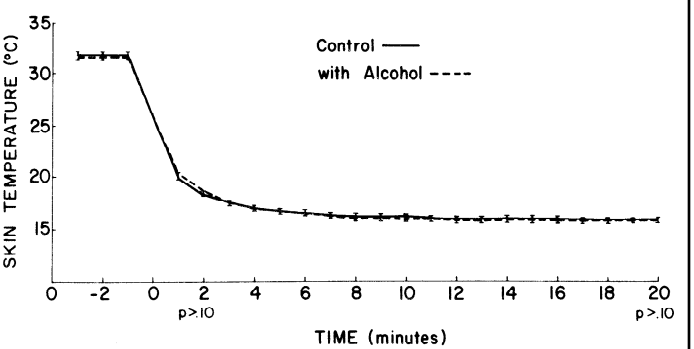

FIG. 4. Comparison of mean surface skin temperature ($\bar{T}_{sk}$) during 20-min cold water immersion. $N = 13$.

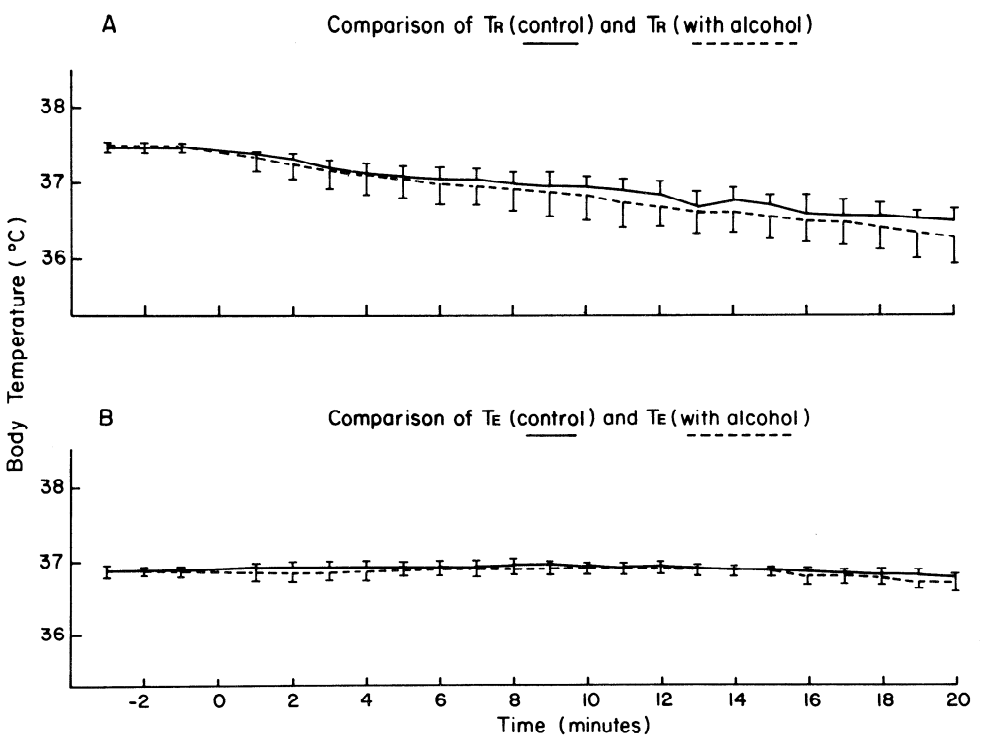

FIG. 3. *A*: Comparison of rectal temperature (T_{re}) during 20-min cold water immersion. $N = 13$. *B*: Comparison of aural temperature (T_e) during 20-min cold water immersion. $N = 13$.

volunteers found the cold water immersion less uncomfortable after alcohol ingestion.

DISCUSSION

The results showed there was no correlation between the blood alcohol levels and the changes in body temperature, skin temperature, and respiration.

The mean blood alcohol level of the subjects before entering the cold water was 90 mg·(100 ml)$^{-1}$. Initially it was hoped to attain a blood alcohol level at about the driving legal value of 80 mg·(100 ml)$^{-1}$, and an attempt was made to give an alcohol volume consistent with body size, to control the time of ingestion (20 min), and to regulate the metabolic state of the subjects (fasting for 2 h). This was done to insure better alcohol absorption since both the rate and efficiency of alcohol absorption is increased in the fasting state (9).

However, in spite of these few restrictions, a wide range of blood alcohol levels was evident. Some reasons which might account for this are the actual metabolic state of the subject and individual differences in alcohol absorption. Since the rate of alcohol absorption varies for individuals from 2 to 6 h (10) and there is an essentially constant metabolic rate, about 10 ml·h^{-1} (5), the variations in the second blood sample might also reflect the above-mentioned conditions. It is not possible to determine from this investigation, because of the paucity of blood samples, the exact blood alcohol state of the subjects. However it might be inferred that those individuals who showed an increased blood alcohol level in the second sample would be in the absorption phase of the alcohol curve, while those subjects whose blood alcohol levels had decreased might be in the elimination phase of the alcohol metabolism curve.

The peripheral vasodilator effects of alcohol are often said to contribute to a serious thermal imbalance if a person is exposed to cold. In view of this the mean skin temperature pattern was interesting. While the relationship of superficial skin temperature to blood flow is nonlinear (2), and under the conditions of these experiments it would be difficult to give an accurate assessment of blood flow from skin temperature measurements, it would be expected that large changes in skin blood flow would produce some apparent change in skin temperature. Assuming that such an assumption can be made for the first two minutes of the immersion, the vasoconstriction elicited by the cold water stimulus appeared to be less after alcohol consumption, but the readings were not significantly different from those obtained during the immersion without alcohol. It might be concluded that no significant change in skin blood flow occurred with the alcohol consumption and, if a change was present, its effect was overridden by the cold-induced vasoconstriction at a water temperature of 13.5°C. As a result, there was no increased heat loss during the immersion.

In view of the above finding, it was interesting to note that although great variability was evident in the volunteers' shivering patterns, the initiation of shivering occurred only 0.6 min later in the immersion following alcohol consumption than in the immersion without alcohol. It is possible that during both immersions, the peripheral receptors were monitoring a similar skin thermal topography. Thus the actual neuronal firing pattern was not altered, resulting in an equal afferent stimulation during both immersions. If a greater peripheral blood flow, as a result of alcohol ingestion, had been evident, it might be expected that the initiation of shivering would have occurred at a much later time during that cold water exposure.

In general the changes in body temperature, measured rectally, approximate those of an earlier study (7), but the overall temperature changes in the present investigation showed a greater decline. This difference may be due to diversity of physical characteristics of the volunteers, and the colder water temperature (2°C lower). The rapid changes in rectal temperature seen during the water immersions may be evidence of local cooling of the rectum due to the return of cooled blood from the legs, rather than an indication of true core temperature.

Aural temperature closely parallels changes in esophageal temperature during deep body temperature changes (8) and avoids the lag that rectal temperature shows in relation to true core temperature (3). Thus it is a more accurate measure of the core changes for these experiments. The aural temperature remained nearly constant during both immersions, with slight changes occurring during the last 4 min.

In man, moderate amounts of alcohol are known both to depress and stimulate respiration (10). There was no evidence in our data that any of these responses had been changed even though the blood alcohol levels were so high that the subjects would be considered legally "impaired." However, a more erratic respiratory pattern was evident during the cold water immersion following alcohol ingestion.

The subjective responses of the volunteers were interesting. It was generally felt, with one exception, that the cold water immersion after alcohol consumption was less discomforting, that the degree of boredom consequent upon a 20-min immersion with movement confined, was decreased, and time was described as "passing more quickly," than during the control immersion. Thus it might appear that alcohol consumption could minimize the discomfort and panic attendant on a sudden cold water immersion incurred as the result of an accident. Whether this condition would be an asset in increasing a person's survival chances during a long exposure in cold water is still not clear.

In summary, the effect of alcohol ingestion, in the quantities given in this investigation, did not alter the initial ventilatory responses elicited during a 20-min cold water immersion. Alcohol did not increase body heat loss during cold water immersion, since there were no statistically significant differences in $\bar{T}_{sk}$, T_{re}, or T_e during the times of immersion. The reported blood alcohol levels would appear not to affect either skin blood flow or the central temperature regulators. It is possible that a longer immersion in colder water might yield different results. However, the enhanced vasoconstric-

tion which would be evident in that situation might still be powerful enough to cancel the postulated vasodilator effect of alcohol. One other aspect to be investigated in relation to body temperature changes would be alcohol consumption followed by immersion in warm water (22°C or above) so that the vasodilator effect of alcohol might become evident.

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