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Effects of alcohol on autonomic responses and thermal sensation during cold exposure in humans

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Abstract

We investigated the effects of alcohol on thermoregulatory responses and thermal sensations during cold exposure in humans. Eight healthy men (mean age 22.3 ± 0.7 year) participated in this study. Experiments were conducted twice for each subject at a room temperature of 18°C. After a 30-min resting period, the subject drank either 15% alcohol at a dose of 0.36 g/kg body weight (alcohol session) or an equal volume of distilled water (control session), and remained in a sitting position for another 60 min. Mean skin temperature continued to decrease and was similar in control and alcohol sessions. Metabolic rate was lower in the alcohol session, but the difference did not affect core temperature, which decreased in a similar manner in both alcohol and control sessions (from 36.9 ± 0.1°C to 36.6 ± 0.1°C). Whole body sensations of cold and thermal discomfort became successively stronger in the control session, whereas these sensations were both greatly diminished after drinking alcohol. In a previous study we performed in the heat, using a similar protocol, alcohol produced a definite, coordinated effect on all autonomic and sentient heat loss effectors. In the current study in the cold, as compared to responses in the heat, alcohol intake was followed by lesser alterations in autonomic effector responses, but increased changes in sensations of temperature and thermal discomfort. Overall, our results indicate that although alcohol influences thermoregulation in the cold as well as in the heat, detailed aspects of the influence are quite different.

Keywords: Alcohol; Cold exposure; Thermoregulation; Thermal sensation; Human

Introduction

The pharmacological and physiological effects of alcohol are very complex, as are its effects on the thermoregulatory systems of animals. In addition to possessing an unusually steep dose–response curve (Crawshaw et al., 1998), alcohol affects body temperature in two disparate ways. High alcohol doses and severe environmental conditions lead to nonspecific disruptive effects, with very hot and very cold environments producing hyperthermia and hypothermia, respectively (see Yoda et al., 2005). Less severe environmental conditions and moderate doses of ethanol lead to decreases in body temperature. This fall in body temperature has been demonstrated in mice, rats, and fish and is due to a decrease in the regulated body temperature (Gordon & Stead, 1986; Gordon et al., 1988; O'Connor et al., 1988, 1989). The temperature decrease appears to be an adaptive response, because the lethal dose of ethanol in mice is decreased by 21% following a 17°C decrease in body temperature (Malcom & Alkana, 1983).

In humans, the effects of alcohol on temperature regulation are particularly difficult to discern. The overall effect seems to be less than with other, smaller mammals (Johnston et al., 1996), and although many studies have been published, there is little commonality between alcohol dose, type and degree of thermal stress, and experimental methodology. Although initial studies on the effect of alcohol in a warm environment showed little effect on thermoregulation, they were performed in situations of extreme heat stress involving either 40°C water immersion (Allison & Reger, 1992) or exercise at 35°C (Desruelle et al., 1996).

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By administering alcohol (0.36 g/kg) at 33°C, a more moderate condition, we were able to demonstrate a coordinated heat loss response. For period from 10 to 30 min after alcohol ingestion, sweat rate and skin blood flow increased significantly over control values, as did the perception of warmth. During this same period, core temperature fell significantly for the alcohol group. The perception of warmth increased in spite of a decrease in the mean skin temperature, due to increased sweating.

As was the situation in the heat, previous work with humans involving alcohol administration in a cold environment has produced enticing results. Although administration of moderate doses of alcohol to humans in the cold typically has minor effects on core body temperature (T_{core}), or thermal effector systems (Andersen et al., 1963; Fellows et al., 1984; Fox et al., 1979; Graham & Baulk, 1980; Johnston et al., 1996; Martin et al., 1977), it has been noted that perception of cold as well as the associated cold discomfort are clearly decreased following alcohol ingestion (Andersen et al., 1963; Fox et al., 1979; Graham & Baulk, 1980; Martin et al., 1977). This relationship between thermal sensation and physiological thermoregulatory responses is atypical and has led to disparate suggestions such as that although alcohol's behavioral effects could be used for minimizing the discomfort of sudden cold exposure (Martin et al., 1977), they also might be a major factor in the development of accidental hypothermia (Johnston et al., 1996).

Thus, there are both theoretical and practical reasons for further study of the effects of alcohol in a cold environment. Because we established that a clear dose and protocol for eliciting a consistent array of heat loss responses for all thermoeffector systems in a warm environment (Yoda et al., 2005), in this study we administered an identical dose of alcohol in an environment of moderate cold (18°C). We used the same protocol as in the experiments at 33°C. Our first hypothesis was that, because the dose and protocol were identical, alcohol ingestion would be followed by consistent decreases in heat production and in the sensation of cold discomfort, as well as increases in heat loss. Our second hypothesis was that changes in cold discomfort and cold sensation would not be directly related to alterations in skin temperature.

Materials and methods

Eight healthy, male Japanese subjects participated in the study. Subjects were screened by a personal history as well as by medical examination. All were occasional drinkers but no subjects had a current or past diagnosis of alcohol abuse or dependence. Some Japanese (5–10%) cannot drink alcohol at all, probably because of the lack of mitochondrial aldehyde dehydrogenase (ALDH2) activity (Harada et al., 1980; Shibuya et al., 1989). Such potential subjects were screened out of these experiments. The subjects gave informed consent for the experimental protocol, which was approved by the Human Research Ethics Committee in the School of Sport Sciences, Waseda University. Their mean age was 22.3 ± 0.7 (S.E.M.) years, body weight 67.0 ± 2.0 kg, and height 170.6 ± 1.5 cm.

Experiments were conducted twice for each subject. They fasted from 8:00 pm on the day before the experiment, but were allowed an isotonic drink the following morning. They arrived at the laboratory at 8:00 am and changed to shorts, after which they entered the environmental chamber (18°C with 50% relative humidity). The subjects then rested in a sitting position for 1 h during which time all measuring devices were applied. They rested for another 30 min as baseline data were obtained. Then, the subjects drank either 15 vol% (ml/100 ml) alcohol at a dose of 0.36 g/kg body weight (alcohol session) or an equal volume of distilled water (control session), and remained in a sitting position for another 60 min. Ethanol of 99.5% was used and given as a 15 vol% solution diluted with distillated water. The order of the two sessions was randomly chosen; there was a 2-day interval between experiments. To avoid affecting T_{core} or the temperature sensor (see below), both alcohol and water were ingested at 37°C. The alcohol solution was prepared immediately before drinking.

T_{core} was measured with a telemetry system (CoreTemp2000, HIT Technologies, Inc.). The transmitter pill was swallowed 90 min before the initiation of baseline data recording. Recordings of T_{core} were made each min and were presented as 10 min means. Heart rate (HR) was measured with the same device (CoreTemp2000, HIT Technologies, Inc.) and was similarly recorded. Skin temperatures at eight sites (forehead, chest, back, arm, hand, thigh, calf, and toe) were measured with copper–constantan thermocouples. Mean skin temperature (mean T_{sk}) was calculated from temperatures of the eight skin sites according to the area weighting formula of Hardy and DuBois (1938). Skin temperature was recorded every 10 s and averaged over 10 min. Indirect calorimetry was used to assess metabolic rate (MR). Oxygen and carbon dioxide concentrations of the expired gases were collected from a valved face mask and were analyzed every 1 min (AE-300, Minato Medical Science). Metabolic rate was calculated from the values of the nonprotein respiration quotient, the oxygen consumption rate, and the flow rate, and was expressed as kilocalories per body surface area (m^2) per hour.

Hensel (1981) delineates two kinds of sensory awareness to temperature—temperature sensation and thermal comfort. Temperature sensations provide an organism with an assessment of the thermal status of the immediate surround, whereas thermal comfort relates the thermal condition of the body to ''optimal'' conditions. When the body is near or at ''optimal'' the person will report comfort, but as the thermal condition of the body moves farther above or below the ''optimal'' level, greater feelings of discomfort will ensue. Both types of thermal awareness are likely to be involved in behavioral thermoregulatory responses, so we

measured both. Subjects were asked to report each sensation separately by marking on a linear 10-cm line rating scale. A vertical line drawn at the center of the scale indicated "neutral." The temperature sensation scale was labeled "cold" to the left of "neutral" and "hot" to the right. Similarly, the comfort scale was labeled "discomfort" to the left of "neutral" and "comfort" to the right. Both scales ranged from −5 to +5 and, if the sensations were sufficiently intense, subjects were allowed to indicate values beyond this range. The length from the neutral point to the point marked by the subject was measured and quantified as the rating score of either thermal sensation or thermal comfort. The responses were recorded as negative values if subjects indicated that their sensations were cold or uncomfortable. These estimates of temperature sensation and thermal comfort were made every 5 min during the resting and recovery period and every 2 min for the 40 min after drinking.

Differences in the measured values between the alcohol and control sessions were assessed by analysis of variance with repeated measures. A significant difference of means between the two sessions, at a specific time point, was subsequently identified by the Newman−Keuls procedure. Values except deep body temperature are expressed as changes from the means in the period prior to drinking (−20 to 0 min). All values are presented as means ± S.E.M.; the alpha level for statistical significance was set at 0.05. Throughout the paper alcohol dosage is given as g absolute ethanol/kg body weight; this required a calculation for many of the studies referred to. Literature blood ethanol concentration (BEC) values are given as mM/l of blood; this also required calculation in some cases. For reference, 1.0 g ethanol/kg = 1.26 ml ethanol/kg and 0.5 g ethanol/100 ml blood = 10.0 mM/l blood.

Results

T_{core} gradually decreased throughout the entire period of measurement in both the alcohol and the control sessions (Fig. 1). The decrease in T_{core} was the same for both groups during this span (36.9 ± 0.1°C [−20 min] to 36.6 ± 0.1°C [60 min] in the alcohol session, and from 36.9 ± 0.1°C [−20 min] to 36.6 ± 0.1°C [60 min] in the control session).

Fig. 2 shows changes in mean skin temperature (mean ΔT_{sk}; Fig. 2A), metabolic rate (ΔMR; Fig. 2B) and heart rate (ΔHR; Fig. 2C) expressed as differences from baseline (mean of the period from −20 to 0 min). Mean ΔT_{sk} decreased markedly and similarly for alcohol and control sessions, reaching −0.86 ± 0.13°C and −0.84 ± 0.15°C by the end of the alcohol and control sessions, respectively. After the initial 30 min, ΔMR in the control session increased and rose to 6.77 ± 3.61 kcal/m^2/h at the end of the measurement period. In contrast, in the alcohol session, ΔMR remained unchanged and was significantly below the control session for the final four periods. There was little change in ΔHR throughout the 90-min of measurement in the control session, whereas in the alcohol session ΔHR increased after drinking alcohol, with the final period significantly above the control values.

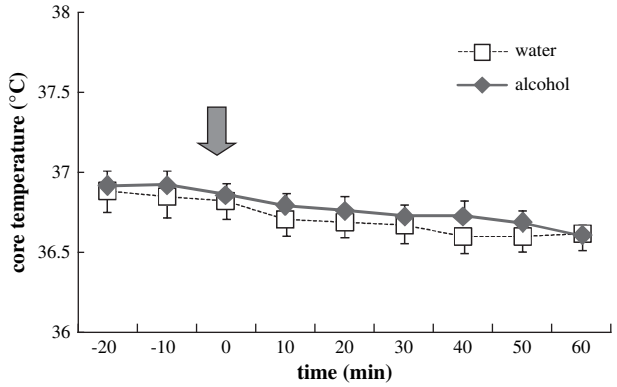

Fig. 1. Deep body temperature in the alcohol and control sessions. The arrow shows the time of drinking alcohol or water. Values are means ± S.E.M. (n = 8).

Assessments of whole body temperature sensation and thermal comfort/discomfort are depicted in Fig. 3A and B, respectively. Estimates of temperature sensation in both alcohol and control sessions were slightly "cold" (−1.75 ± 0.53 and −2.06 ± 0.52) at the initiation of measurements. The cold sensation became successively more intense in the control session, whereas in the experimental session the sensation closely approached "neutral" soon after drinking alcohol. Thermal discomfort in the control session also increased with time of cold exposure. On the other hand, in the alcohol session, thermal discomfort abated soon after alcohol consumption. In contrast to the physiological responses, cold sensation and thermal discomfort estimates rapidly diverged between the alcohol and control groups and, in both cases, attained and maintained a statistically significant difference that began less than 20 min after alcohol consumption.

Discussion

Our first hypothesis was clearly rejected. Despite the use of a similar dose and protocol as in our previous study performed in the heat, wherein there was a similar, definite increase in the response of all autonomic and sentient effector systems, in the current study a consistent, parallel response of the effectors was not observed. Although the metabolic rate of the alcohol group remained fairly constant over the session, the metabolic rate of the control group increased over the same time period. T_{core} did not differ from control values even though, at 18°C, heat loss is strongly favored. Thermal sensations, on the other hand, showed even stronger effects than those seen in the heat. Ongoing sensations of cold and cold discomfort were markedly reduced.

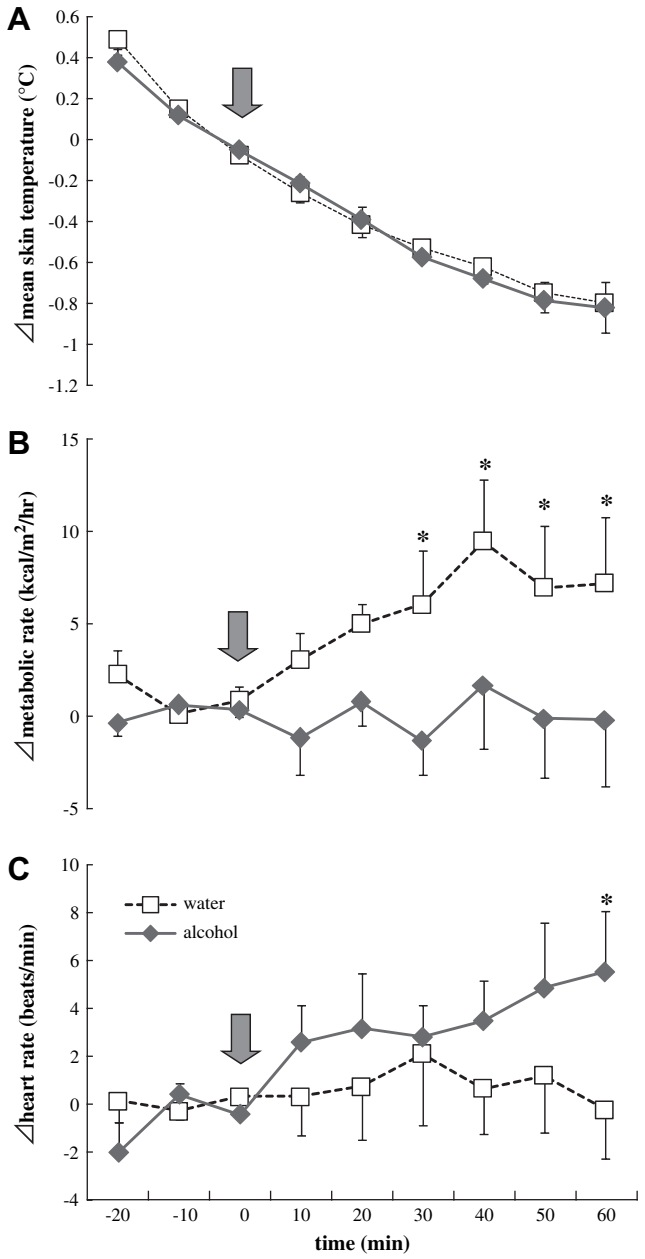

Fig. 2. Mean (A) skin temperature, (B) metabolic rate, and (C) heart rate in the alcohol and control sessions. The arrows show the time of drinking alcohol or water. Values are changes from the mean value in the period prior to drinking (−20 to 0 min). Values are means ± S.E.M. ($n = 8$). *$P < .05$ (alcohol vs. control sessions).

Our second hypothesis was supported. The major decrease in cold sensation was not due to a local effect on the skin. Although it is often specified that alcohol acts directly on cutaneous blood vessels and causes them to dilate (Wasielewski & Holloway, 2001), and that the ensuing warming of the skin produces the increased warm (or decreased cold) sensation (Fleming et al., 2001), we saw no evidence for either dilated vessels or warmed skin as judged from the skin temperature measurements. This indicates a central nervous origin for the decrease in cold sensation and cold discomfort produced by alcohol. Other evidence confirming a central effect comes from a study on quadriplegics which found that, following alcohol ingestion, vessels in skin areas innervated by peripheral nerves above the level of spinal cord damage became dilated, whereas vessels innervated by peripheral nerves below the damage level did not (Malps et al., 1990). The present results together with those of the previous study at 33°C, in which the techniques and doses are the same, suggest that the neural mechanisms underlying thermal comfort and skin vasomotor control are distinct and independent. This is because although there was a change in thermal comfort in both the warm and cold conditions, skin vasodilation occurred only in the warm condition.

Unlike our study in the heat, our findings in this work, in general, are in close agreement with existing studies. In the cold, as summarized by Johnston et al. (1996), alcohol typically has little or no effect on T_{core}. Even under extreme levels of cold stress, alcohol intake still produces only an insignificant difference in T_{core}. Thus Graham and Baulk (1980) dosed subjects with alcohol (dose: 0.79 g/kg; BEC: 20 mM/l) or a control solution and then placed them in 13°C water for 24 min, followed by 24 min (still wet) out of water at 22.5°C. In the 48 min of exposure, T_{core} evidenced a 1.8°C decrease for the alcohol group compared to a 1.4°C decrease for the control group. In the current study, the statistically significant difference in metabolic rate between the experimental and control groups was physiologically insignificant. Over the 60 min period following alcohol ingestion, the mean decrease in metabolic rate was 7.5 Kcal/h. Assuming a whole body specific heat of 0.8 cal/°C, the predicted difference in core temperature between the experimental and control groups is slightly less than 0.1°C.

Other studies have noted no alteration of effector activity following alcohol administration in the cold. These studies include Andersen et al. (1963) who used 20°C and 15°C (dose: 1 and 1.5 g/kg) and monitored heat production and skin surface temperature, Hughes et al. (1984) who used 20°C and monitored cutaneous blood flow, and Martin et al. (1977) who used 13°C water (dose: varied; BEC: 19.5 mM/l) and monitored ventilatory responses and mean skin temperature. A roughly equal number of investigators noted definite autonomic responses from at least one effector, although the responses were typically not of physiological significance in terms of overall heat balance. In the experiment of Graham and Baulk (1980) mentioned above, the initiation of visible shivering was delayed and time spent shivering was less for the alcohol group. Also, Johnston et al. (1996), using passive cooling in 28°C water, (dose: 0.79 g/kg with later 0.2 g/kg top up; BEC: 21.1 mM/l) demonstrated a 0.3°C decrease in the threshold for vasoconstriction following alcohol as compared to controls. Thresholds for sweating and shivering were unaffected. Fox et al. (1979), using 10°C water, (dose: 0.87 g/kg; BEC: 17.8 mM/l) noted that the alcohol group showed a 13%

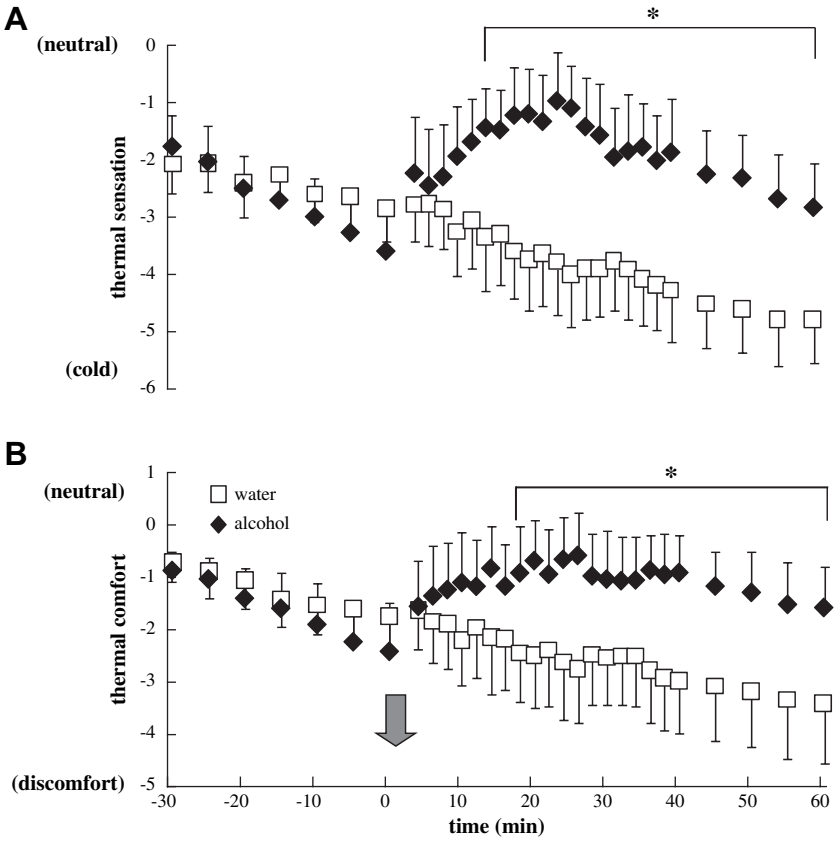

Fig. 3. Scores of subjective (A) thermal sensation and (B) thermal comfort sensation in the alcohol and control sessions. (A) Positive and negative values indicate hot and cold sensations, respectively, and the score 0 indicates neutral (no sensation at all). Maximum score is 5 and minimum score is −5. (B) Positive and negative values indicate comfort and discomfort, respectively, and the score 0 indicates neutral. The arrow shows the time of drinking alcohol or water. Values are means ± S.E.M. ($n = 8$). *$P < .05$ (alcohol vs. control sessions).

reduction in heat production as compared to the controls. The overall conclusion is clear. Alcohol elicits a slight change in autonomic responses that favor a decrease in T_{core} but such responses are of only minor relevance to T_{core}.

The repeatedly observed disconnect between physiological responses and thermal sensation has led to suggestions that, due to the lessening of discomfort, alcohol might prove beneficial when it is necessary to persevere (Martin et al., 1977) or sleep comfortably (Andersen et al., 1963) in a cold environment. Although this could be true in a relatively benign environment, in hazardous situations the dysfunctionality produced by alcohol consumption would pose a major risk. Further, with continued alcohol intake, the disconnection between sensory and physiological responses to cold could prove a serious impairment. During the early stages of intoxication, due to a lack of cold sensation, a person might initially remove clothing or fail to take proper precautions, and then with continued consumption, could encounter major decreases in T_{core} as continued increases in BEC led to behavioral and physiological dysfunctionality.

The differential effects of similar doses of alcohol in the heat and cold have implications for the properties of the regulator of body temperature. Although alcohol clearly has an effect, the lack of symmetry in the response of the various automomic and sentient effector systems indicates that the regulator is not simply shifted up or down. Rather, the supposition that the regulatory system is composed of parallel but somewhat separate modules (Kanosue et al., 1998) is supported by the current results.

In conclusion, we have demonstrated that alcohol mediated decreases in the perception of cold in a cold environment are not due to local effects of alcohol on blood vessels but are most likely due to a direct effect of ethanol on the central nervous system. We have also extended previous observations that, in a cool temperature, moderate doses of alcohol produce substantial decreases in cold sensation that are accompanied by minor effects on autonomic thermoregulatory responses.

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