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Ice slurry ingestion reduces both core and facial skin temperatures in a warm environment

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ABSTRACT

Internal body cooling by ingesting ice slurry has recently attracted attention. Because ice slurries are ingested through the mouth, it is possible that this results in conductive cooling of the facial skin and brain. However, no studies have investigated this possibility. Thus, the aim of this study was to investigate the effects of ice slurry ingestion on forehead skin temperature at the point of conductive cooling between the forehead skin and brain. Eight male subjects ingested either 7.5 g/kg of ice slurry (−1 °C; ICE), a cold sports drink (4 °C; COOL), or a warm sports drink (37 °C; CON) for 15 min in a warm environment (30 °C, 80% relative humidity). Then, they remained at rest for 1 h. As physiological indices, rectal temperature (T_{re}), mean skin temperature, forehead skin temperature (T_{head}), heart rate, nude body mass, and urine specific gravity were measured. Subjective thermal sensation (TS) was measured at 5-min intervals throughout the experiment. With ICE, T_{re} and T_{head} were significantly reduced compared with CON and COOL conditions ($p<0.05$). The results of the other physiological indices were not significantly different. TS with ICE was significantly lower than that with CON and COOL ($p<0.05$) and was correlated with T_{re} or T_{head} ($p<0.05$). These results indicate that ice slurry ingestion may induce conductive cooling between forehead skin and brain, and reduction in core and forehead skin temperature reduced thermal sensation.

1. Introduction

Cold water immersion or wearing a cooling jacket and applying ice packs are effective methods for pre-exercise body cooling. It is believed that body cooling contributes to improved endurance exercise performance under heat stress. González-Alonso et al. (1999) reported that pre-cooling by cold water immersion for 30 min increased heat storage during exercise and the exercise time to exhaustion. Castle et al. (2006) reported that the peak power output during maximal pedaling was improved when the thigh and leg areas were cooled with ice packs before intermittent exercise in heat. However, Sleivert et al. (2001) reported that cooling the thigh area using perfusion with water at 4 °C for 45 min before exercise reduced the power output during a sprint test due to a reduction in muscle temperature by directly cooling the active muscles involved. Thus, this indicates that the external body cooling, which was often used previously, may reduce exercise performance due to a reduced muscle temperature, posing logistical challenges such as difficulties in accessing a large volume of water required for cooling and electricity to maintain water temperature and the discomfort when this is applied (Ross et al., 2010; Siegel et al., 2012).

Cold drink ingestion has been reported as an easier and more practical internal body cooling method than external cooling. Lee et al. (2008) reported that when subjects ingested cold water (4 °C) or warm water (37 °C) before and during cycling exercise in heat, their rectal temperature was reduced by 0.5 °C before exercise with cold water ingestion and their time to exhaustion was significantly improved. Mundel et al. (2006) reported that the volume of ingested water was greater with cold drink ingestion, incremental changes in rectal temperature and heart rate were attenuated, and endurance exercise capacity was improved when subjects ingested a flavored drink at 4 °C or 19 °C *ad libitum* during endurance exercise until exhaustion in a warm environment.

A more aggressive internal body cooling process appears to occur when ingesting an ice slurry mixture (Siegel et al., 2012). Ice slurries are icy mixtures that are consumed like a drink. Siegel et al. (2010) reported that when subjects ingested ice slurry (−1 °C) or cold water (4 °C) before exercise in a warm environment, their rectal temperature was significantly reduced and time to exhaustion was improved by 19% with ice slurry ingestion. Subsequently, Siegel et al. (2012) investigated the effect of pre-cooling by ice slurry ingestion or water immersion on

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thermoregulation and endurance exercise performance in a warm environment, and reported that ice slurry ingestion significantly reduced rectal temperature and resulted in a running time equal to that with water immersion.

An ice slurry might also affect brain function. Vanden Hoek et al. (2004) compared the core temperatures in swine after central catheter infusions of saline ice slurry (50 ml/kg) vs. an equal volume of chilled saline, and reported that ice slurry significantly reduced these animals' brain temperature. If ice slurry ingestion can reduce brain temperature, it would be a more effective cooling method that attenuates both peripheral and central fatigue and, thereby, improve exercise capacity. However, previous studies focused only on the effects on core temperature, and no studies have focused on the effects of ice slurry ingestion on brain temperature.

It is difficult to non-invasively measure the brain temperatures in humans; therefore, we focused on the forehead skin temperature as an index for the measurement of the brain temperature. Many previous studies investigating selective brain cooling have used the forehead skin temperature (Cabanac, 1986; Cabanac and Caputa, 1979; Falk, 1990; Gallup and Gallup, 2007; Zenker and Kubik, 1996); furthermore, forehead cooling has been shown to be involved in the thermoregulation (cooling) of the brain (Cabanac, 1986; Gallup and Gallup, 2007; Zenker and Kubik, 1996). Forehead cooling is assumed to simulate brain cooling in a combination of ways. It cools the venous blood of the skin, which in turn cools the arterial (carotid) blood supply to the brain. The other major brain cooling mechanisms include the dissipation of heat through facial emissary veins (Cabanac, 1986; Cabanac and Brinnel, 1985; Gallup and Gallup, 2007; Zenker and Kubik, 1996), or heat loss through the skull. Indeed, in clinical trials, Mellergård (1992) reported that head cooling using a gel cap reduced epidural temperature by ~1 °C. Thus, it is assumed that reduction in the forehead skin temperature can reflect brain cooling.

Therefore, the aim of this study was to investigate the effect of ice slurry ingestion on brain temperature at the point of conductive cooling from cooling the facial area. To exclude the effect of exercise on thermoregulation, we did the experiment at rest.

2. Methods

2.1. Participants

Eight healthy males (mean age of 22.9 ± 1.1 years, mean height of 1.71 ± 0.03 m, mean body mass of 59.1 ± 4.6 kg, and mean BMI of 20.1 ± 1.4) participated in this study. Our experiments were approved by the Ethics in Human Research Committee of Hiroshima University and all participants signed an informed consent form before our experiments began.

2.2. Experimental design

Our experiment included three separate conditions: ingesting warm sports drink (37 °C: CON), ingesting cold sports drink (4 °C: COOL), and ingesting ice slurry (−1 °C: ICE). Throughout the study period, subjects were asked to keep their normal lifestyle activities at a stable level, including their physical activity and nutritional habits. During the 24-h period prior to conducting our trials, subjects were asked to avoid consuming alcohol and caffeine. The three experimental trials were separated by 5 days in a counterbalanced order, and conducted at the same time of day to eliminate any effects of circadian variations.

Upon their arrival in our laboratory, subjects had urine samples collected and were weighed nude to the nearest 50 g (UC-300; A & D, Tokyo, Japan). Then, skin thermistors and electrodes for heart rate were attached. Participants entered a room that was kept at 30 °C with 80% relative humidity and remained at rest for 5 min. Then, they ingested either 7.5 g/kg of warm sports drink (37 °C), cold sports drink (4 °C), or ice slurry (−1 °C) for 15 min. To ensure a standardized ingestion rate, participants were given 2.5 g/kg of the particular drink every 5 min. After ingestion, participants remained at rest for 1 h. All beverages were conventional sports drinks (Pocari Sweat, Otsuka Pharmaceutical, Japan), and ice slurry was made using a slurry machine (DM1000, Margaritaville, Australia).

2.3. Measurements

As physiological indices, rectal temperature (T_{re}), forehead skin temperature (T_{head}), mean skin temperature (T_{sk}), heart rate (HR), nude body mass, and urine specific gravity were measured. T_{re} was measured with a thermistor (LT-ST08-21, Nikkiso-Therm Co. Ltd., Japan) that was inserted 12 cm from the anal sphincter with a disposable rubber sheath (11Y24, Nikkiso-Therm Co. Ltd.). Skin temperature was measured at four sites (forehead, chest, upper arm, and thigh) using thermistors (LT-ST08-12, Nikkiso-Therm Co. Ltd.) that were secured with micropore tape. All thermistors were connected to a data collection device (LT-8 A, Gram Corporation, Japan), and temperatures were recorded every 5 min. T_{sk} was calculated using the formula of Roberts et al. (1977): $T_{sk} = 0.43 \times T_{chest} + 0.25 \times T_{arm} + 0.32 \times T_{thigh}$. Heart rate values were monitored continuously using short-range radio telemetry (RS800CX, Polar Electro, Kempele, Finland). Nude body mass was measured using a weighing machine (UC-300, A & D, Japan) and urine specific gravity was determined using a digital urine specific gravity scale (UG-D, Atago, Japan) before and after the experiment. Sweat rate was calculated using the following formula: (body mass before the experiment-body mass after the experiment)+the amount of the ingested drink. Subjective thermal sensation (TS) was measured at 5-min intervals throughout the experiment using the scale derived by Gagge et al. (1969) (0=very cold to 8=very hot).

2.4. Statistical analysis

Results are given as means ± SDs. Statistical comparisons of results for T_{re}, skin temperatures, HR, TS, body mass, and urine specific gravity were made using two-factor (condition × time) ANOVA with repeated measures, followed by Tukey HSD tests. Results, before and after the experiment for body mass and urine specific gravity, were compared using *t*-tests. Pearson correlation coefficients were determined to assess possible correlations between T_{re}/T_{head} and TS results. Statistical significance was accepted at $p < 0.05$. In this study, a recorded value before ingesting a drink (−20 min) was defined as the baseline value.

3. Results

3.1. Physiological measurements

The changes in T_{re} during the experiment and the mean changes in T_{re} (ΔT_{re}) from baseline to 15 min (20 min after the end of drink ingestion) are shown in Fig. 1A and B, respectively. T_{re} with ICE was significantly reduced from 5 to 30 min as compared to baseline values and results with COOL ($p < 0.05$) and from 5 to 35 min as compared with results with CON ($p < 0.01$). ΔT_{re} with the ICE condition was significantly higher as compared with those with CON ($p < 0.01$) and with COOL ($p < 0.05$).

Fig. 2A and B shows the changes in T_{head} during the experiment and the mean changes in T_{head} (ΔT_{head}) from baseline to 0 min, respectively. T_{head} with ICE was significantly reduced from 0 to