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Beneficial Effects of Ice Ingestion as a Precooling Strategy on 40-km Cycling Time-Trial Performance

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Purpose: The effect of crushed ice ingestion as a precooling method on 40-km cycling time trial (CTT) performance was investigated. ***Methods:*** Seven trained male subjects underwent a familiarization trial and two experimental CTT which were preceded by 30 min of either crushed ice ingestion (ICE) or tap water (CON) consumption amounting to 6.8 $g \cdot kg^{-1}$ body mass. The CTT required athletes to complete 1200 kJ of work on a wind-braked cycle ergometer. During the CTT, gastrointestinal (T_{gi}) and skin (T_{sk}) temperatures, cycling time, power output, heart rate (HR), blood lactate (BLa), ratings of perceived exertion (RPE) and thermal sensation (RPTS) were measured at set intervals of work. ***Results:*** Precooling lowered the T_{gi} after ICE significantly more than CON (36.74 ± 0.67°C vs 37.27 ± 0.24°C, $P < .05$). This difference remained evident until 200 kJ of work was completed on the bike (37.43 ± 0.42°C vs 37.64 ± 0.21°C). No significant differences existed between conditions at any time point for T_{sk}, RPE or HR ($P > .05$). The CTT completion time was 6.5% faster in ICE when compared with CON (ICE: 5011 ± 810 s, CON: 5359 ± 820 s, $P < .05$). ***Conclusions:*** Crushed ice ingestion was effective in lowering T_{gi} and improving subsequent 40-km cycling time trial performance. The mechanisms for this enhanced exercise performance remain to be clarified.

Keywords: core temperature, thermal strain, cooling, heat

Precooling is a temperature regulation strategy whereby core temperature (T_c) is lowered before exercise, and has been consistently shown to improve endurance capacity and athletic performance.[1–4] However, precooling protocols such as water immersion and cold air exposure are time consuming, logistically demanding and in some instances may result in adverse thermal responses, making these conventional methods impractical as a pre-event strategy.[3,5,6]

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Endogenous cooling methods such as fluid ingestion have been shown to attenuate the rise in T_c during exercise.[7,8] It is suggested that fluid ingestion preserves plasma volume and serum osmolality, which allows for efficient dissipation of heat to the environment via an enhanced sweat response.[9] Previous work would suggest that water ingestion during exercise most effectively attenuates the rise in T_c when a large single bolus (0.75–1 L) of fluid is consumed[13,28] as opposed to serial feedings of smaller proportions.[9] However, the proposed bolus of fluid (0.75–1 L) provided as a single serving is not a practical recommendation for use during a competitive endurance event.

In addition to the positive effects of fluid ingestion on T_c responses to exercise, the effect of fluid temperature has also been examined. Mundel et al[10] showed that the consumption of a cold drink (4°C) during exercise was responsible for a significant increase in cycle time to exhaustion (>12%), and decreases in rectal temperature (0.25°C), when compared with consumption of fluid at greater temperatures (19°C). Furthermore, Lee et al[9] showed that cold fluid consumption (4°C) both before, and at 10-min intervals during exercise was responsible for a significantly increased cycling time to exhaustion, in association with significantly lower rectal temperatures and heart rates before exercise commencement. It is proposed that these cold beverages act as a heat sink, which attenuates the rise in body temperature.[10]

Given the positive effects on T_c resulting from the consumption of a cold beverage highlighted above, it is plausible to assume that greater effects for the same given volume might present should the fluid ingested be exchanged for crushed ice. Previously, an ice slurry provided intravenously in swine was shown as a powerful inducer of hypothermia, with cooling rates nearly 7°C per hour greater than a chilled saline equivalent.[11] The ingestion of ice may theoretically increase the potential for heat storage since approximately 333.55 J of thermal energy is required to convert 1 g of ice to liquid.[12] This phase change phenomenon is known as *the latent heat of fusion*.[12] Furthermore, crushed ice ingestion may be a more practical method of pre-event cooling techniques, since it removes the need for cumbersome equipment and time-consuming protocols. As such, the purpose of this study was to examine the effect of crushed ice ingestion as a precooling method on body temperature response, and on cycling time-trial performance.

Methods

Subjects

Seven endurance trained male subjects, regularly competing in cycling or triathlon events (age: 27.7 ± 3.1 y, height: 176.7 ± 5.8 cm, mass: 81.38 ± 9.09 kg, cycling more than four sessions and >150 km per week) were recruited for participation in this investigation. Subjects were informed of the risks and requirements involved with participation, and a written informed consent was obtained in accordance with the Human Ethics Committee of the University of Western Australia before participation. Adequate hydration was strongly encouraged before testing, and was monitored via urine specific gravity (USG) examination before each trial. No subjects presented as severely dehydrated (USG < 1.020 μg) before any testing session.[13] Subjects were asked to keep a record of their food intake during the 24 h before their first experimental testing session, and were encouraged to replicate this dietary consumption before their second trial. Finally, subjects were instructed to refrain from strenuous physical activity, alcohol and caffeinated beverages for 24 h before all tests.

Experimental Overview

During this investigation, each subject completed a familiarization, and two experimental testing sessions of a 40-km cycling time trial (CTT) on a wind-braked cycle ergometer (Evolution Pty. Ltd., Adelaide, Australia), modified with clip in pedals and racing handle bars. The two experimental CTTs included one trial preceded by a 30-min period of no cooling (CON), and the other trial preceded by a 30-min period of precooling via crushed ice consumption (ICE). The order of trial completion was randomized, counterbalanced, crossed over and completed within 14 d following the initial session. Each 40-km CTT required subjects to complete 1200 kJ of work in the fastest time possible. The target workload of 1200 kJ was chosen to represent 40 km because previous research has used 500 kJ as an indication of 20 km, with a mean completion time of approximately 28 min.[14] As such, to avoid underestimating 40 km of cycling, a slightly higher work target of 1200 kJ was selected. All CTTs were undertaken at the same time of the day to minimize the effects of circadian rhythm on HR and T_c.

Experimental Procedures

Familiarization Cycle Time Trial. The familiarization CTT was performed under neutral environmental conditions (22.6 ± 0.7°C and 47.9 ± 9% RH). No performance or physiological measures were recorded during the familiarization trial because the primary purpose for this session was to acquaint the subjects with the general procedures and equipment to be used, for better reproducibility of results during the subsequent two CTTs.

40-km Cycle Time Trials. Eight to ten hours before commencement of the CTT, subjects were required to swallow a telemetric temperature measuring pill (CorTemp, HQ Inc., Palmetto, FL). Upon arrival to the laboratory, BM was recorded and a urine sample was obtained for measurement of USG. Subsequently, the subjects were fitted with a heart rate (HR) monitor (Polar, Accurex Plus, Finland) and skin thermistors to three sites on the body. Next, a 30-min period was allowed for the CON or ICE intervention to be administered. Subsequently, a 10-min warm-up was undertaken before the subject was allowed a 5-min transition period to move into the climate controlled chamber (30°C, 75% RH), where the CTT was then completed. During the CTT, split times at every 100 kJ, total time and the corresponding mean power output (MPO) were recorded using customized computer software (Cyclemax, School of Sport Science, Exercise and Health, University of Western Australia). Furthermore, HR was monitored each 100 kJ, and fluid intake was restricted to 100 mL of tap water (26.8 ± 1.3°C) provided after 200, 500, 800 and 1100 kJ of work had been completed. All subjects consumed the entire 100 mL of tap water at each of the four allocated time points. Upon completing the CTT, subjects toweled themselves dry, and BM was retaken.

Precooling. A 30-min period of either CON or ICE preceded the performance trials. For the ICE protocol, subjects ingested a relative amount of 6.8 $g \cdot kg^{-1}$

BM as this amount was estimated to initiate a decrease of approximately 0.6°C in T_c (Based on data obtained from pilot testing on 9 healthy individuals in our laboratory before the commencement of this investigation, 6.8 $g \cdot kg^{-1}$ was found to be the maximal tolerable amount of ice consumable within a 30-min period). The ice cubes were blended in a commercially available food blender (Sunbeam Multi-Blender, Australia) to a slushy-like consistency, before being weighed and the temperature measured (1.4 ± 1.1°C) using an alcohol-based glass thermometer (Lanxi, China). Servings were provided in serial aliquots of 150 to 200 g at 8- to 10-min intervals, over a 30-min period, ensuring the stipulated amount of ice to be consumed was reached. For CON, subjects consumed 6.8 $g \cdot kg^{-1}$ BM of tap water in the same serving proportions and timing as those for the ICE trial. As in ICE, the temperature of the ingested water was measured before being served (26.8 ± 1.3°C). For both CON and ICE, the absolute amount to be consumed was determined based on the BM measured on the day of the trial.

CTT Warm-Up. An identical 10-min warm-up preceded both experimental trials. Subjects were required to cycle at 60% of their age predicted maximum HR (220 – age) for 10 min, which included 4 × 20-s bouts representative of their typical time trial pace at the beginning of the 4th, 5th, 6th and 7th minute.

Blood Lactate. Capillary blood samples were taken from the earlobe before the start, at every 300 kJ during, and at the immediate completion of the CTT. The collection site was wiped with an alcohol swab and the initial drop of blood was discarded. Blood was subsequently collected in a heparinized glass capillary tube (35 μL) and measured immediately for lactate concentration (ABL 625, Radiometer Medical A/S, Copenhagen, Denmark)

Temperature Measurements and Calculation. Gastrointestinal temperature (T_{gi}) was measured as representative of T_c by the use of ingestible temperature measurement pills (CorTemp, HQ Inc., Palmetto, FL). These pills are temperature sensitive and transmit changes in the form of continuous low-frequency radio waves to a handheld data logger (HT150001, CorTemp, HQ Inc., Palmetto, FL). The accuracy and precision of the manufacturer's calibration of this equipment has previously been investigated and has been confirmed as a valid measurement of T_c.[15] Subjects were instructed to ingest these pills 8 to 10 h before all performance trials to ensure the pill was out of the stomach, thereby avoiding variability in T_c due to pill movement and fluid / food consumption.[16] Skin temperatures were measured using skin thermistors (Yellow Springs, Ohio, USA) attached to three sites, including lateral calf of the left leg (T_{ca}), anterior surface of the left forearm (T_{fa}) and to the sternum (T_{st}). These thermistors were linked to a computer interface, equipped with a recording software (Thermes TPC-Win software, Physitemp instruments Inc., Clifton, NJ). All temperature measurements were taken at 5-min intervals during the precooling and warm-up phases, before commencement of the trial and at every 100 kJ thereafter. The mean T_{sk} was determined using the following equation:[17]

$$T_{sk} = (0.5 \times T_{st}) + (0.14 \times T_{fa}) + (0.36 \times T_{ca})$$

Perceptual Ratings. The subjects rating of perceived exertion (RPE) was assessed using Borg's 6-to-20 scale (6 = no exertion to 20 = maximal exertion).[18] Ratings of perceived thermal sensation (RPTS) was assessed using an 8-point scale

(0 = unbearably cold to 8 = unbearably hot).[19] This method of assessment has been used in a number studies previously and was found to be significantly correlated to changes in T_c ($R = .72$, $P < .01$).[20,21] The RPE and RPTS were taken immediately after the warm-up, before the CTT, at each 200 kJ, and at the trials' immediate completion.

Statistical Analysis. Statistical analysis was performed using SPSS version 15 software (SPSS Inc. Chicago, IL). All results are expressed as mean and standard deviation (mean ± SD). A repeated-measures ANOVA was used to determine differences between measured variables in the ICE and CON trials. Where significant differences were noted, post hoc paired sample *t* tests were used to locate exact differences. The alpha level was set at $P \leq .05$.

Results

There were no significant differences between the ICE and CON trials for pre-CTT measures of USG (ICE: 1.013 ± 0.006; CON: 1.014 ± 0.009, $P = .50$), chamber environmental conditions (ICE: 30.4 ± 0.2°C and 73.9 ± 1.3%; CON: 30.3 ± 0.2 and 73.6 ± 0.9%, $P = .40$), and BM (ICE: 81.50 ± 9.06 kg; CON: 81.25 ± 9.11 kg, $P = .40$). At the conclusion of the CTT, BM was significantly lower in both the ICE (79.19 ± 8.73 kg, $P = .0001$) and the CON (79.16 ± 8.54 kg, $P = .0001$) trials. However, these BM losses were not significantly different between trials ($P = .90$). The percentage BM losses in ICE (2.06 ± 0.69%) and CON (2.85 ± 0.52%) were also not significantly different between trials ($P = .12$).

40-km Cycling Time Trial

Time. The CTT was significantly faster by 6.5% in the ICE trial (5011 ± 810 s) when compared with the CON (5359 ± 820 s) ($P = .049$). Split times at 100-kJ intervals are presented in Figure 1. The split times at 900 kJ (ICE: 443 ± 90 s; CON: 478 ± 91 s, $P = .018$), 1000 kJ (ICE: 455 ± 98 s; CON: 496 ± 109 s, $P = .025$) and 1100 kJ (ICE: 466 ± 113 s; CON: 508 ± 116 s, $P = .029$) were significantly faster in ICE compared with CON.

Power Output. The overall MPO was 6.9% greater in the ICE condition (247 ± 35 W) when compared with CON trial (231 ± 32 W). This difference approached significance between trials ($P = .06$).

Temperature

Gastrointestinal Temperature. Figure 2 represents the T_{gi} measurements gathered during precooling, warm-up and CTT for the ICE and CON trials. There were no significant differences in T_{gi} between the ICE and CON before precooling ($P = .393$). The T_{gi} before CTT in CON was significantly higher than baseline following the 10-min warm and 5-min rest period ($P = .028$). In the ICE trial, significant decrements in T_{gi} were observed compared with baseline from 15 min onwards during precooling ($P < .05$). The T_{gi} at the end of ICE ingestion was 1.1 ± 0.59°C lower compared with baseline ($P = .011$). The T_{gi} in the ICE trial was not significantly higher than baseline until 200 kJ of work had been achieved during

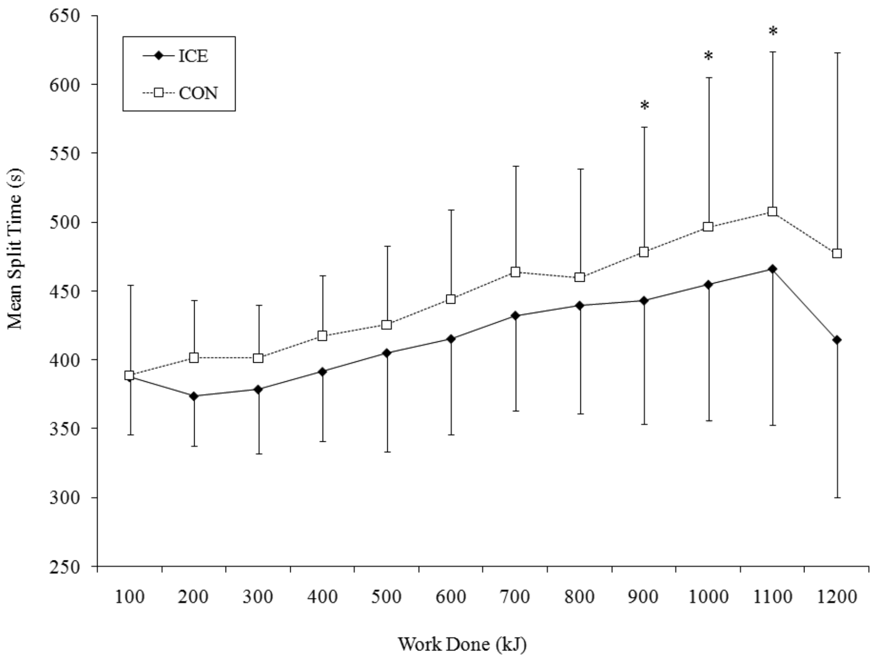

Figure 1 — Mean (±SD) split time taken at 100-kJ intervals during the cycling time trial (CTT) between ice ingestion (ICE) and control (CON) precooling trials. *Significantly different between conditions ($P < .05$).

the CTT. Between conditions, T_{gi} was significantly lower in ICE compared with CON from 20 min onwards during precooling ($P < .05$). Before commencement of the CTT, the T_{gi} was significantly lower in ICE compared with CON ($P = .04$). However, no significant differences in T_{gi} were observed between conditions after 100 kJ during the CTT.

Skin Temperature. Figure 3 represents the T_{sk} measurements gathered during precooling, warm-up and CTT for the ICE and the CON trials. No significant T_{sk} differences were observed between the two conditions before precooling ($P = .81$). No significant differences from baseline were noted in T_{sk} during the precooling period for both CON and ICE ($P > .05$).There was a significant decrease in T_{sk} compared with baseline during the warm up in both CON ($P = .001$) and ICE ($P = .007$); however, this was not different between trials. In contrast, a significant rise in T_{sk} was evident upon the athletes entering the climate chamber in both conditions ($P = .0001$). The T_{sk} for CON and ICE was significantly higher compared with baseline at all time points during the CTT ($P < .05$). No significant differences were noted between CON and ICE at any time points during the CTT ($P > .05$).

Perceptual Ratings, Heart Rate and Blood Lactate. The RPTS before precooling was not significantly different between the CON and the ICE trials (CON: 3.9 ± 0.2; ICE: 3.9 ± 0.6, $P = .766$). However, the RPTS in the ICE trial (2.4) was

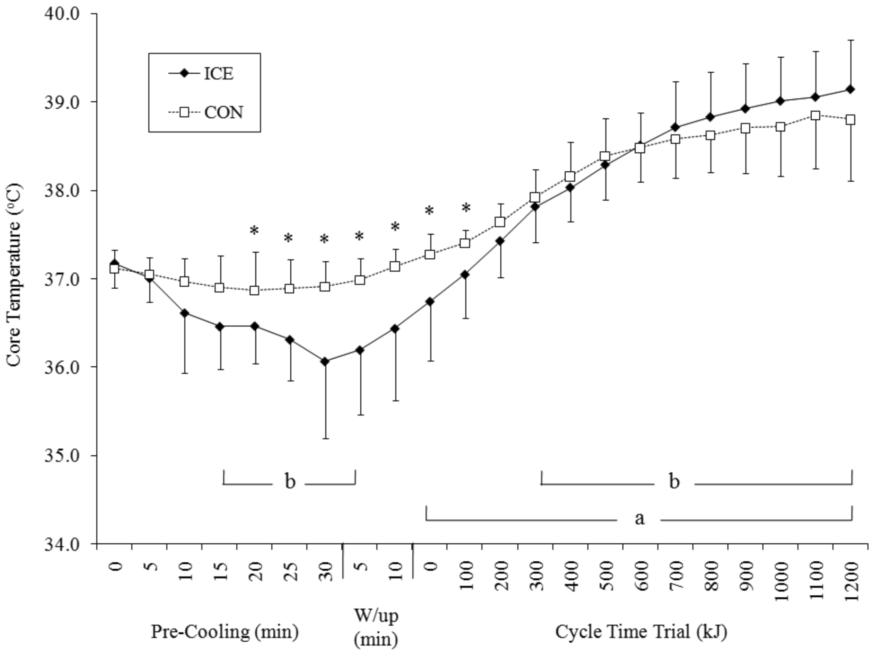

Figure 2 — Mean (±SD) changes in gastrointestinal temperature (T_{gi}) during precooling, warm-up and the cycling time trial (CTT) between ice ingestion (ICE) and control (CON) precooling trials. [a]Significantly different from baseline within CON ($P < .05$). [b]Significantly different from baseline within ICE ($P < .05$). *Significantly different between conditions ($P < .05$).

significantly lower compared with baseline (4.0, $P = .009$) and compared with CON (3.9, $P = .025$) at the end of precooling. During the CTT, RPTS was significantly lower in ICE compared with CON at 200 kJ (ICE: 5.6; CON: 6.1; $P = .005$). No significant differences in HR, RPE and BLa were seen between conditions at any of the sampled time points ($P > .05$).

Discussion

The purpose of this study was to investigate ice ingestion as a viable precooling method before competitive activity. This study showed that ingesting crushed ice reduced T_{gi} when compared with baseline, and when compared with ingesting tap water of similar amounts at the end of a 30-min precooling period. Subsequently, 40-km CTT performance was 6.5% faster in the ICE trial compared with CON.

Previously, it has been shown that drinking approximately 1 to 1.7 L of cold water can result in a reduction to T_c in the range of 0.6 to 0.8°C.[22,23] Furthermore, it was also shown that ingesting a large one-off bolus of cold water (0.75 to 1 L at 0.5 to 10°C) during submaximal exercise reduced the rate of rise in T_c.[7,8] Such cooling conferred by ingestion relies upon the specific heat capacity of the beverage and the

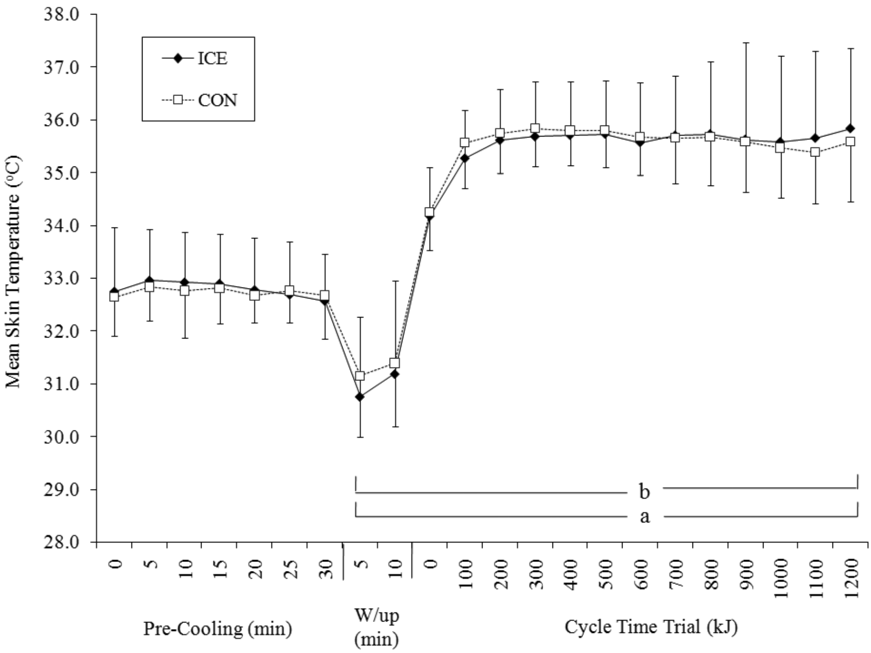

Figure 3 — Mean (±SD) changes in skin temperature (T_{sk}) during precooling, warm-up and the cycling time trial (CTT) between ice ingestion (ICE) and control (CON) precooling trials. [a]Significantly different from baseline within CON ($P < .05$). [b]Significantly different from baseline within ICE ($P < .05$). *Significantly different between conditions ($P < .05$).

beverage temperature. Here, however, we have shown that a greater cooling effect with a smaller volume is possible when ingesting crushed ice as compared with water alone. Furthermore, a performance benefit has been shown when applying this procedure as a precooling strategy to endurance cycling performance.

The decrements seen in T_{gi} following 30 min of ice ingestion are favorable when compared with other precooling methods reported in the literature. Lee and Haymes[4] observed a 0.37°C reduction in T_c following 30 min of cold air exposure. Furthermore, Booth et al[2] and Marino and Booth[5] reported a 0.8°C and 0.7°C reduction in T_c respectively, following 50 to 60 min of full-body water immersion with gradual decreases in water temperature from 28 to 23°C. However, these more common precooling methods are logistically demanding, time consuming, and have been associated with negative thermoregulatory responses, such as depleted muscle glycogen stores by up to 20% and increases to metabolic rate by 93%.[24,25] Ice ingestion, however, has been shown here as effective in reducing precompetition T_{gi}, effective in enhancing endurance performance, is time efficient, and does not rely on large amounts of equipment or time-consuming protocols. The metabolic response to consuming such a bolus of crushed ice, however, remains to be elucidated.

Precooling via crushed ice ingestion enabled exercise to be commenced at a lower T_{gi} compared with baseline and CON. However, this positive effect was no longer evident by the completion of 200 kJ of work in the ICE trial. In contrast, precooling via other methods has shown a more sustained effect on T_c despite the similarities in ambient conditions to those used here (approximately 32°C and 60% RH). Notably, Booth et al[2] demonstrated that T_c following 60 min of water immersion was significantly lower compared with no precooling for up to 20 min during a 30-min self-paced running trial. However, these authors had exercise commenced within 3 min following the precooling period. In contrast, here the CTT was commenced after 15 min following the precooling intervention, during which a 10-min warm-up and 5-min transition period was undertaken. Completion of a warm-up is a widely practiced and advocated preactivity ritual used by athletes and coaches to warm the muscle ready for high-intensity performance. Because an increased muscle and core temperature comes as a result of a warm-up, the lack of such procedures used in previous research potentially inflates the precooling effect on actual competitive athletic performance. In the current study, significant reductions in T_{gi} in the ICE trial compared with CON were still evident following a warm-up, whereas the T_{gi} in the CON trial was significantly higher than baseline at the same time point.

Previously, it has been shown that by commencing exercise at a lower T_c, an increased intensity or duration of effort before a "critical" T_c is reached may result.[2,26] In the current study, T_c following ice ingestion was significantly lower compared with CON before 200 kJ of work had been achieved. Moreover, T_{gi} in the ICE trial was not considerably elevated compared with baseline until 300 kJ of work. It is interesting to note, however, that the split times and the MPO were not significantly higher during the early periods of the CTT when the reduced T_{gi} was most evident. This would suggest that the ICE consumption was not responsible for a change in pacing strategy early in the CTT performance. However, it was evident that the split times were significantly faster in the ICE trial during the latter stages of the CTT (900–1100 kJ), despite no significant differences in HR, T_{gi}, RPE or BLa measures compared with the CON trial. Such an outcome is consistent with Booth et al,[2] who reported a significant improvement in distance covered during a 30-min running trial in the heat (32°C, 60% RH) following precooling. Although these authors indicated a higher intensity was generally sustained throughout the 30 min, it was evident that a greater work output was achieved in the latter stages of the run (25–30 min), with no significant differences in T_c evident between the precooling and control groups.

The potential mechanism explaining this enhanced ability of ice to cool the body may be explained by the latent heat of fusion. The conversion of ice to a liquid form requires 333.55 $J \cdot g^{-1}$ of thermal energy.[12] As such, the consumption of ice before activity would draw this thermal energy from the core, thereby augmenting heat storage capacity and reducing the rise in T_c during the initial stages of activity. It is possible that this lower core body temperature may in turn result in an enhanced exercise performance as a result of a glycogen sparing effect since it has been shown that net muscle glycogen utilization is reduced when rises in T_c are attenuated during exercise,[27] and that high ambient temperatures can increase glycogen breakdown as a result of increases in T_c and circulating catecholamines.[28] Alternatively, it has also been suggested that hyperthermia leads to a failure in central activation, resulting in a marked reduction in the voluntary force development of a muscle.[29] This failure of the central nervous system to provide adequate drive results in an increased difficulty of the muscle to maintain its required power output.[30] With this in mind, it is possible that the reduced T_{gi} at the onset of the CTT in the ICE condition may have attenuated a reduced central drive, thereby avoiding the reduction in cycling power output toward the end of the exercise bout. Despite such proposed mechanisms of exercise performance enhancement as a result of precooling via crushed ice consumption, one should be mindful that the variables required to elucidate such conclusions from the present investigation were not assessed here, and as such these rationales remain speculative to the consumption of ice preexercise.

Practical Application

The results of this investigation have shown that precooling via crushed ice consumption can have a positive impact on cycling time-trial performance. The benefits of this method allow the athlete to cool and hydrate before competition, simultaneously. Furthermore, this method of precooling reduces the logistics of more conventional methods, allowing more effective preparation for the athlete and support staff. The results of this investigation however, are limited to male cyclists, and therefore future investigations should target team sport athletes.

Conclusion

The current study shows that crushed ice ingestion ($6.8\ g \cdot kg^{-1}$) is effective in lowering T_{gi} within a 30-min period. The effect upon T_{gi} was still evident following a light warm-up and transition period (15 min) before competitive activity. In addition, 40-km CTT performance was improved by 6.5% following crushed ice ingestion compared with ingesting water at 26.8 ± 1.3°C. A reduction in T_{gi} was evident in ICE compared with CON at the start of the CTT, which may have provided a greater heat storage capacity, resulting in an enhanced time trial performance. The mechanisms explaining this increased exercise performance as a result of ice consumption remain to be clarified.

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