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Original article

Comparison of the effects of cold water and ice ingestion on endurance cycling capacity in the heat

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Abstract

Purpose: The purpose of this study was to examine the effects of pre-cooling and fluid replacement with either crushed ice or cold water.
Methods: On 2 separate occasions, in a counterbalanced order, 9 recreationally-trained males ingested 1.25 g/kg (80–100 g) of either crushed ice (0.5°C) or cold water (4°C) every 5 min for 30 min before exercise. They also ingested 2.0 g/kg (130–160 g) of the same treatment drink at 15 min, 30 min, and 45 min after the commencement of cycling to exhaustion at 60%VO_{2max} until voluntary exhaustion in a hot environment (35°C and 30% relative humidity).
Results: The cycling time to exhaustion in the crushed ice trial (50.0 ± 12.2 min) was longer than the cold water trial (42.2 ± 10.1 min; $p = 0.02$). Although the rectal temperature fell by 0.37°C ± 0.03°C ($p = 0.01$) at the end of the resting period after the crushed ice ingestion, the rates of rise in rectal temperature during the exercise period were not significantly different between these 2 conditions (crushed ice: 0.23°C ± 0.07°C, 5 min; cold water: 0.22°C ± 0.07°C, 5 min; $p = 0.94$).
Conclusion: Crushed ice ingestion before and during exercise in a hot environment may be a preferred and effective approach for minimizing thermal strain, and for improving endurance performance as compared with cold water ingestion.

Keywords: Cold water ingestion; Pre-cooling; Rectal temperature; Thermoregulation

1. Introduction

A moderate elevation of the body core temperature (T_c) enhances exercise performance.[1] However, an excessive increase in the T_c results in a deterioration of exercise performance.[2,3] Numerous studies have reported that the attainment of a critical T_c is the main limiting factor inhibiting exercise performance,[4–6] as evidenced by a reduced central nervous system drive to the skeletal muscle[7] and other adverse effects, including cardiovascular strain and metabolic disturbances. Therefore, the development of hyperthermia is associated with an earlier voluntary termination during exercise performance.[4,8]

Several strategies, such as pre-cooling and water ingestion during exercise, have been proposed to improve exercise performance and prevent hyperthermia in hot environments.[9–11] The theoretical mechanism of pre-cooling is to reduce the T_c before exercise in the heat, thereby increasing the heat storage capacity and prolonging the duration before reaching a critical T_c.[9–11] The ingestion of ice, including ice slurry or crushed ice (ICE), appears to be an effective and practical method for lowering the T_c.[12–14] In particular, the reduction in the T_c resulting from ice ingestion may prevent the decline in the central neural drive that contributes to decreased performance in hot environments.[7,15]

Moreover, many studies have reported that internal cooling via fluid ingestion during exercise is effective for preventing hyperthermia, and for improving endurance performance in the heat.[16,17] The ingestion of ice during exercise also appears to be effective for cooling with respect to the T_c and for improving endurance performance.[18,19] Stevens et al.[19] showed that 10 g/kg body mass (BM) of ice slurry ingestion during the cycle leg of a simulated Olympic distance triathlon decreased the gastrointestinal temperature, and subsequently improved the 10 km running performance time by 2.5%.

The use of combined cooling methods with pre-cooling and fluid ingestion during exercise may increase the ergogenic benefits on performance via a decrease in thermoregulatory strain. Hasegawa et al.[20] reported that combined methods employing

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pre-cooling and water ingestion (14°C–16°C) during exercise widened the thermoregulatory margin before the critical T_c, thus enhancing exercise capacity in a hot environment. Lee et al.[21] reported the effects of cold (4°C) *vs.* warm (37°C) water ingestion before and during exercise on cycling performance in hot, humid conditions. In that study, cold water ingestion reduced the rectal temperature (T_{re}) by 0.5°C ± 0.1°C before exercise and significantly increased the cycling time to exhaustion (TTE) by 23% ± 6% as compared to warm water. However, thus far, there has been no direct comparison of the effects of both pre-cooling and fluid ingestion during exercise with ice *vs.* cold water during exercise. Combining both solid and liquid H_2O into a ICE solution has the added heat sink benefit requiring the heat capacity from both the solid and liquid H_2O, as well as the enthalpy of fusion required for the phase change, and provides a far greater cooling effect than water at a similar temperature.[22] The sum of these thermodynamic properties in a ICE mixture results in a larger heat storing capacity than liquid H_2O alone (cold water, CW).

The purpose of the present study was therefore to investigate the effects of the ingestion of ICE before and during exercise on exercise capacity and thermoregulatory responses as compared with CW. We hypothesized that ingesting ICE before and during exercise would reduce the T_{re} before and during exercise, and hence improve exercise capacity as compared with CW ingestion.

2. Methods

2.1. Participants

Nine non-heat-acclimatized, physically active male recreational cyclists (age = 23 ± 4 years, height = 1.72 ± 0.06 m, BM = 64.0 ± 9.6 kg, maximal oxygen uptake (VO_{2max}) = 47.7 ± 8.7 mL/kg/min) were recruited for this study. All participants were non-smokers, normotensive, free from any known autonomic dysfunction or cardiovascular disease, and were not taking any medications. The study protocol was approved by the Ethics Committee of Human-Environment Studies, Kyushu University, Japan, and all participants gave their written informed consent prior to commencing the study.

2.2. Preliminary measurements

In order to determine the VO_{2max}, on the first visit to the laboratory, each participant performed a progressive exercise test on a cycle ergometer (Ergomedic 828 E; Monark, Varberg, Sweden) at room temperature (25°C and 50% relative humidity (RH)). Their height and BM were measured to the nearest 0.1 cm and 10 g (TBF-210, Tanita Co., Tokyo, Japan), respectively. The protocol consisted of progressive exercise beginning at 90 W for 3 min, followed by increments of 30 W every 3 min until volitional exhaustion.[23] Respiratory gases were measured every 30 s during the test using a pre-calibrated automatic gas analyzer (AE-310s; Minato Medical Science, Tokyo, Japan). The heart rate (HR) was monitored continuously via telemetry using an HR monitor (DS-3140; Fukuda Denshi, Tokyo, Japan). The test was considered to be valid if 2 of the following 3 criteria were met: (1) oxygen consumption reached a plateau, (2) HR remained within 10% of the predicted maximum (220 − age), or (3) the respiratory exchange ratio was above 1.05.[23] On the second visit, between 4 and 14 days later, the participants performed a familiarization trial involving cycling to exhaustion at an intensity of 60%VO_{2max} in the same hot environment as the experimental trials.[4,14,21]

2.3. Experimental trials

In a randomized counterbalanced design, the participants performed 2 trials, ingesting either ICE or CW. During the 24 h period before the experimental trial, the participants were instructed to avoid strenuous exercise, as well as the consumption of alcohol, caffeine, nonsteroidal anti-inflammatory drugs, and nutritional supplements. All participants completed a diary that was replicated prior to the second trial. Each participant arrived at the laboratory after having refrained from eating for 6 h and drinking any type of beverage for 2 h. They were instructed to drink 500 mL of plain water 2 h before all tests to help promote euhydration prior to the start of each trial. For each participant, the 2 trials were commenced at the same time in the afternoon to control for circadian variations in the T_c, separated by 4–14 days.

Upon arrival at the laboratory, the participants' height and BM were recorded before they entered a climate-controlled room (35°C and 30% RH). A rectal thermistor (ITP010-11; Nikkiso-Therm Co., Ltd., Tokyo, Japan) was inserted approximately 15 cm into the rectum. Three skin thermistors were affixed using hypoallergenic polyacrylate adhesive tape (ITP082-24; Nikkiso-Therm Co., Ltd.) at the left rectus femoris, forearm, and sternum. An HR monitor was then fixed to each participant's chest before a 5-min rest period to gather baseline data.

ICE was made using a commercially available food blender (TM8100; Tescom Co., Ltd., Tokyo, Japan). The participants were given 1.25 g/kg BM of ICE (0.5°C) or CW (4°C) every 5 min for 30 min to ensure a standardized ingestion rate.[13,14] The participants then mounted the cycle ergometer to start the cycling exercise at an intensity equivalent to 60%VO_{2max} until voluntary exhaustion, approximately 5 min after fully ingesting the last drink. The participants were asked to maintain a pedal cadence of 60 rev/min throughout the exercise. Exhaustion was defined as being unable to maintain 60 rev/min for 10 s. The participants subsequently ingested 2.0 g/kg BM of the same treatment drink at 15 min, 30 min, and 45 min after the commencement of the exercises. After the exercise period, the participants dried themselves with a towel and were weighed again to determine their BM.

2.4. Measurements

The VO_2 was measured at 9–14 min, 24–29 min, and 39–44 min during the exercise. The HR was monitored continuously throughout the trial, and reported as the average for each 5 min interval. Throughout the 2 trials, the T_{re} and skin temperature (T_{sk}) were recorded continuously via a data logger (N542R; Nikkiso-Therm Co., Ltd.) and logged intermittently at 30 s intervals. The mean T_{sk} was calculated using the formula from Roberts et al.:[24] $T_{sk} = 0.43 \times (T_{chest}) + 0.25 \times (T_{arm}) + 0.32 \times (T_{thigh})$. The mean body temperature (T_b) was calculated using the formula from Colin et al.:[25] $\triangle T_b = 0.8 \times (\triangle T_{re}) + 0.2 \times (\triangle T_{sk}) + 0.4$. Heat storage was calculated at 5 min increments using the formula described by Adams et al.:[26] heat storage $= 0.965 \times m \times \triangle T_b/AD$, where 0.965 is the specific heat storage capacity of the body (W/kg/°C), m is the mean body mass (kg) over the duration of the trial, and AD is the body surface area (m^2): $AD = 0.202 \times m^{0.425} \times height^{0.725}$.[27] A rating of the subjective thermal sensation[28] (RTS; 9-point scale ranging from 1 = *very cold* to 9 = *very hot*) was recorded every 5 min throughout each trial, while a rating of the perceived exertion[29] (RPE; 20-point scale) was recorded every 5 min during exercise.

2.5. Statistical analysis

All statistical computations were performed using the IBM SPSS Statistics Version 21.0 software package (IBM Corp., Armonk, NY, USA). A two-way (Drink × Time) repeated-measures ANOVA was performed to compare the changes in the T_{re}, T_{sk}, HR, RPE, and RTS between the experimental conditions. The BM, TTE, heat storage, VO_2, and physiological variables at exhaustion between the 2 experimental conditions were examined using a *t* test. When a significant main effect or interaction effect was identified, the differences were delineated using a Bonferroni adjustment. The VO_2 at 39–44 min was not analyzed, because 4 participants in the CW trial reached exhaustion before 45 min. For all comparisons, significance was set at a *p* value <0.05. All figures represent means ± SEM for clarity of presentation, and all other data are presented as the mean ± SD.

3. Results

The volume of beverage consumed during the pre-exercise period was 480 ± 72 g for all treatments, and the volume of beverage consumed during exercise was 316 ± 67 g for all treatments. There were no significant differences in the pre-exercise measurements of the BM between the ICE (64.0 ± 9.7 kg) and CW (64.2 ± 9.4 kg) trials. At the conclusion of the TTE, the BM values were significantly lower in both the ICE (62.2 ± 9.0 kg, $p = 0.001$) and CW (62.5 ± 8.7 kg, $p = 0.001$) trials. However, the loss of BM did not differ significantly between the 2 conditions ($p = 0.690$).

3.1. Cycling TTE

The cycling TTE findings for all participants are shown in Fig. 1. Eight of the 9 participants cycled for a longer time in the ICE trial as compared to the CW trial (50.0 ± 12.2 min *vs.* 42.2 ± 10.1 min, $p = 0.02$).

3.2. T_{re} and T_{sk}

There were no significant differences in T_{re} between the 2 conditions from 35 min (ICE: 37.09°C ± 0.28°C; CW: 37.20°C ± 0.18°C) to 15 min prior to exercise (Fig. 2A).

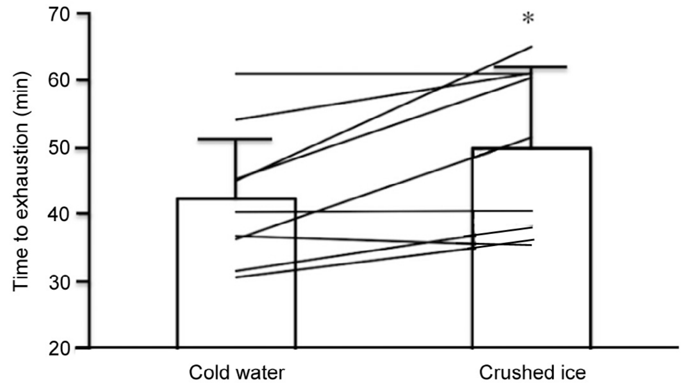

Fig. 1. Cycling time to exhaustion under the 2 experimental conditions. The lines denote the raw data from individual participants ($n = 9$). *$p < 0.05$.

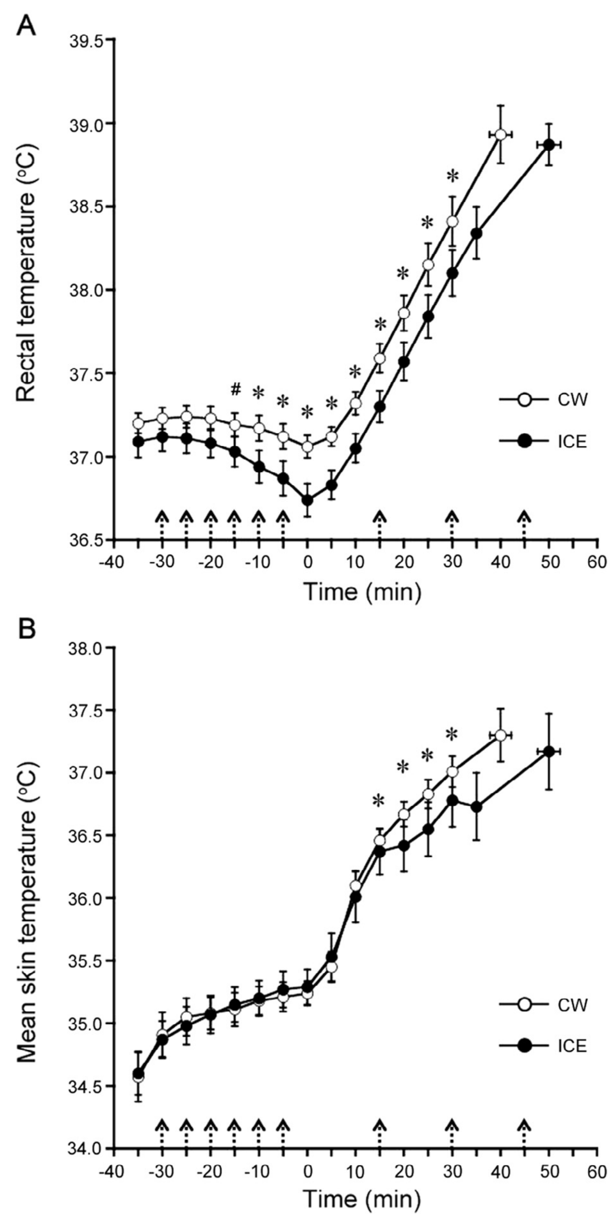

Fig. 2. Rectal temperature (A) and mean skin temperature (B) under the 2 experimental conditions. The arrows denote when the drink was ingested. The values are expressed as means ± SEM of all 9 participants. Time × Drink effect ICE *vs.* CW: *$p < 0.05$, #$p < 0.10$. CW = cold water; ICE = crushed ice.

However, the ingestion of the ICE caused the T_{re} to fall by 0.37°C to 36.74°C ($p = 0.001$). Consequently, the T_{re} before the start of exercise was 0.32°C ± 0.09°C lower after ICE ingestion than after CW ingestion ($p = 0.01$). The T_{re} increased progressively in both ICE and CW trials during exercise, but remained lower in the ICE trial for the first 30 min of exercise ($p = 0.001$). The rate of rise in the T_{re} during exercise was not significantly different between the 2 conditions (ICE: 0.23°C ± 0.07°C, 5 min; CW: 0.22°C ± 0.07°C, 5 min; $p = 0.942$). At exhaustion, the T_{re} was not significantly different between the 2 conditions (ICE: 38.87°C ± 0.38°C; CW: 38.93°C ± 0.52°C; $p = 0.575$). No significant differences in the T_{sk} were observed between the conditions at rest ($p = 0.868$; Fig. 2B). During the pre-exercise period, the T_{sk} increased from 34.87°C ± 0.45°C to 35.29°C ± 0.42°C in the ICE trial, and from 34.91°C ± 0.53°C to 35.24°C ± 0.29°C in the CW trial ($p = 0.002$). The rate of rise in the T_{sk} at 15–30 min during exercise was significantly slower after the ingestion of ICE *vs.* CW (0.14°C ± 0.01°C, 5 min *vs.* 0.18°C ± 0.01°C, 5 min; $p = 0.005$). However, there were no significant differences in the T_{sk} between the 2 conditions either prior to the commencement of exercise or during exercise.

3.3. Heat storage

Heat storage in the ICE (−5.52 ± 2.25 W/m^2) trial during the 30 min pre-exercise period was lower than that observed in the CW trial (−1.46 ± 1.22 W/m^2, $p = 0.01$). During exercise, the amount of heat stored was not significantly different between the ICE (67.53 ± 5.94 W/m^2) and CW (68.76 ± 6.76 W/m^2) trials, including that noted at exhaustion.

3.4. RTS, RPE, and perceptual responses

Measurements of the RTS and RPE are presented in Fig. 3. There were no significant differences in the RTS between the ICE (6.0 ± 0.9) and CW trails (6.3 ± 1.0) at rest. However, the RTS in the ICE trial decreased significantly from 20 min prior to exercise to the first 5 min of exercise, as compared with that observed in the CW trial ($p < 0.05$). Both RTS and RPE increased significantly ($p = 0.001$) during exercise. The RPE in the ICE trial tended to be lower than those noted in the CW trial for the first 5 min of exercise ($p = 0.07$). The RTS and RPE at exhaustion were similar between the ICE and CW trials ($p = 1.00$). In the pre-exercise period, 3 of the 9 participants experienced headaches while consuming ICE, whereas none experienced this symptom with CW ingestion. No participants reported any headaches or gastrointestinal discomfort during either trial when exercising.

3.5. VO_2 and HR

There were no significant differences in the VO_2 between the 2 conditions during the first 9–14 min (ICE: 34.5 ± 5.5 mL/kg/min; CW: 33.3 ± 5.5 mL/kg/min) and at 24–29 min (ICE: 32.0 ± 5.0 mL/kg/min; CW: 32.2 ± 5.9 mL/kg/min). The HR values are shown in Fig. 4. The HR did not differ significantly between the 2 conditions in the rest period (ICE: 72 ± 5 bpm; CW: 74 ± 6 bpm, $p = 0.309$) and the commencement of exercise (ICE: 70 ± 9 bpm; CW: 72 ± 6 bpm,

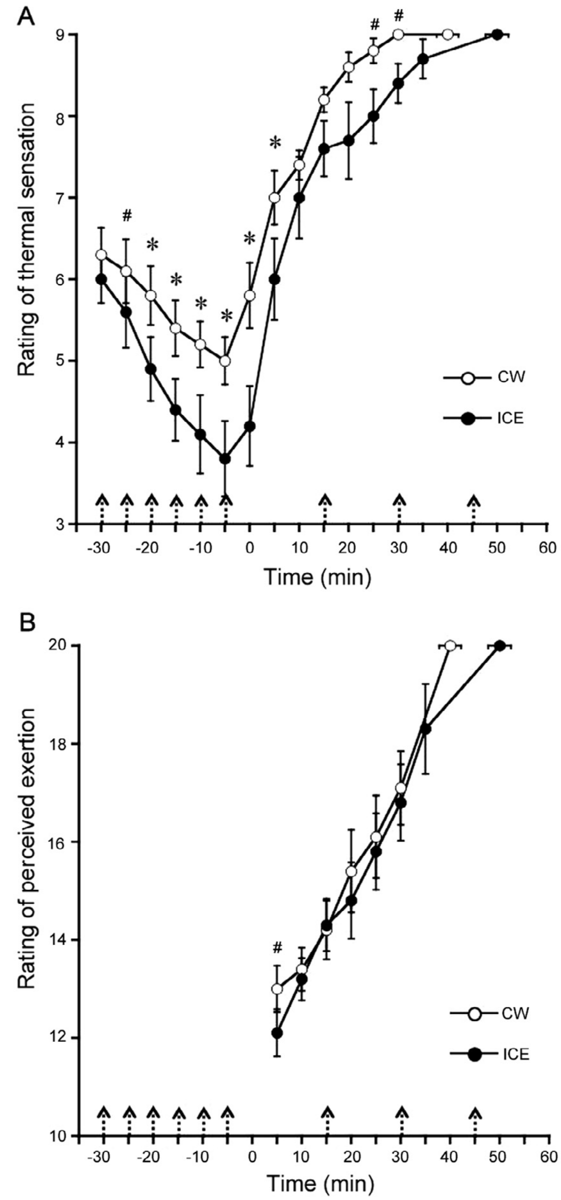

Fig. 3. Rating of the thermal sensation (A) and perceived exertion (B) under the 2 experimental conditions. The arrows denote when the drink was ingested. The values are expressed as means ± SEM of all 9 participants. Time × Drink effect ICE *vs.* CW: *$p < 0.05$, $^{\#}p < 0.10$. CW = cold water; ICE = crushed ice.

$p = 0.215$). The HR increased continuously ($p = 0.001$) during exercise, but was unaffected by the beverage type ($p = 0.398$). At exhaustion, the HR was similar between the ICE (191 ± 7 bpm) and CW (189 ± 5 bpm) conditions (Fig. 4).

4. Discussion

The main findings of the present study are as follows: 1) The ingestion of ICE rather than a cold drink before and during prolonged cycling exercise resulted in a longer cycling TTE (by 7.8 min: 16%) in a hot environment; 2) ICE ingestion before exercise reduced the T_{re} as compared with CW.

In the present study, the ingestion of ICE (0.5°C) reduced the T_{re} by 0.32°C as compared with CW ingestion before the start

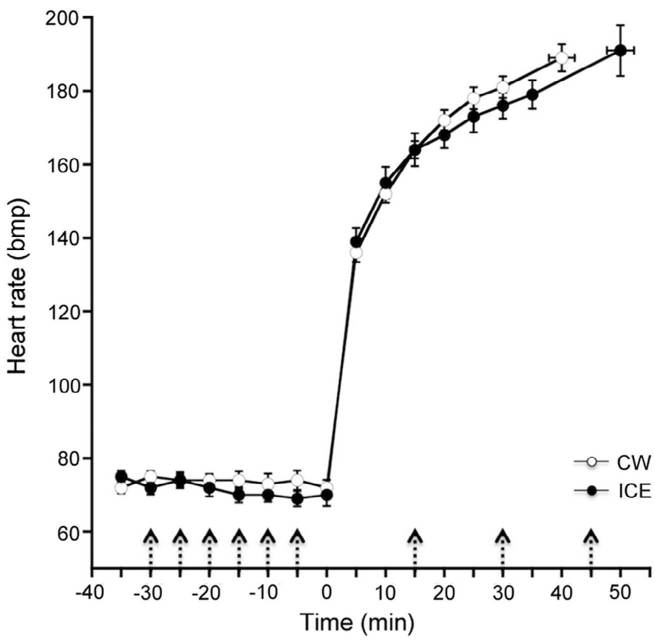

Fig. 4. Heart rate under the 2 experimental conditions. The arrows denote when the drink was ingested. The values are expressed as means ± SEM of all 9 participants. CW = cold water; ICE = crushed ice.

of exercise in the heat. This result is consistent with the findings of previous studies showing that ice ingestion provided internal pre-cooling, which effectively reduced the T_c as compared with CW ingestion.[12–14,23] Siegel et al.[13] observed that the pre-exercise ingestion of an ice slurry (−1°C) reduced the T_{re} by 0.32°C as compared with CW ingestion before the start of exercise in the heat. Similarly, Ihsan et al.[12] found that the pre-exercise ingestion of ICE (1.4°C) reduced the gastrointestinal temperature by 1.1°C as compared with tap water ingestion in a hot environment (30°C and 74%HR). Additionally, Stanley et al.[23] reported that consuming an ice-slush (−0.8°C) during recovery from 75 min of steady-state cycling exercise decreased the T_{re} by 0.4°C more than cool fluid ingestion. This enhanced ability of ice to cool the body may be explained by the latent heat of fusion.[22] Moreover, there were no significant differences in the T_{sk} and BM between the 2 conditions in the present study; therefore, it is difficult to determine whether these changes can be attributed to water or heat loss. Hence, it is possible that the delayed attainment of the critical T_c and the increased cycling time found using ICE greatly enhanced the heat sink effect as compared with CW ingestion.

Differences in the rate of rise in the T_{re} between the 2 conditions may influence the time required to attain the critical T_c and, in turn, the end point of exercise. In the present study, the rate of rise in the T_{re} during exercise was not significantly different between the 2 conditions (ICE: 0.23°C, 5 min; CW: 0.22°C, 5 min; $p = 0.942$). This finding does not concur with the current literature. Siegel et al.[13] reported that the ingestion of ice slurry before exercise tended to increase the rise in T_{re} during exercise as compared with CW ingestion, despite the decrease in the T_{re} prior to the commencement of exercise. Other previous studies have reported that the rate of rise in the T_{re} tends to be higher following the ingestion of ice slurry as compared with CW.[14,23] It is possible that the lower T_{re} observed during exercise in the ICE trial may be explained by the decreased rate of rise in the T_{sk} achieved with ICE ingestion during exercise. A decreased rate of rise in the T_{sk} results in a higher core-to-skin temperature gradient, leading to a slower rise in the T_{re} during exercise.[14] Burdon et al.[18] reported that the T_{sk} during exercise tended to be lower following the ingestion of 3.5 g/kg BM ice slurry every 15 min during exercise. Indeed, the rate of rise in the T_{sk} at 15–30 min intervals during exercise in the present study was significantly slower after the ingestion of ICE *vs.* CW (0.14°C, 5 min *vs.* 0.18°C, 5 min; $p = 0.005$). Therefore, the present results suggest that the ingestion of ICE before and during exercise may reduce the pre-exercise T_{re}, as well as maintain a lower T_{re} during exercise.

It is generally accepted that the attainment of a high T_c may contribute to the subjective decision to terminate endurance exercise in the heat.[4] Therefore, we used the TTE to investigate the attainment of a critical T_{re}. González-Alonso et al.[4] demonstrated that well-trained participants (VO_{2max} = 65.8 mL/kg/min) fatigued at the same esophageal temperature (40.1°C) at the end of cycling at 60%VO_{2peak} in a hot environment (40°C), despite any differences in the initial esophageal temperature (35.9°C *vs.* 37.4°C) induced by immersing the participants in water of different temperatures for 30 min. Although the T_{re} of the participants at exhaustion in the present study did not reach 40°C, Cheung and McLellan[30] showed that untrained participants (VO_{2max} < 50.0 mL/kg/min) were exhausted when their T_{re} reached 38.7°C. The authors reported that the critical limiting temperature may be associated with the level of aerobic fitness. Therefore, in the present study, considering the participant's VO_{2max} (47.7 mL/kg/min), we hypothesized that the T_{re} at exhaustion reached the critical T_c between the 2 conditions.

Consuming larger volumes of fluid may cause gastrointestinal discomfort in some athletes. Byrne et al.[31] reported that ingesting 900 mL of CW (2°C) over 35 min in the pre-exercise period produced a mean 0.4°C reduction in the T_{re} at the start of exercise and resulted in a lower T_{re} during exercise than did the ingestion of warm water (37°C). Previous studies have also demonstrated that ingesting CW before exercise reduces the Tre by 0.4°C–0.6°C as compared with warm water (37°C).[21,31] In the present study, we provided the participants with a total volume of approximately 500 g of ICE to consume during the pre-exercise period in a hot environment, which subsequently reduced the T_{re} by 0.32°C as compared with CW ingestion. Previous studies provided participants with approximately twice the total volume of beverage to consume than that used in the present study. Hence, ICE may serve as a practical pre-cooling maneuver during cycling-based exercise, as ingesting small volumes of ICE was more effective in decreasing the T_{re} than ingesting CW, and was not associated with any gastrointestinal discomfort.

There were also no significant differences in the VO_2 or HR during exercise between the 2 trials. This result is consistent with previous studies which reported that the use of ice ingestion to provide internal pre-cooling does not reduce the VO_2 or HR as compared with CW ingestion. These data suggest that

ICE ingestion has no effect on any markers of physiological intensity.

One limitation of the present study is that we cannot rule out whether the placebo effect is responsible for the increase in exercise capacity. Due to the inability to blind pre-cooling research using a true placebo, the participant's expectations of a beneficial effect from using pre-cooling in hot conditions cannot be eliminated. A further limitation of this study is related to the use of a time to exhaustion protocol. We used a time to exhaustion protocol to assess the attainment of a critical T_{re}. Further study is needed to examine the results of performance tests that are more ecologically valid (i.e., discrete tests set for time or distance). Finally, the sample used in the present study is not representative of participants who would potentially undertake prolonged exercise during hyperthermic conditions. Further research should recruit highly fit individuals or elite athletes. Although the current participants appeared to give their full effort, a highly fit group would be more appropriately motivated to exercise, in addition to having the ability to reach a greater core temperature.[32]

5. Conclusion

The present study demonstrated that ICE ingestion before and during exercise in a hot environment effectively increases the endurance cycling time as compared with CW ingestion. In addition, ICE ingestion reduced the pre-exercise T_{re} and attenuated the increase in the T_{re} that occurs during exercise in a hot environment. A reduction in the T_{re} at the start of the TTE and the lower T_{re} observed during TTE were evident in the ICE trial as compared with CW, which may have resulted in a greater heat storage capability, thereby improving exercise capacity. The ingestion of ICE before and during exercise in the heat may be a preferred and effective approach for minimizing thermal strain and for improving exercise capacity.

Authors' contributions

TN carried out the studies of concept, conceived of the study, participated in its design, performed the statistical analysis, and drafted the manuscript; TO participated in the study design and helped to draft the manuscript. Both authors read and approved the final manuscript, and agree with the order of presentation of the authors.

Competing interests

Neither of the authors declare competing financial interests.

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