The Effects of Differences in the Timing of Ice Ingestion before Exercise on Endurance Cycling Capacity, Body Temperature and Perceptual Sensation in the Heat*

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The timing at which ice is ingested prior to exercise may be important for optimizing internal pre-cooling effects. However, previous reports have not evaluated the influence of timing of ice ingestion on internal pre-cooling in the heat. The purpose of this study was to investigate the effects of differences in the timing of ice ingestion on endurance cycling capacity, body temperature and perceptional sensation in the heat. Seven healthy males [age = 26 ± 2 yr, height = 1.71 ± 0.04 m, body mass = 63.6 ± 2.8 kg, body surface area = 1.74 ± 0.03 m², maximal oxygen uptake (VO₂max) = 49.7 ± 4.4 mL·kg⁻¹·min⁻¹] ingested ice for 30 minutes before exercise under three separate conditions: ice ingestion at 30- (30D), 15- (15D) and 5- (5D) minute intervals. The total volume of ice ingestion was identical during 30D, 15D, 5D and was divided equally by the number of drinking times in each experiment. Subjects performed cycling to exhaustion at 70%VO₂max in a hot environment (35°C room temperature and 30% relative humidity). Rating of thermal sensation was lower in 5D at 15 min period during exercise than those under the other conditions (p < .05). Rating of perceived exertion was lower in 5D at 20 and 25 min periods during exercise than those under the other conditions (p < .05). There were no significant differences in rectal temperature, mean skin temperature or exhaustion time between the three conditions. These results suggest that there are no significant differences in exhaustion time and rectal temperature if the total volume of ice ingestion is identical, although the ice ingestion until just before exercise attenuated the perceptual sensation during exercise in a hot environment.

Keywords: internal cooling; pre-cooling; rectal temperature

1. Introduction

An excessive increase of body temperature leads to deterioration of exercise performance and the development of life-threatening heat disorders (Galloway and Maughan, 1997; Parkin et al., 1999). González-Alonso et al. (1999) investigated the effects of differences in core temperature (Tc) before the start of exercise on endurance exercise capacity in the heat. They allowed trained participants to perform cycling exercise until voluntary exhaustion after pre-cooling or pre-heating in a hot environment (40°C), and found that the exercise time of the participants in hot environments was inversely related to their initial body temperature due to fatigue at an identical temperature level (esophageal temperature: Tes = 40.1-40.2°C). Fatigue was also observed to occur in rats at the same temperature level (Fuller et al., 1998; Walters et al., 2000). Marino et al. (2004) called this the “critical limiting temperature” —the point at which hyperthermia jeopardizes homeostasis. Nielsen et al. (2001) investigated the effects of temperature on the central nervous system and measured the Tes and electroencephalographic activity in the frontal cortex of the brain when participants performed cycling at 60% maximal oxygen uptake.
(\(\dot{V}\text{O}_2\text{max}\)) in a hot or a cool environment. The arousal level, as assessed by the \(\alpha/\beta\) spectrum power ratio, was not significantly different when participants performed exercise in a cold environment but was attenuated by an increase in the Tes when participants performed exercise in a hot environment. Nybo and Nielsen (2001b, 2001c) reported that exercise-induced hyperthermia in a hot environment resulted in a reduction of mean blood velocity in the middle cerebral artery and an increased rating of perceived exertion (RPE) during exercise. They also allowed the participants to perform 2 min of sustained maximal voluntary extension (MVC) with their knees immediately after their Tc had increased to 40°C (hyperthermia trial), and also at 38°C (control trial) (Nybo and Nielsen, 2001a). The maximal voluntary isometric contraction and voluntary activation level (MVC/MVC + electrical stimulation) were significantly lower in the hyperthermic subjects than in the controls. In contrast, the total force of the knee extensors (MVC + force from electrical stimulation) did not differ between the two trials. One of the factors that decreased the contraction force in the hyperthermic subjects may not have been associated with the periphery (muscles) but rather with central activation. Thus, central fatigue may be a limiting factor in exercise performance and may elicit an increase of brain temperature, thus potentially compromising exercise performance. Accordingly, several strategies, such as pre-cooling, have been proposed to prevent hyperthermia and improve exercise performance in hot environments (Marino, 2002; Siegel and Laursen, 2012).

Internal cooling by ice ingestion, including the consumption of ice slurry and crushed ice, has been the focus of recent studies. Siegel et al. (2010) showed that ingestion of 7.5 g \(\cdot\) kg body mass (BM)\(^{-1}\) of ice slurry (−1°C) was able to significantly reduce the rectal temperature (Tre) by 0.66°C, enhance the running time to exhaustion at the first ventilator threshold by 19%, and improve the rating of thermal sensation (RTS) and RPE in comparison to ingestion of cold water (4°C). Ihsan et al. (2010) found that pre-exercise ingestion of 6.8 g \(\cdot\) kgBM\(^{-1}\) of crushed ice (1.4°C) reduced the gastrointestinal temperature by 1.1°C and that a 40-km cycling time-trial was improved by 6.5% in comparison to subjects who ingested tap water (26.8°C) in a hot environment (30°C and 74% relative humidity (RH)). These previous studies suggested that the reduction in Tc achieved by ice ingestion may prevent the increase in RTS and RPE, which contributes to decreased performance in hot environments.

Siegel and Laursen (2012) reported that the ambient temperature, and the volume and timing of ice ingestion, might affect the magnitude of internal cooling. Regarding the ambient temperature, Siegel et al. (2010) observed a 0.66°C reduction in Tre after ingestion of 7.5 g \(\cdot\) kgBM\(^{-1}\) of ice in a thermoneutral environment. In a subsequent study, they reported that ingesting the same volume of ice in a hot environment reduced the Tre by 0.43°C. It is possible that ice ingestion may have a greater capacity to reduce the surface temperature of the body in environments with lower ambient temperatures. With regard to ingestion volume, Ross et al. (2011) had participants consume ice in a hot environment and found that ingestion of 500 g and 1 kg of ice resulted in Tre reductions of 0.25°C and 0.60°C, respectively. Their data suggested that drinking larger volumes may be more effective for reducing the Tc.

The timing of ice ingestion prior to exercise may be important for optimizing internal pre-cooling effects (Siegel et al., 2012; Stanley et al., 2010). However, previous reports have not evaluated the influence of timing of ice ingestion for internal pre-cooling on endurance performance and body temperature in the heat. Therefore, the purpose of the present study was to investigate the effects of differences in the timing of ice ingestion on endurance cycling capacity, body temperature and perceptual ratings in the heat.

2. Methods

2.1. Participants

Seven non-heat-acclimatized, physically active male recreational cyclists (age = 26 ± 2 years, height = 1.71 ± 0.04 m, BM = 63.6 ± 2.8 kg, body surface area (AD) = 1.74 ± 0.03 m\(^2\), \(\dot{V}\text{O}_2\text{max} = 49.7 ± 4.4\) mL \(\cdot\) kg\(^{-1}\) \(\cdot\) min\(^{-1}\)) were recruited for this study. All of the participants were normotensive non-smokers, who were free from any known autonomic dysfunction or cardiovascular disease and who were not taking any medications. During the 24-h period prior to conducting our trials, each participant was asked to keep his normal lifestyle activities at a stable level, including physical activity, and to avoid consuming alcohol, caffeine and nutritional supplements. The
participants had previously experienced exercise stress tests, including measurement of maximal oxygen uptake and ergometry. The study protocol was approved by the Ethics Committee for Human-Environment Studies, Kyushu University, Japan (Approval number: 201402). All of the participants provided written informed consent prior to commencement of the study.

2.2. Maximal oxygen uptake (\(\dot{V}O_2\max\)) test

In order to determine the \(\dot{V}O_2\max\), each participant performed a progressive exercise test on a cycle ergometer (Ergomedic 828 E; Monark, Varberg, Sweden) at room temperature (25°C and 50% RH) on their first visit to the laboratory. They arrived at the laboratory 30 min before the test after having refrained from eating for 2 h. Their height and BM were measured to the nearest 0.1 cm and 10 g, respectively (TBF-210; Tanita Co., Tokyo, Japan). 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. Respiratory gases were measured every 30 s during the test using a pre-calibrated automatic gas analyzer (AE-310s; Minato Medical Science, Tokyo, Japan), which were proofread standardized gases (\(O_2: 15.1\%, \ CO_2: 5.05\%\)). The heart rate (HR) was continuously monitored via telemetry using an HR monitor (DS-3140; Fukuda Denshi, Tokyo, Japan). The test was considered to be valid if two of the following three criteria were met: (1) oxygen consumption reached a plateau, (2) the subject’s HR remained within 90% of the predicted maximum (220-age), or (3) the respiratory exchange ratio was above 1.05.

2.3. Experimental protocol

The participants performed three trials, ingesting 7.5 g · kgBM\(^{-1}\) of ice in a single bolus for 30 min before exercise (30D), 3.75 g · kgBM\(^{-1}\) of ice in two boluses every 15 min for 30 min before exercise (15D), and 1.25 g · kgBM\(^{-1}\) of ice in six boluses every 5 min for 30 min before exercise (5D) in a heat chamber (35°C, 30% RH; Figure 1).

Each participant arrived at the laboratory after having refrained from eating for 6 h and drinking any type of beverage for 2 hours. 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. A urine sample was collected,
after which the height and BM of the subjects were recorded. A disposable rectal thermistor was then self-inserted approximately 100-150 mm into the rectum. Three skin thermistors were affixed using hypoallergenic polyacrylate adhesive tape (ITP082-24; Nikkiso-Therm Co., Ltd., Tokyo, Japan) at the left rectus femoris, forearm and sternum. The subjects then entered a climate-controlled room (35°C and 30% RH), and performed one of three experiments before a 5-min rest period to gather baseline data.

The ice drinks were made using a commercially available food blender (TM8100; Tescom Co., Ltd., Tokyo, Japan). The participants then mounted the cycle ergometer to start the cycling exercise at an intensity equivalent to 70% VO2max until voluntary exhaustion, approximately 5 min after fully ingesting the last drink. They were asked to maintain a pedal cadence of 60 rev·min⁻¹ throughout the exercise. Exhaustion was defined as being unable to maintain a cadence of 60 rev·min⁻¹ for 10 s. After the exercise period, the participants dried themselves with a towel and were weighed again to determine their BM before collection of a final urine sample. The experiments were performed using a randomized counterbalanced design, at the same time of day, with a period of more than 4 days between experiments.

2.4. Measurements

Urine samples were measured to evaluate the hydration status of the subjects in terms of urine specific gravity (USG). USG was determined using an analog USG scale (Atago, Japan). The HR of the subjects was monitored continuously throughout the trial using a HR monitor (DS-3140; Fukuda Denshi, Tokyo, Japan), and reported as the average for each 30-s interval. The VO2 was measured continuously using a pre-calibrated automatic gas analyzer, and was reported as the average for each 30-min interval. Throughout the three trials, the Tre and skin temperature were continuously recorded using a data logger (N542R; Nikkiso-Therm Co., Ltd.) and intermittently logged at 5-min intervals. The rate of Tre increase during exercise was calculated at 5-min intervals until exhaustion. The mean skin temperature (Tsk) was calculated using the formula of Roberts et al. (1977): Tsk = 0.43 × (chest temperature) + 0.25 × (arm temperature) + 0.32 × (thigh temperature).

The mean body temperature (Tb) was calculated using Hardy and DuBois’s formula: Tb = 0.8 × (Tre) + 0.2 × (Tsk) (Hardy and DuBois, 1938). AD, which is the body surface area (m²), was calculated as: AD = 0.202 × BM⁰.⁴²⁵ × height⁰.⁷²⁵ (Du Bois & Du Bois, 1989). Total sweat loss was calculated using the following formula: (BM before the experiment —BM after the experiment) + the volume of drink ingested. A rating of thermal sensation (RTS; 9-point scale ranging from 1 = “very cold” to 9 = “very hot”) was recorded every 5 min throughout each of the trials (Kashimura, 1986), while a rating of perceived exertion (RPE; 15-point scale) was recorded every 5 min during exercise using the Onodera and Miyashita scale (Onodera and Miyashita, 1976), which is a translation of the Borg scale (Borg, 1973). In each trial, gastrointestinal discomfort (5-point scale ranging from 1 = “stomach: not upset” to 5 = “stomach: very upset”) was recorded after fully ingesting the last drink (Murray et al. 1989).

2.5. Statistical analysis

All of the statistical analyses were performed using the IBM SPSS statistics 21 software package (SPSS, Inc., Chicago, IL, USA). BM, USG, TTE, total sweat loss and physiological variables at exhaustion under the three experimental conditions were examined using one-way repeated-measures ANOVA. Two-way (drink × time) repeated-measures ANOVA was used to compare the changes in Tre, Tsk, HR, RTS, and RPE under the three experimental conditions. When a significant main effect or interaction effect was identified, the differences were delineated using Bonferroni adjustment. P values of < .05 were considered to indicate statistical significance in all of the comparisons. All values represent means ± SD.

3. Results

The total volume of ice ingested was identical during the 30D, 15D and 5D experiments. The volumes of ice consumed in the 30D, 15D and 5D experiments were 477 ± 21 mL, 238 ± 11 mL, and 80 ± 4 mL in 5D, respectively, and the corresponding times spent consuming the ice were 4.6 ± 2.5 min, 3.4 ± 1.3 min, and 1.5 ± 0.9 min, respectively.

BM, USG, total sweat loss, exhaustion time and gastrointestinal discomfort under the three condi-
Table 1  Mean ± SD of body weight, urine specific gravity, total sweat loss, exhaustion time and gastrointestinal discomfort under three conditions.

| Condition | Pre Exercise | Post Exercise | Pre Exercise | Post Exercise | Pre Exercise | Post Exercise |
|-----------|--------------|---------------|--------------|---------------|--------------|---------------|
| Body weight (kg) | 63.5 ± 2.4 | 63.0 ± 2.5* | 63.4 ± 2.7 | 62.7 ± 3.0* | 63.5 ± 2.7 | 62.7 ± 2.6* |
| Urine specific gravity | 1.013 ± 0.005 | 1.016 ± 0.005 | 1.014 ± 0.006 | 1.020 ± 0.007* | 1.015 ± 0.008 | 1.018 ± 0.009* |
| Total sweat loss (ml) | 976 ± 306 | 1020 ± 351 | 1272 ± 357 |
| Exhaustion time (min:sec) | 31:37 ± 6:48 | 31:19 ± 2:15 | 34:19 ± 5:47 |
| Gastrointestinal discomfort | No subjects reported any gastrointestinal discomfort during or after crushed ice ingestion. |

* Pre vs Post (p < .05)

Figure 2  The oxygen uptake (A) and heart rate (B) under the three experimental conditions. The mean values are expressed as mean ± SD of seven participants (30D: ○, 15D: ●, 5D: ◇). There were no significant differences in the oxygen uptake and heart rate between conditions.

Figure 3  The rectal temperature (A), mean skin temperature (B), and mean body temperature (C) under the three experimental conditions. The mean values are expressed as mean ± SD of seven participants (30D: ○, 15D: ●, 5D: ◇). Time × Drink effect 30D vs 15D: p < .05, 30D vs 5D: # p < .05. **, p < .05 compared with baseline in 30D; ##, p < .05 compared with baseline in 15D; ††, p < .05 compared with baseline in 5D.
participants reported any gastrointestinal discomfort after ice ingestion in any of the trials.

Changes in VO$_2$ and HR are shown in Figure 2. There were no significant differences in VO$_2$ or HR among any of the experimental conditions.

Figure 3 shows Tre, Tsk and Tb for each condition. There were no differences in Tre before ice ingestion. Tre at 10 min prior to exercise was lower in the 30D trial than in the 15D and 5D trials ($p < .05$). Furthermore, Tre at 5 min prior to exercise was lower in the 30D trial than in the 15D trial ($p < .05$). Tre before the start of exercise was 0.5 ± 0.2°C, 0.5 ± 0.1°C, and 0.5 ± 0.1°C lower than the baseline Tre in the 30D, 15D, and 5D trials, respectively, but none of the differences were significant. Tre increased progressively in each trial during exercise, but the rate of increase in Tre during exercise did not differ to a significant extent among the different conditions (0.3 ± 0.1°C·5 min$^{-1}$). At exhaustion, Tre did not differ to a significant extent among the different conditions (30D: 38.2 ± 0.5°C, 15D: 38.2 ± 0.3°C, 5D: 38.2 ± 0.5°C). No significant differences in Tsk were observed, before or after ice ingestion, among the different conditions. Tsk increased progressively during exercise in each of the trials, but Tsk at exhaustion did not differ to a significant extent among the different conditions (30D: 36.9 ± 0.6°C, 15D: 37.1 ± 0.5°C, 5D: 37.0 ± 0.8°C). In the 30D trial, Tb was significantly reduced from 20 to 5 min prior to exercise in comparison to the 15D trial, and from 15 to 10 min prior to exercise in comparison to the 5D trial ($p < .05$). Tb increased progressively in each trial during exercise, but Tb at exhaustion did not differ to a significant extent among the different conditions (30D: 38.2 ± 0.5°C, 15D: 38.2 ± 0.3°C, 5D: 38.2 ± 0.5°C).

The changes in RTS and RPE during the experiment are shown in Figure 4. RTS in the 30D trial was lower than that in the 15D trial at 15 min before the start of exercise and that of the 5D trial from 25 to 20 min before the start of exercise ($p < .05$). RTS in the 5D trial was significantly decreased from 10 to 15 min during exercise in comparison to the 15D trial and from 15 to 20 min during exercise in comparison to the 30D trial ($p < .05$). RPE in the 5D trial was reduced from 20 to 25 min in comparison to the 15D and 30D trials ($p < .05$).

4. Discussion

In the present study, the total volume of ice ingested was set at 7.5 g·kgBM$^{-1}$ based on the reports of Siegel et al. (2010, 2012). In addition, participants ingested ice 30 min before exercise because ice had often been ingested 30 min prior to exercise in previous studies of internal cooling by ice ingestion before exercise. We investigated whether differences in the timing of ice ingestion altered endurance performance, body temperature or perceptual ratings among the three conditions (30D, 15D and 5D). There were no significant differences in exhaustion time, rectal or mean body temperature during exercise when the total volume of ice ingested by the sub-
jects was equal, even though participants ingested ice in a single bolus for 30 min before exercise (30D), in two boluses every 15 min for 30 min before exercise (15D), and 1.25 g·kgBM⁻¹ of ice in six boluses every 5 min for 30 min before exercise (5D). On the other hand, intermittent internal cooling by ingestion of ice every 5 min before exercise (in which the volume of ice at each interval was smaller) attenuated the degrees of RTS and RPE in the middle stage of exercise.

In the present study, changes in BM before and after exercise and USG as a dehydration index were similar among the three experimental conditions (Table 1) and were sustained at normal levels (Sawka et al., 2007); however, dehydration during exercise has been shown to impair endurance performance (González-Alonso et al., 1998). It is possible that exercise intensity under the three conditions was comparable because there were no significant differences in VO₂ or HR before or during exercise, or at exhaustion, among the three conditions.

Some previous studies have reported that internal cooling by ice ingestion before exercise reduced Tc prior to the start of exercise (Ihsan et al., 2010; Levels et al., 2013; Ross et al., 2011; Siegel et al., 2010; Siegel et al., 2012). Tre at 15 min before exercise in the 30D trial was significantly lower than at the same time in the 15D and 5D trial. This may be because a larger assumed volume of ice had been ingested at that point in the 30D trial (Tetsuguchi et al., 2006). However, Tre before the start of exercise was 0.5°C lower than at the baseline for each condition (Figure 3-A), and this degree of reduction was similar to that reported in previous studies (Ross et al., 2011; Siegel et al., 2010; Siegel et al., 2012).

A likely explanation is that “critical limiting temperature” is one of the factors involved in reduction of endurance exercise performance in the heat (Marino et al., 2004). González-Alonso et al. (1999) reported that a higher Tes affected the central and peripheral nervous systems and induced fatigue, thereby contributing to the subjective decision to terminate endurance cycling. Tre at exhaustion was approximately 38.5°C under each of the conditions used in the present study. Cheung and McLellan (1998) demonstrated that, at exhaustion, Tre of trained participants (VO₂max > 55 mL·kg⁻¹·min⁻¹) was higher than that of untrained participants (VO₂max < 50 mL·kg⁻¹·min⁻¹) (39.3 vs. 38.7°C), regardless of whether the subjects were acclimated to the heat and their hydration state. VO₂max of the participants in this study was 49.7 mL·kg⁻¹·min⁻¹. This level of training corresponded to “untrained” in Cheung and McLellan’s study (1998), and Tres at exhaustion under each of the conditions used in the present study were similar to those they reported. Furthermore, Tre at exhaustion among the untrained participants in their study did not reach 40°C. These results suggest that the “critical limiting temperature” may be affected by aerobic capacity, because VO₂max in trained participants of the study by González-Alonso et al. (1999) was 65.9 mL·kg⁻¹·min⁻¹. Thus, the aerobic physical fitness of subjects may be a factor in reaching a Tre of 40°C at exhaustion. Another possible factor is that Tre was measured as the Tc index. In the study by González-Alonso et al. (1999), Tes was used as an index of Tc. Unlike Tes, Tre did not reach 40°C in previous studies because the latter increases more slowly than the former (Nielsen and Nielsen, 1962). Although further studies are needed to investigate whether “critical limiting temperature” is a limiting factor for endurance performance, it appears that a greater reduction in Tc is associated with a greater performance benefit (Siegel and Laursen, 2012). In the present study, when the total volume of ice ingested before exercise was identical, there were no significant differences in Tre prior to the start of exercise, even though the timing of ice ingestion was different. This may be one of the reasons why we did not observe any significant differences in endurance performance among the three conditions.

It has been suggested that fatigue during exercise in hot environments is associated with the central nervous system. Nybo and Nielsen (2001b, 2001c) reported that an excessive increase of body temperature during exercise in hot environments reduced the mean blood velocity in the middle cerebral artery and increased RPE during exercise. It is possible that internal cooling by ice ingestion before exercise results in conductive cooling of the brain because ice is ingested through the mouth (Siegel et al., 2012). Onitsuka et al. (2015) demonstrated that pre-exercise ingestion of 7.5 g·kgBM⁻¹ of ice reduced Tre, forehead Tsk and RTS in comparison to subjects who ingested cold water. In addition, ingestion of 360-400 mL of liquid (4°C) reduced the gastrointestinal temperature for 17-30 min (McArthur and Feldman, 1989; Sun et al., 1988). Thermoreceptors are probably present in the mouth, esophagus (El
Ouazzani and Mei, 1982), stomach (Villanova et al., 1997) and muscles (Benzinger, 1969) of humans. Thus, it is possible that these thermoreceptors transmit afferent feedback signals when cold water or ice is ingested, thereby reducing RTS and RPE.

RTS from 20 to 10 min prior to the start of exercise was lower in the 30D trial than in the 15D and 5D trial. This may be because a larger volume of ice had been ingested by the subjects at that point in the 30D trial. However, there were no significant differences in RTS before the start of exercise among the three conditions. At the middle stage, RPE in the 5D trial, where the subjects had almost constantly ingested ice until just before exercise, was lower: however, the RPE at exhaustion did not differ to any significant extent among the three conditions. At the middle stage, RPE in the 5D trial, where the subjects had almost constantly ingested ice until just before exercise, was lower: however, the RPE at exhaustion did not differ to any significant extent among the three conditions. At the middle stage, RPE in the 5D trial, where the subjects had almost constantly ingested ice until just before exercise, was lower: however, the RPE at exhaustion did not differ to any significant extent among the three conditions. At the middle stage, RPE in the 5D trial, where the subjects had almost constantly ingested ice until just before exercise, was lower: however, the RPE at exhaustion did not differ to any significant extent among the three conditions. Thus, it is possible that these thermoreceptors transmit afferent feedback signals when cold water or ice is ingested, thereby reducing RTS and RPE.

A previous study pointed out the need to investigate the timing of ice ingestion before exercise in order to determine whether a greater internal cooling effect occurs in subjects with impaired endurance performance (Siegel et al., 2012). However, there were no significant differences in endurance performance under the three experimental conditions. The present study had some limitations. First, the participants were not trained. Tre in trained participants at exhaustion is reportedly higher than that of untrained participants (Cheung and McLellan, 1998). Additionally, Nielsen et al. (1990) have suggested that a highly fit group would be more appropriately motivated to exercise and have the ability to reach a greater core temperature. Hence, a further study of highly fit individuals or elite athletes may be needed. Second, it is assumed that the exercise time was shorter. The effects of pre-cooling on exercise capacity were previously shown to be of greater benefit to endurance exercise than high-intensity sprinting or intermittent exercise (Wegmann et al., 2012). It is possible that there were no significant differences in Tre or endurance performance of the subjects under the three experimental conditions, because exercise intensity in the present study was high, with a VO2max of 70%, while the exercise time, at approximately 30 min, was short. Thus, a further study should be performed to investigate exercise at moderate intensity in order to extend the exercise time. In addition, the effects of pre-cooling by ice ingestion need to be investigated for intermittent exercise, time-trial tests and time to exhaustion. The improvement of exercise performance conferred by pre-cooling has been reported to differ according to the type of exercise (Wegmann et al., 2012). Faulkner et al. (2015) reported that RTS affected self-paced distribution in a time-trial test. If intermittent exercise or time-trial tests had been used as the measurement protocol, the results of the present study might have been different. Further research may therefore be needed to investigate the effects of the type of exercise on exercise-induced psychophysiological responses after pre-cooling. Finally, in accordance with previous studies, the timing of ice ingestion was standardized and started 30 min before exercise. It is possible that there may be a more effective time at which to start fluid consumption before exercise in order to attenuate the increase in Tre during exercise or the reduction of exercise performance. Further studies will be needed to investigate novel experimental designs for determining the effects of both the volume and timing of ice ingestion before exercise.
5. Conclusions

The aim of the present study was to investigate the effects of timing of ice ingestion on endurance performance, body temperature and perceptual ratings before and during exercise. Participants performed endurance cycling at an intensity equivalent to their 70% VO\textsubscript{2max} until voluntary exhaustion, while the timing of ice ingestion in the 30 min before exercise was altered. Our results showed that internal cooling with a shorter interval reduced the RTS and RPE in the middle stage of exercise, but there were no significant differences in exhaustion time or Tre among the different conditions. These results suggest that there were no significant differences in exhaustion time or Tre when the subjects ingested the same total volume of ice. We also found that ice ingestion until just before exercise attenuated the perceptual ratings during exercise in a hot environment.

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• Takashi, Naito. and Tetsuro, Ogaki. (In press). Comparison of the effects of cold water and ice ingestion on endurance cycling capacity in the heat. Journal of Sport and Health Science.
• Takashi, Naito. and Tetsuro, Ogaki. (2016). Pre-cooling with intermittent ice ingestion lowers core temperature in a hot environment as compared with the ingestion of a single bolus. Journal of Thermal Biology, 59: 13-17.

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