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Effect of Ice Slurry Ingestion on Post-Exercise Physiological Responses in Rugby Union Players

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Abstract: Delayed recovery of the core body temperature after exercise adversely affects physiological functions, and the effects of ingesting lower-temperature ice slurry on post-exercise recovery remain unclear. We investigated the effects of ingesting −2 °C ice slurry on physiological recovery after field-based rugby union training. Fifteen university rugby union players participated in our randomized controlled study. The players participated in the training for 60 min in a hot outdoor environment (wet-bulb globe temperature, 30.5 °C). Physiological responses were measured during a physical performance test performed after the players ingested either −2 °C-ice slurry (ICE, N = 7) at 5 g/kg body mass or a 30 °C-fluid (CON, N = 8) during the 15 min recovery period after the training. Tympanic temperatures and heart rates were measured as the physiological indices, as well as heat storage. The ICE group showed significantly decreased tympanic temperatures and heart rates ($p < 0.05$) during the recovery period and increased heat storage ($p < 0.05$) but did not show improvement of physiological indices during the performance test compared to the CON group. These results suggest that ingestion of −2 °C ice slurry in even lower amounts than those previously reported is useful for physiological recovery after training in hot outdoor environments.

Keywords: ice slurry; tympanic temperature; hot environment; rugby union; cooling strategy

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1. Introduction

Performing intense exercises in hot environments increases the core body temperature and could lead to heat exhaustion, heat stroke, and serious dysfunction of the central nervous system [1,2]. As the core body temperature rises, the body tries to keep its temperature in a normal range via sweating, increased blood flow to the skin, and decreased physical activity [1,3]. Rapid recovery from hyperthermia is important for athletes because extremely high core body temperatures can adversely affect physiological responses and impair endurance exercise performance in hot environments [4–6]. In general, recovery methods from hyperthermia have included internal cooling and external cooling methods [7,8]. No consistent effectiveness of external cooling methods has been reported from previous studies. Cold water immersion—an external cooling method—has been reported to enhance endurance exercise performance [9–11], whereas wearing an ice vest—another external cooling method—has been reported not to decrease the core body temperature during high-intensity exercise or to enhance exercise performance [12]. On the other hand, internal cooling is known to lower the core, skin, and tympanic temperature (T_{ty}) and to enhance exercise performance in hot environments [11,13,14]. Siegel et al. reported that ingestion of −1 °C-ice slurry at 7.5 g/kg body mass (BM) before exercise reduced the core body temperature by 0.7 °C and prolonged the run time to exhaustion as compared with ingestion of 4 °C water, which was considered to be primarily attributable to the amount of heat transfer associated with the enthalpy of the fusion of ice [15]. The theoretical basis of pre-cooling is to increase the margin for rising core body temperatures before a critical limit is reached. In other words, pre-cooling allows a greater rate of heat storage (HS) with less strain on physiological functions during endurance exercise. Therefore, it is important to increase the HS to improve exercise performance during sports competitions [16].

In most previous study protocols involving ice slurry ingestion, the study has been conducted in climate chambers, in which only the temperature and relative humidity can be controlled [17]. A climate chamber environment is generally less influenced by environmental factors (e.g., ambient temperature, solar radiation, wind) than outdoor environments. Therefore, the physiological responses to heat stress may differ in hot outdoor environments. A few studies have evaluated the effects of ice slurry ingestion in outdoor environments [18,19]. However, one of the operational issues associated with the ingestion of ice slurry is that large amounts of ice slurry (7.5 g/kg BM) must be ingested in order to lower the core body temperature, and realistically, it is difficult to expect athletes to ingest such large amounts of ice slurry before exercise. Our previous study, although it was conducted in a climate chamber, has suggested that lowering the temperature of ice slurry to −2 °C allows even small ingested amounts to lower the T_{ty} and enhance exercise performance [14]. However, the effects of the ingestion of small amounts of −2 °C ice slurry in hot outdoor environments still remain unclear. According to previous studies conducted in outdoor environments, ice slurry ingestion before exercise may be effective for enhancing endurance exercise [18,19].

A recent study showed that several sports competitions are held in hot conditions (WBGT, 25–36 °C) [20,21], so that cooling strategies are needed for several competitive sports activities. Rugby union—a typical example of such sports activities—is an intermittent-exercise team sport played by 15 players, with matches played over two 40 min halves separated by a half-time break, and is characterized by repeated body collisions and high-intensity running efforts [22]. In particular, matches and exercises in hot environments have detrimental effects on physiological functions and the World Rugby Guidelines do not recommend the playing of rugby union matches in hot environments with an air temperature of over 30 °C and/or a relative humidity of over 60% [23]. Therefore, rapid recovery of physiological indices via cooling strategies has important implications in the performance and safety of rugby union players playing in hot environments. While previous studies have shown that ice slurry ingestion before and during exercise can enhance endurance performance [18,19], the effects of ingesting ice slurry on post-exercise recovery in hot outdoor environments are not yet known.

Therefore, the aim of the present study was to evaluate the effects of an internal cooling intervention—namely, the ingestion of small amounts (5 g/kg BM) of −2 °C ice slurry after field-based rugby union training—on physiological responses in a hot environment. We hypothesized that the ingestion of even relatively small amounts of lower-temperature ice slurry can improve physiological responses in a hot outdoor environment.

2. Materials and Methods

2.1. Subjects

Fifteen university rugby union players were recruited in this study. The inclusion criteria were as follows: healthy and physically active males aged 18 years or older and more than three years rugby union experience. The exclusion criteria were as follows: players in the acute injury and rehabilitation phases or players who were otherwise unable to participate in training, games, and other activities. All players provided their informed consent for participation prior to the commencement of the study. The study protocol was approved by the Ethics Committee of Keio University Graduate School of System Design and Management in Japan (SDM-2020-E017). The study complied with the Declaration of Helsinki.

2.2. Study Design

Figure 1 shows the experimental protocol. This randomized, controlled trial was conducted in September in Kanagawa prefecture, Japan. The subjects completed one familiarization trial and measured their maximum heart rate (HR) and maximal oxygen uptake (VO_2 max) from the Yo-Yo intermittent recovery test level 1 [24] two weeks prior to the experimental trial. At the start of the study, they were randomized into two groups: a control fluid ingestion (CON) group (N = 8) and an ice slurry ingestion (ICE) group (N = 7). Before the start of the experimental trial, the subjects performed a 30 min standardized warm-up exercise, consisting of low-to-moderate speed running and stretching exercises. The subjects then underwent field-based rugby union training [25,26]. The training comprised exercises split into 4 × 15 min exercise blocks. Blocks 1 and 3 were followed by 4 min active rest. A 10 min rest followed Block 2. Each exercise block consisted of walking, jogging, cruising, scrummaging, rucking, and mauling. In each block, the mean heart rate was 70–90% of the maximum heart rate, the total distance was 722 m, and the number of accelerations (2.5 m/s^2) was 14. Water at ambient temperature was available ad libitum to the subjects during the training. After the training, during the 15 min recovery period, they were asked to ingest either ice slurry or a control fluid. After the recovery period, the subjects performed the physical performance test (TEST). The Yo-Yo intermittent recovery test level 1 was used for the TEST [24]. The subjects had to run repeatedly between two markers placed 20 m apart, following digital audio cues that dictated the running speed required. After each 40 m run, the subjects took active rest for 10 s before starting to run again. At regular intervals, the required running speed was increased. The total running distance and time were recorded when the subjects failed to return to the starting line. The experimental trial was performed in a hot outdoor environment (34.6 ± 1.0 °C, 55.1% ± 2.4% relative humidity, WBGT 30.5 ± 0.4 °C). The environmental conditions were measured 1.5 m above ground level using a WBGT meter (TC-300, Tanita Corporation, Tokyo, Japan) before and after the training and before and after the TEST. The subjects were instructed to refrain from exercises, medicines, dietary supplements, caffeine, or alcohol for 24 h before the day of the experimental trial. The subjects had a breakfast (47 g protein, 219 g carbohydrates, and 43 g fat) 4 h before the experimental trial.

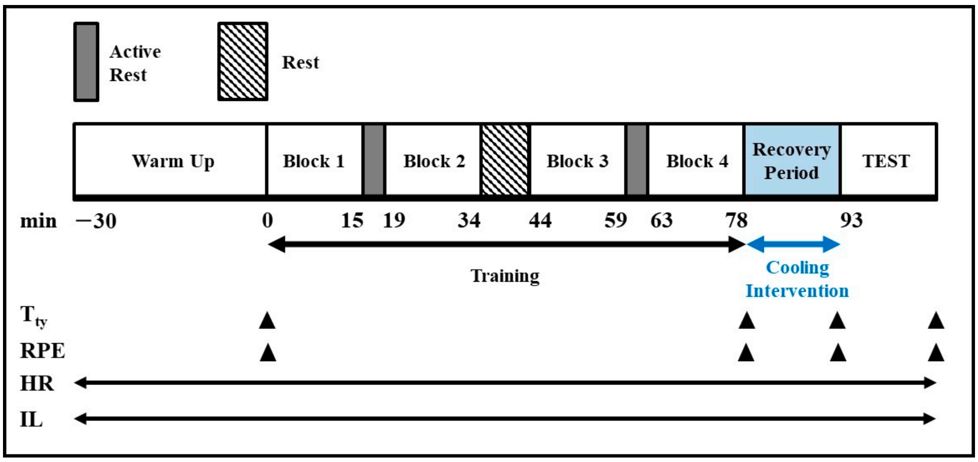

Figure 1. Experimental protocol. T_{ty}: tympanic temperature; RPE: rating of perceived exertion; HR: heart rate; IL: intensity of locomotion; TEST: physical performance test.

2.3. Cooling Procedures

As in a previous indoor study [14], the subjects ingested 5 g/kg BM of a 30 °C fluid or −2 °C ice slurry during the 15 min recovery period. The control fluid and ice slurry contained 14 g of carbohydrate, 20.3 mg of potassium, and 94.0 mg of sodium per 100 mL. The subjects ingested the control fluid or ice slurry in aluminum foil bags.

2.4. Measurements

The nude BM mass was measured to the nearest 0.1 kg using a body mass scale (WB-150, Tanita Co., Ltd., Tokyo, Japan) and height was measured to the nearest 0.1 cm using the Centurion Kit instrumentation (Rosscraft, Surrey, BC, Canada), before the experimental trial. The T_{ty} and rating of perceived exertion (RPE) were measured at four time-points (before and after the training, and before and after the TEST). The T_{ty} was measured using an infrared ear thermometer, IRT6500 (Braun GmbH, Kronberg, Germany), with the average of three measurements used for the analysis. The RPE was measured on the 6- to 20-point Borg Scale [27]. The subjects were familiarized with the RPE measure. The HS was calculated with the formula of Adams et al. [28]: HS (W/m^2) = $0.965M\Delta T_{ty}/SA$; where M is the body mass (kg) during the experimental trial, ΔT_{ty} is the change in the T_{ty} during the TEST, SA is the body surface area (m^2) according to Du Bois et al. [29]—SA = $0.202M^{0.425} \times \text{height}^{0.725}$—and 0.965 is the mean specific heat storage capacity of the body. Heart rate (HR) was measured every 1 min by a Polar OH1 (Polar Electro, Inc., Lake Success, NY, USA) worn on the subjects' upper arm during the experimental trial [30]. Intensity of locomotion was measured with a coin-shaped actigraphy device (MTN-220, Acos Co., Ltd., Nagano, Japan) using an internal three-axis accelerometer. Every 0.125 s, the number of times that acceleration exceeded a reference value was calculated as the activity value over 2 min bins. The intensity of locomotion was calculated from the activity value as a value from 0 to 31 (32 levels). Higher values indicated higher levels of activity [31,32]. The subjects were required to wear the MTN-220 on the front side of their pants during the experimental trial.

2.5. Statistical Analysis

All data are presented as the mean ± standard deviation. The required sample size was calculated using G*Power software (version 3.1.9.6; Düsseldorf, Germany), considering the gastrointestinal temperature, as a previous study [18] has reported differences in the degree of reduction in gastrointestinal temperatures after the ingestion of ice slurry as compared with that after the ingestion of an ambient-temperature beverage. To calculate the sample size, the power (0.95) and alpha (0.05) were considered, and it was determined that at least six subjects were required in each group. All statistical computations were performed using SAS version 9.4 (SAS Institute Japan Ltd., Tokyo, Japan). The normality of the data and homogeneity of variance between the groups were tested using the Shapiro–Wilk's test and Bartlett's test, respectively. Homoscedastic data were analyzed by Student's *t*-test, and heteroscedastic data were analyzed by Aspin–Welch's *t*-test to compare the demographic characteristics, HS, intensity of locomotion, and total running distance and time between the two groups. Two-way (time × group) repeated-measures analysis of variance (ANOVA) was used to determine the differences in the T_{ty}, HR, and RPE. When the ANOVA results indicated a significant difference, post hoc analyses were performed using the Bonferroni adjustment. The level of significance was set at $p < 0.05$ in all the tests.

3. Results

3.1. Subjects

All subjects (eight forwards, seven backs) completed the study. The demographic characteristics of the subjects are shown in Table 1.

Table 1. Demographic characteristics of subjects.

Variables	CON	ICE
Age, years	19.1 ± 1.0	18.9 ± 0.7
Height, m	1.73 ± 0.06	1.71 ± 0.05
Body mass, kg	83.6 ± 8.7	84.1 ± 7.9
BMI, kg/m^2	28.1 ± 2.0	28.9 ± 3.6
VO_2 max, mL/kg/min	45.6 ± 2.2	46.0 ± 3.3

CON: 30 °C-fluid; ICE: −2 °C-ice slurry. Values are expressed as the mean ± standard deviation. There were no significant differences between the CON and ICE groups.

3.2. Tympanic Temperature and Heat Storage

Figure 2 shows the T_{ty} during the training and TEST periods; there was no interaction effect ($p = 0.576$). However, the main effects of time ($p < 0.001$) and group ($p = 0.008$) were found for the T_{ty}; the T_{ty} was significantly lower in the ICE group than in the CON group at the Pre-TEST ($p = 0.020$). Figure 3 shows the HS in the CON and ICE groups; the HS was significantly higher in the ICE group than in the CON group ($p = 0.035$).

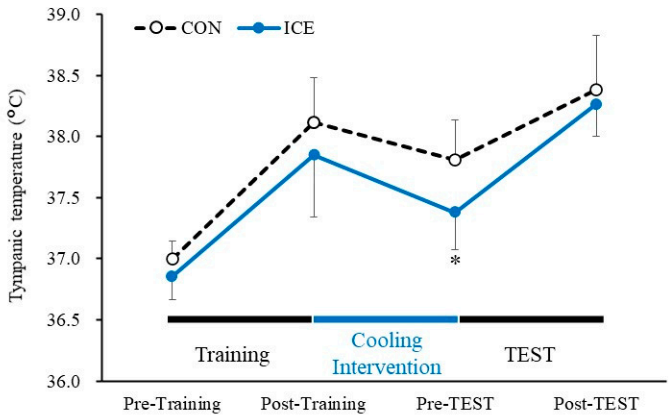

Figure 2. Tympanic temperature. CON: 30 °C fluid; ICE: −2 °C ice slurry; TEST: physical performance test. Values are expressed as the means ± standard deviation. * $p < 0.05$ vs. the CON group.

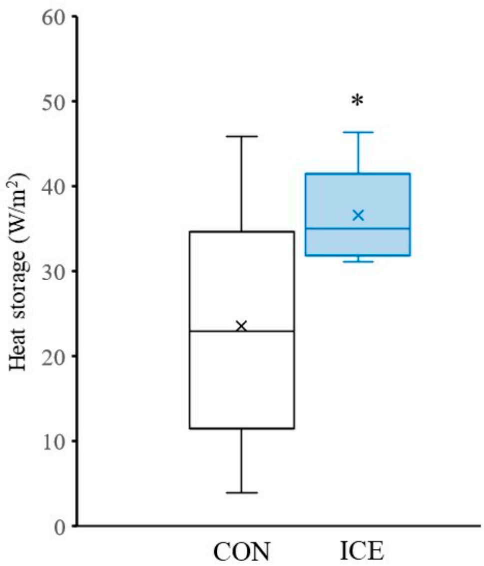

Figure 3. Heat storage. Heat storage was calculated from the tympanic temperature change during the physical performance test. CON: 30 °C fluid; ICE: −2 °C ice slurry. Boxplot shows the median and upper and lower quartiles, and the minimum and maximum. × in the boxplot denotes the mean. * $p < 0.05$ vs. the CON group.

3.3. Heart Rate

Figure 4 shows the HR during the cooling intervention; there was no interaction effect ($p = 0.648$). However, the main effects of time ($p < 0.001$) and group ($p < 0.001$) were found for the HR; the HR was significantly lower in the ICE group than in the CON group at 1 min ($p = 0.005$), 2 min ($p = 0.040$), 8 min ($p = 0.028$), 10 min ($p = 0.030$), 12 min ($p = 0.031$), and 14 min ($p = 0.048$) Post-Training.

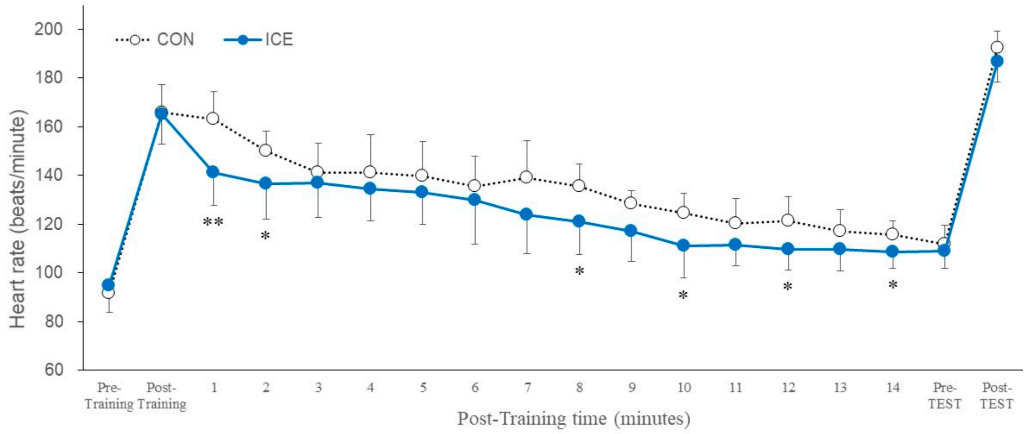

Figure 4. Heart rate. CON: 30 °C fluid; ICE: −2 °C ice slurry; TEST: physical performance test. Values are expressed as the mean ± standard deviation. * $p < 0.05$, ** $p < 0.01$ vs. the CON group.

3.4. Rating of Perceived Exertion

There was no interaction effect ($p = 0.922$) or main effect of group ($p = 0.152$), but a significant main effect of time ($p < 0.001$) on the RPE. The RPE increased significantly relative to Pre-Training in the CON and ICE groups ($p < 0.05$), but there were no significant differences between the CON and ICE groups (Table 2).

Table 2. Rating of perceived exertion.

Group	Pre-Training	Post-Training	Pre-TEST	Post-TEST
CON	10.1 ± 1.4	15.5 ± 1.4	14.9 ± 1.8	18.3 ± 1.2
ICE	10.4 ± 1.9	16.4 ± 1.3	15.4 ± 1.3	18.6 ± 0.5

CON: 30 °C fluid; ICE: −2 °C ice slurry; TEST: physical performance test. Values are expressed as the means ± standard deviation. There were no significant differences between the CON and ICE groups.

3.5. Physical Performance Test

There was no significant difference in the total running distance or time between the two groups (Table 3).

Table 3. Physical performance test (Yo-Yo intermittent recovery test level 1).

Group	Total Running Distance (m)	Total Running Time (min)
CON	1095.0 ± 265.3	6.6 ± 1.6
ICE	1142.9 ± 394.5	6.9 ± 2.4

CON: 30 °C fluid; ICE: −2 °C ice slurry; m: meters; min: minutes. Values are expressed as the means ± standard deviation. There were no significant differences between the CON and ICE groups.

3.6. Intensity of Locomotion

There were no significant differences in the intensity of locomotion during either the training or TEST period between the CON and ICE groups (Table 4).

Table 4. Intensity of locomotion.

Group	Training (Counts)	TEST (Counts)
CON	1282.8 ± 111.7	238.9 ± 41.8
ICE	1306.1 ± 42.0	242.9 ± 74.9

CON: 30 °C fluid; ICE: −2 °C ice slurry; TEST: physical performance test. Values are expressed as the means ± standard deviation. There were no significant differences between the CON and ICE groups.

4. Discussion

The aim of the present study was to evaluate the effects of ingesting small amounts of lower-temperature ice slurry on the recovery of physiological responses after field-based rugby union training in a hot outdoor environment. The implications of this study were that ingestion of −2 °C ice slurry at 5 g/kg BM after training decreased the T_{ty} and HR rapidly, lending support to the hypothesis that the ingestion of even small amounts of lower-temperature ice slurry after training in a hot outdoor environment could improve physiological responses.

Most conventional ice slurry studies have been conducted in climate chambers where temperature and humidity are kept constant [17], but this is the first study to show that ice slurry ingestion after training in a hot outdoor environment can rapidly improve body temperature and HR. In one previous outdoor study, ingestion of ice slurry at 8 g/kg BM was required to obtain a decrease in core body temperature [18], but it is impractical to expect athletes to ingest large amounts (8 g/kg BM) of ice slurry during the short recovery period. However, in the present study, the amount of −2 °C ice slurry ingested was set at 5 g/kg BM post-exercise, and the ICE group showed a significant decrease in T_{ty} during the 15 min recovery period—similar to the observation in the previous indoor study [14]. Although the exercise protocol in the present study was different from that in the previous study [14], it was clear that even in a hot outdoor environment, the ingestion of −2 °C ice slurry even in small amounts of 5 g/kg BM was sufficient to accelerate the recovery of physiological indices after training.

On the other hand, Nakamura et al. reported that ingestion of 0.5 °C ice slurry at 4 g/kg BM after exercise resulted in a decrease in core body temperature but no significant improvement in HR or blood pressure compared to the control group [33]. As the temperature of the 0.5 °C ice slurry is higher than the −0.4 °C ice slurry (average drinking temperature) in the studies included in the meta-analysis conducted by Choo et al., the ingestion amount of 4 g/kg may be too small [17]. In the present study, there was no significant change in HR 15 min after ice slurry ingestion. This might be attributed to vagal stimulation due to the abrupt cessation of exercise. Future studies are needed to investigate the relationship between the temperature and amount of ice slurry ingestion and the recovery of physiological indices (e.g., HR, blood pressure, and core body temperature) for the practical application of ice slurry in competition settings. In the present study, a short-duration physical performance test (approximately 4–10 min) was conducted after the 15 min recovery period, and the HS, RPE, and total running distance and time were measured. The HS was significantly increased by the ingestion of ice slurry, but the RPE and total running distance and time were not significantly changed. In a previous study in which subjects ingested 5 g/kg of −2 °C ice slurry and performed intermittent endurance exercise for 30 min, the increase in the HS was 50.6 W/m^2, while in the present study, it was 36.6 W/m^2—a much smaller value. This may be because the average exercise time in the physical performance test was as short as 6.8 min, which may have resulted in an underestimation of the HS, because the increase in the T_{ty} was small.

Although measurements of rectal temperature are recommended for evaluating the core body temperature, the training in this study involved contact play, and the T_{ty} was measured instead for the safety of subjects—as in the previous study [14]. The T_{ty} is a good parameter to measure the core body temperature [34] because it is close to the carotid artery and the brain [35–37], although it has been reported to be lower than the rectal temperature during exercise [38]. Onitsuka et al. reported that ingestion of −1 °C ice slurry at 7.5 g/kg BM decreased the brain temperature as measured using non-invasive magnetic resonance spectroscopy, and it is possible that the present study also improved physiological indices by decreasing the brain temperature [39]. It is well known that the brain plays an important role in thermoregulation by detecting changes in the environmental temperature and regulating heat production and heat loss to the external environment via the autonomic nervous system and cardiovascular system [40,41]. However, these protective physiologic functions may be notably lost in the injured brain because of a failure to preserve the brain temperature amid rising systemic temperatures, weakening a critical adaptive mechanism and leading to catastrophic brain hyperthermia [42]. Therefore, it is important to lower the temperature of the circulating blood flow and control excessive increases in brain temperature for the rapid recovery of physiological responses [42,43].

The present findings may have several implications for athletes engaged in field sport activities. Although ice slurry ingestion has been reported to enhance endurance exercise performance in previous studies, its effects on short-duration exercise have not yet been clarified. In the present study, there was no significant improvement in exercise performance or physiological indices during exercise after the ingestion of ice slurry. Yeo et al. reported that the core body temperature was lowest 35 min after ingestion of ice slurry [18], but in the present study, the TEST was completed within 25 min after the ingestion of ice slurry. If the exercise duration had been longer, the ingestion of ice slurry might have improved exercise performance. However, lowering the temperature of the ingested ice slurry to −2 °C rapidly improved physiological indices after exercise in both outdoor and indoor hot environments, even in small ingestion amounts—suggesting that this may be an effective cooling strategy for field competitions in the future. One advantage of ice slurry is that they not only replenish water and electrolytes, but also provide carbohydrates and proteins, which are important nutrients for post-exercise recovery. In our previous study, −5 °C ice slurry—whose temperature was lowered by lowering the freezing point using carbohydrates and amino acids—suppressed inflammatory cytokine levels in the circulating blood in a hot environment [44]. Further practical studies in field competitions would be useful to clarify the significance of lowering the temperature of ice slurry for protecting the brains of athletes.

This study had a few limitations: First, the T_{ty} was used as a surrogate for core body temperature measurements to ensure the safety of the subjects. However, the effects of solar radiation and convection from outside cannot be ignored, and the correlation between the core body temperature and T_{ty} during rugby training in hot outdoor environments should be further investigated in the future with reference to the ice slurry study conducted by Deshayes et al. using a telemetric pill [45]. In addition, the physical performance test conducted in the present study was a short-duration exercise test with a small sample size; therefore, the change in exercise performance associated with increased the HS may not have been demonstrated. It is necessary to clarify how ice slurry ingestion might affect the type of exercise in a larger randomized controlled trial in the future.

5. Conclusions

Ingestion of lower-temperature ice slurry, even in small amounts, after rugby exercise improved the T_{ty} and HR, and increased the HS in a hot outdoor environment. Conversely, ingestion of ice slurry did not improve physiological indices during a maximal fitness performance test after cooling intervention. These results suggested that ingesting lower-temperature ice slurry is useful for recovering the post-exercise physiological responses of athletes in sports competitions in hot outdoor environments.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Keio University Graduate School of System Design (SDM-2020-E017).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest: A.M., S.Y., M.S. and K.K. are employees of Taisho Pharmaceutical Co., Ltd. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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