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EFFECTS OF SPORTS DRINK ICE SLURRY INGESTION DURING RECOVERY ON CYCLING PERFORMANCE & THERMOREGULATORY RESPONSES IN WARM-HUMID ENVIRONMENT AMONG TRAINED JUNIOR CYCLISTS

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ABSTRACT

This study investigated the effect of sports drink ice slurry ingestion during recovery on cycling performance and thermoregulatory responses in a warm and humid environment. A randomized crossover study design with two separated visits of trials, 7 male Kelantan state cyclist ingested 1.25 g/kg body weight of sport drink ice slurry (0.4°C) and plain water (27°C) during 30-min recovery period after fixed-intensity cycling and time trial exercise bouts (Exercise 1) but before exercising the next subsequent exercise bouts (Exercise 2) in the warm and humid laboratory setting (30.86 ± 0.14°C, 69.32 ± 0.72% RH and 31.01 ± 0.21°C, 67.83 ± 1.29% RH). The average of work performed, rectal and skin temperature, heart rate (HR), rating of perceived exertion (RPE), thermal sensation, and thermal discomfort ratings were measured. The average work completed in the 15-minute time trial for ice slurry (146.9 ± 22.2 kJ) was higher than the control (134.7 ± 28.6 kJ), but it was not significantly different. The heart rate response in Exercise 2 ice slurry was elevated, but there was no significant difference between the two trials, $p = 0.572$. There was no significant mean difference in core temperature during both exercise bouts between trials, $p = 0.512$. However, there was a reduction in core temperature with ice slurry in Exercise 2. During exercise, there was a significant difference in mean skin temperature between ice slurry and control trials, $p = 0.02$. Ice slurry ingestion during recovery did not significantly change RPE ($p = 0.543$), thermal discomfort ($p = 0.972$), and thermal sensation ($p = 0.732$). Ingestion of sports drinks ice slurry improved cycling performance in subsequent exercise compared to plain water ingestion. In addition, ice slurry also attenuated the skin temperatures during the subsequent exercise in a warm and humid environment. However, ice slurry ingestion during recovery did not affect core temperature, heart rate, RPE, thermal discomfort, and thermal sensation in subsequent exercise.

Keywords: *Ice slurry, cycling performance, warm and humid*

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INTRODUCTION

Many sporting events occur during the hottest season, in warm to hot climates, or in the hottest part of the day. Several physiological and metabolic alterations potentially contribute to fatigue during exercise in the heat. These include alterations in energy metabolism, cardiovascular function, fluid balance, central nervous system function, and motor drive. However, a common element in fatigue during exercise in the heat appears to be a critically high core temperature (Atares, Camaries, & Sitco., 2023). In addition, when exercising in the heat, the rate of rising core temperature and heat storage were faster in higher humidity (Jenkins, Campbell, Lee, Mundel, Cotter., 2023; Maughan, Otani, & Watson, 2012). The combination of heat and humidity in prolonged exercise can cause dehydration and hyperthermia, a condition of elevated body temperature due to failed thermoregulation when the body absorbs more heat than it dissipates. A study demonstrated that the exercise capacity in the warm/heat progressively reduces as the environmental humidity rises. Early fatigue in the higher humidity trials was accompanied by a faster rate of rising core temperature and a greater weighted mean skin temperature, with no differences in heart rate, skin blood flow, or metabolic response to exercise (Maughan et al., 2012; Ely, Cheuvront, Kenefick, & Sawka, 2010).

A cooling strategy to delay heat stress and fatigue in prolonged exercise can be introduced to minimise the risk of heat-related illness and to optimise performance. Various cooling methods can be applied externally by direct application to the body or internally through ingestion, such as pre-cooling, per-cooling, and/or post-cooling (Kerkhof, Bongers, Periard & Aijsvogels., 2024). Furthermore, in many competitive situations, only a few hours separate the next bout of competitive effort. Ice slurry ingestion introduces a new way of heat transfer (internal heat transfer) for an athlete exercising in the heat in addition to the four avenues of heat transfer at the skin surface (evaporation, convection, radiation, and conduction) (Meir, Chapman, & Climstein., 2023). A study by Byrne, Owen, Cosnefroy, & Lee (2011) demonstrated that pre-exercise cold fluid ingestion is a simple, effective precooling method suitable for field-based applications. They found that during rest, a greater decrease in rectal temperature was observed with ingesting cold fluid (2°C) than the control fluid (37°C) over 35 to 5 minutes before exercise. Distanced cycled was greater after ingestion of the cold fluid than after ingestion of control fluid, but no difference was observed for pacing, mean skin temperature, heart rate, blood lactate, thermal comfort, perceived exertion, and sweat loss (Kjertakov, 2024; Byrne, et al., 2011). A study by Mejuto, Chalmers, Gilbert, & Bently (2018) demonstrated a significant decrease in rectal temperature in the combined cooling strategies of ice slurry ingestion and iced towel during pre-exercise and then ingesting ice slurry during steady-state cycling. In this study, seven well-trained and unacclimated male road cyclists warmed up for 15 min and were given the ice slurry (-1°C) as the pre-cooling intervention. Before cycling at steady state for 45 min at 70% of VO_2max in 32°C, 50% RH climatic conditions, with ice slurry administered every 15 min as mid-cooling intervention. They conclude that the combined pre-cooling and mid-cooling did not enhance cycling performance. However, it did reduce the core temperature compared to the exercise without pre- and mid-cooling intervention.

Therefore, a novel aspect of this study is introducing a practical cooling method to local (Malaysian) athletes to attenuate high core temperature during training or competition in Malaysia's hot and humid climatic conditions. The use of sports drink ice slurry ingestion in this study offers a more practical, inexpensive, and affordable method for athletes in any sports institution to apply. In addition, the information from this study will give an appropriate guideline for athletes to sustain longer during exercise in the Malaysian climate.

METHODOLOGY

Participants

Seven healthy, junior male cyclists gave informed consent to participate in the study. The participants' characteristics were (mean ± SD): age, 16 ± 2.2 years; height, 1.7 ± 4.1 m; weight, 54.9 ± 10.4 kg; VO_2peak, 63 ± 5.2 ml/kg/min; maximal heart rate, 204 ± 2 beats/min and peak aerobic power, 276 ± 34.2 W. All participants were well-trained cyclists with at least 2 years of competitive experience at the national level. The Human Ethics Committee of Universiti Sains Malaysia (USM/JePEM/19020108) approved the protocol and performed according to the latest Declaration of Helsinki. The study complied with ethical requirements, including obtaining guardian consent for all participants.

Participants arrived at the laboratory for all experimental trials after refraining from strenuous exercise, caffeine, and tobacco for 24 hours.

Experimental Overview

Participants visited the laboratory on a total of four occasions. In the following order, these visits included (1) preliminary submaximal and maximal tests, (2) experimental familiarization, and (3 and 4) experimental trial and control trial. All the visits were separated by 7 days and conducted at the same time of day. Experimental trials included control (room temperature sports drink) and ice slurry trials. A schematic diagram can be seen in *Figure 1*. All the trials were completed on an electronically braked cycle ergometer (Excalibur Sport, Lode Groningen, Nederland), used either in the cadence-independent mode (hyperbolic mode, for steady-state) or a cadence-dependent mode (linear mode, for time trial).

Preliminary Trial and Familiarization

Following body weight (Tanita, Japan) and height (Seca, Germany) measurements, this session was conducted in a moderate laboratory environment (22-25ºC) with a fan located in front of the participants with an airflow of 20 km/h. A submaximal test required the participants to cycle on an electronically brake cycle ergometer (Lode Excalibur, The Netherlands) for 6-min at each of four consecutive submaximal power outputs which were 100 W, 150 W, 200 W, and 250 W. Following a 30-minute rest, VO_2max was determined by a ramp protocol with 15 W/min until volitional fatigue. Expired gases were collected continuously (ParvoMedics TrueOne, Murray, Utah, USA) to determine ventilation, and VO_2 and heart rate (Polar Electro Oy, Finland) were constantly collected throughout both tests. Following this, a linear relationship between the mean rate of VO_2 during the last 2 minutes of each submaximal stage and power output was determined to calculate a power output that elicited a time trial (75% VO_2max) for each participant.

A familiarization trial was conducted in a warm-humid environment at a dry bulb temperature of 31 ± 0.1ºC and relative humidity of 70 ± 0.7%, with a fan in front of the participants and an airflow of 20 km/h. This session was undertaken to ensure the participants were accustomed to the procedures employed during the investigation and to minimise any potential learning or anxiety effects during experimental trials.

Ice Slurry Formulation

Ice slurry was made using a commercially available ice blender (Philips Ice Crushing Blender). Sports drink (100Plus®, Fraser and Neave Limited, Malaysia; Carbohydrate 5.6 g/100 ml, sodium 42 mg/100 ml, potassium 19 mg/100 ml) was placed into the freezer overnight. An hour prior to the experimental trial, sports drink ice was blended to turn into a slurry. The volume of ice slurry provided was calculated as 1.25 g/kg body weight for each participant (Naito, Iribe, & Ogaki, 2017). The ice slurry was insulated, and its temperature was maintained at 0.4ºC before ingestion to ensure consistency of the cooling rate across participants and maintaining the ice slurry above freezing to avoid discomfort or risk of cold-induced injuries to the mouth, oesophagus, or stomach.

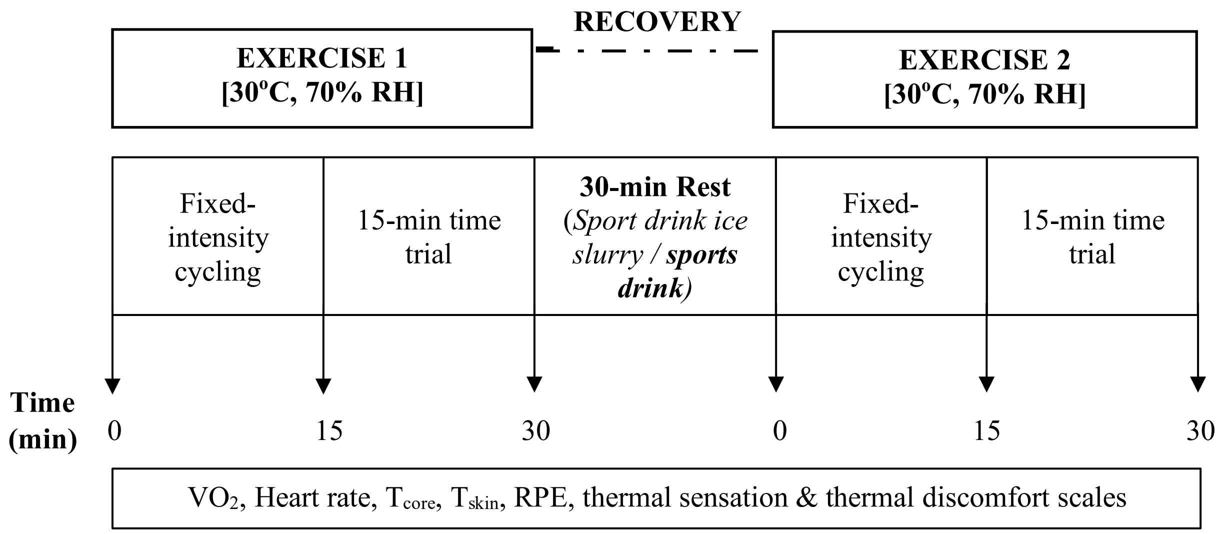


Figure 1: A schematic overview of the experimental protocol.

Experimental Trials

On arrival at the laboratory, participants voided, and nude body weight was measured. Participants then self-inserted a rectal thermistor (YSI Incorporated, United States) to a depth of 12 cm beyond the anal sphincter. They entered the environmental chamber wearing only cycling shorts, shoes, and socks. The heart rate monitor (Polar Electro Oy, Finland) was positioned across the chest. Four skin surface thermistors (YSI Incorporated, United States) were attached to the chest, arm, thigh, and calf on the right side of the body. All thermistors were connected to a temperature monitor (Libra Medical Corporation, United States). Weighted mean skin temperature was calculated according to Ramanathan's equation (1964).

In the ambient environment was set at 30.86 ± 0.14°C, 69.32 ± 0.72% RH, and 31.01 ± 0.21°C, 67.83 ± 1.29% RH, participants performed two identical exercise bouts separated by a 30-minute recovery period. During each exercise bout, participants completed an exercise consisting of **5-min fixed-intensity cycling at each of three consecutive workloads: 100, 150, and 200 W.** Immediately on completion of the fixed-intensity steady-state period, the ergometer was set to linear mode, and during this time the participants went a time-trial to complete as much work as possible in the 15-min. Following completion of the time trial, participants performed a low-intensity cool-down for at least 5-min, where recovery was monitored to ensure participants' safety, reduce the risk of heat illness, and follow best practices for recovery. Rectal, skin temperature and heart rate, Borg's rating of perceived exertion, thermal comfort, and sensation scale **were recorded every 5 minutes** throughout the experimental trials. The ergometer was set to linear mode immediately after completing the fixed-intensity steady-state period. During this time, the participants went through a time trial to complete as much work as possible in 15 minutes. Following completion of the time trial, participants performed a low-intensity cool-down for at least 5-min. Recovery was monitored to ensure participants' safety, reduce the risk of heat illness, and follow best practices for recovery.

On exiting the environmental chamber, participants were allowed to towel down and remain seated in a comfortable moderate laboratory environment (23ºC, 55% RH) for the following 30 minutes. At the start of this recovery period, participants received either 1.25 g/kg body weight of sports drink ice slurry (0.4ºC) or **room temperature sports drink (20ºC)**. Following this recovery period, the above exercise protocol and measures were repeated (Exercise bout 2).

Statistical Analysis

The statistical analysis was conducted using SPSS software for Windows (IBM SPSS Statistics 24). Data were checked for normality using Shapiro-Wilk test. A paired sample t-test was used to determine the difference between cycling time trial performance and experimental trials (Control vs. Sports drink ice slurry). In contrast, all other measures were analysed by 2-way (trial x time) ANOVA for repeated measures with post-hoc pairwise analyses performed where main or interaction effects occurred, with statistical significance set at $P<0.05$. sphericity was assessed, and where the assumption of sphericity could not be assumed, adjustments to the degrees of freedom were made ($\varepsilon > 0.75$ = Huynh-Feldt; $\varepsilon < 0.75$ = Greenhouse-Geisser).

A two-way (trial × time) repeated measures analysis of variance (ANOVA) was conducted to determine the difference between trials on core temperature, skin temperature, heart rate, and RPE. Descriptive values were obtained and reported as means and standard deviation with statistical significance set at $p<0.05$.

RESULTS

Time Trial Performance

In the Control trial, work completed during Exercise 2 (134.7 ± 28.6 kJ) was less than in Exercise 1 (139.7 ± 28.6 kJ), but no significant differences were observed ($p = 0.187$). There were also no significant differences ($p = 0.099$) in total work output between Exercise 1 (130.5 ± 4.2 kJ) and Exercise 2 (146.9 ± 22.2 kJ) in the Ice trial. However, as a result, ice slurry ingestion during a short recovery period between bouts could improve subsequence performance (EX1 Con vs. EX2 Ice and EX1 Ice vs. EX2 Ice) *(Figure 2)*.

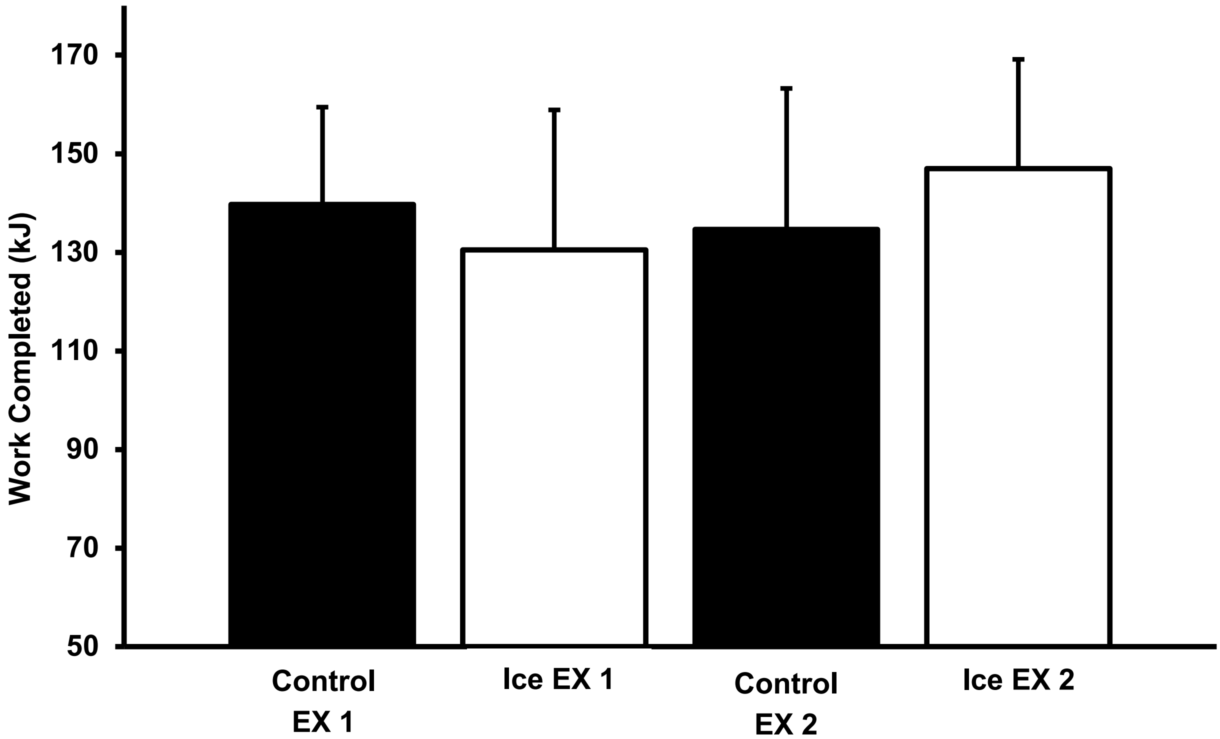
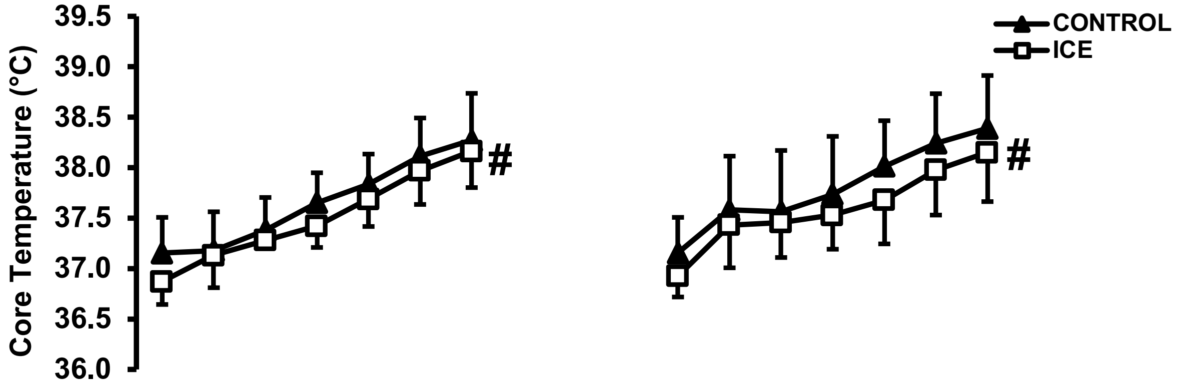


Figure 2: Mean total work completed (kJ) during the 15-min time trial for Control and Ice trials before (EX 1) and after (EX 2) a 30-min recovery. Data are expressed as mean ± SD.

Thermoregulatory Responses

Thermoregulatory measures of rectal and mean skin temperatures are depicted in *Figure 3*. There was no significant mean difference in core temperature during both exercise bouts between the Control and Ice trials; $F(3, 24) = 0.789$, $p = 0.512$. Main effect time was observed for core temperature; $F(2.166, 51.984) = 41.078$, $p < 0.01$ such that values increased progressively at every 5-min interval for all exercise in both trials. Meanwhile, there was a significant difference in mean skin temperature during both exercise bouts between trials; $F(3, 24) = 6.663$, $p = 0.02$. Bonferroni post hoc analysis showed that mean skin temperature was significantly lower during Exercise 2 Control than Exercise 1 Control trials ($p < 0.05$). A significant difference was also observed between Exercise 1 Control and Exercise 2 Ice trial ($p < 0.05$), where the mean skin temperature was significantly lower during Exercise 2 compared to Exercise 1.

(a)



(b)

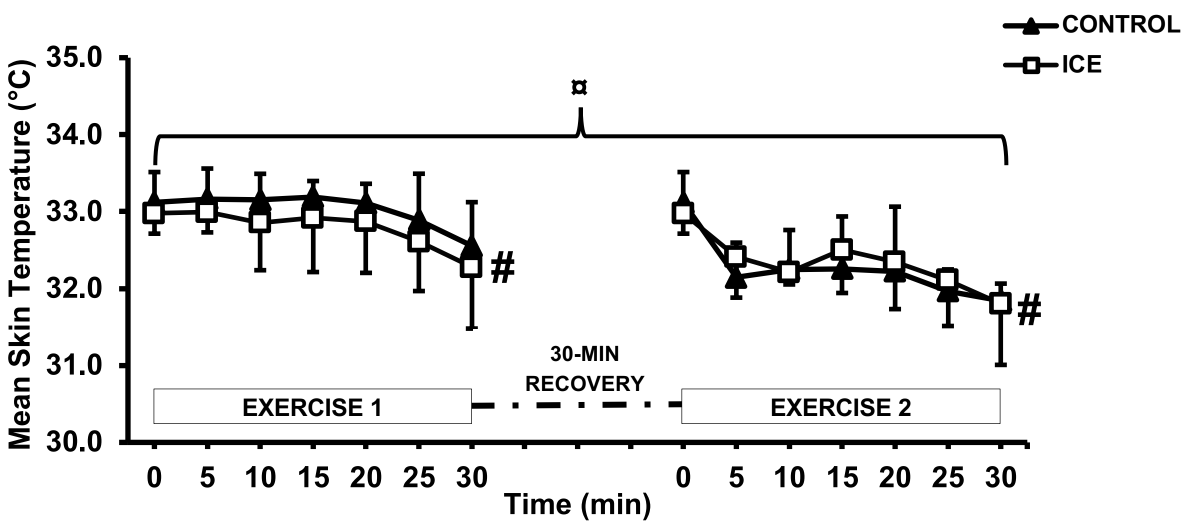


Figure 3: Rectal temperature (a) and mean skin temperature (b) at rest, steady-state cycling, and 15-min time trial for control trial (▲) and sports drink ice slurry trial (□). Data are expressed as mean ± SD.

 # denotes significant main effect of time (p < 0.05)

¤ denotes a significant difference between EX 1 Control and EX 2 Ice trials (p < 0.05)

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Cardiovascular Response

There was no significant mean difference in heart rate between the Control and Ice trials; $F (1, 24) = 0.682$, $p = 0.572$. The main effect time was observed for heart rate for both trials, $F (2.341, 56.194) = 162.6$, $p < 0.01$ *(Figure 4)*.

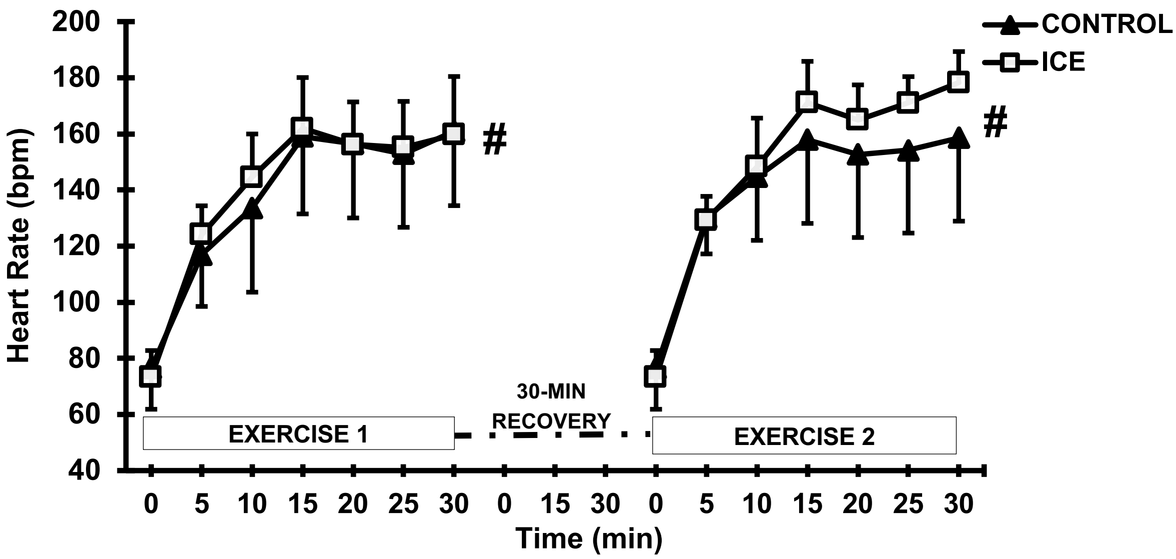

Figure 4: Heart rate for control trial (▲) and sports drink ice slurry trial (□). Data are expressed as mean ± SD.

 # denotes the significant main effect of time (p<0.05).

Perceptual Responses

There was no significant difference in RPE during both exercise bouts between Control and Ice trials; $F (3, 24) = 0.732$, $p = 0.543$. There were significant differences for all mean RPE scores with the time for both exercises in the Control and Ice trials; $F (3.359, 80.609) = 19.857$, $p < 0.001$ *(Figure 5)*.

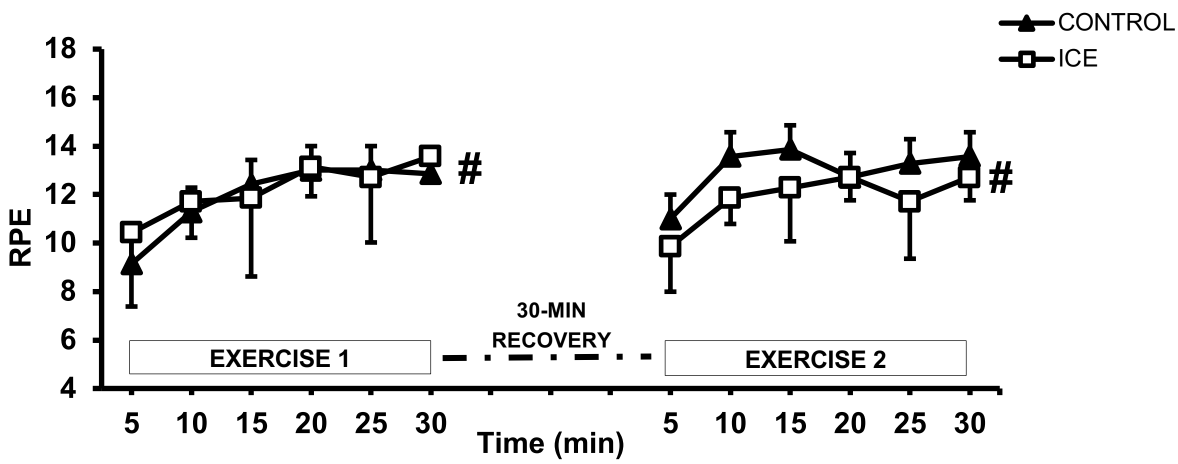

Figure 5: RPE for control trial (□) and sports drink ice slurry trial (▲). Data are expressed as mean ± SD.

 # denotes the significant main effect of time (p<0.05).

DISCUSSION

The present study is the first to determine whether sports drink ice slurry ingestion influences cycling performance after recovering from an exercise about 30 minutes before under conditions that stimulate a tropical environment. Cycling is a complex exercise where various physiological, mechanical, and environmental factors interact to influence power and speed; thus, cycling performance in this study was assessed by the total work output (kJ) 15 minutes after fixed-intensity cycling. Furthermore, this protocol under thermal stress conditions was highly reliable for trained and familiarised male cyclists (Che Jusoh, Morton, Stannard, & Mündel, 2015). During the 15-minute time trial, the ergometer was in linear mode, so the work rate increased with an increasing pedalling rate. This way, the participant could pace himself and maintain a high pedalling rate over 15 minutes to maximize power output. Exercising in high temperatures and/or humid climates decreases time to exhaustion, increases heat storage, and reduces endurance performance. In most existing literature, ice or cold beverage ingestion has been reported to improve exercise performance in the heat. However, the mechanisms behind the improvement of exercise remain debated.

The total work completed during Exercise 1 and Exercise 2 for ice slurry (Ice EX1 and Ice EX2) was 130.5 ± 4.2 kJ and 146.9 ± 22.2 kJ, respectively. The main finding is that ice slurry after such exercise could improve performance (Exercise 2) and thus enhance recovery compared to Exercise 1 in both control and ice slurry trials. However, the lack of statistically significant difference between trials was observed in the current study ($p > 0.05$). The failure to observe a significant difference between trials might be due to the low number of participants. Nonetheless, there was a 12% improvement in work completed for time trial after sport drink ice slurry ingestion during the recovery period compared to Exercise 1 ice slurry. This shows that ingesting sports drink ice slurry during short recovery improves the second bout of exercise performance. Another finding that stands out from the results reported earlier is that even a modest intake of low-temperature ice slurry during half-time intervals of field sports in hot conditions can significantly boost performance in the subsequent session (Morito, Inami, Hirata, Yamada, Shimomasuda, Haramoto & Kohtake., 2022).

It has been proposed that the ice slurry can delay the time to reach a critically high core temperature (T_c) and, therefore, improve endurance exercise performance in the latter stage of a time trial (Morito, Inami, Hirata, & et. al., 2022; Stevens, Dascombe, Boyko, Sculley, & Callister, 2013; Siegel, Mate, & Lay, 2010). This study confirms that increasing core temperature due to higher heat production during exercise increases heat storage (Kerkhof, Bongers, Periard & Aijsvogels., 2024). There are several possible explanations for the current study's time trial result. The first possible explanation for this might be that the ergogenic effect of ice is associated with the cooling of the gastrointestinal tract (Gopathi, Tiwari, & Kalpana., 2023), which may reduce heat strain during exercise and thus generate more power output. Increasing body temperature generally reduces the body's physiological efficiency in sustaining prolonged stress in a hot and humid environment. Observations of fatigue during exercise in the heat associated with attaining a so-called "critical" level of body core temperature have led to suggestions that hyperthermia may be acting via an effect on the central nervous system and motor activation (Ng, & Wingo., 2023; Hargreaves, 2008). In addition, exercise that induces hyperthermia reduces force during sustained maximal voluntary contractions (MVC), suggesting that hyperthermia may affect the ability to maintain voluntary activation (O'Brient, Goosey, & Leicht., 2024). T_C was slightly lower in the ice slurry trial compared to the control in the time trial at exhaustion. The body core temperature at the end of Exercise 2 time trial in the ice slurry and Exercise 2 time trial in the control were 38.2 ± 0.5°C and 38.3 ± 0.7°C, respectively. A trend was observed that sports drink ice slurry ingestion after Exercise 1 in a hot and humid environment could slightly decrease the core temperature in the subsequent exercise (Exercise 2) after recovery, even though there was no statistically significant difference between trials. Secondly, it is said that ice slurry or menthol created more pleasant sensations during thermal stress, through temperature detections by some regions of the brain to maintain and increase motivation to exercise (Timms, 2022; Trong, Riera, Rinaldi, Briki, & Hue, 2015). This also accords with our observations that participants claimed cold body sensation before Exercise 2 in the ice slurry trial led to more work completed. The time trial improvement in this study is consistent with the suggestion that the benefit of ice slurry ingestion is related to a sensory effect (O'Brien, Goosey, & Leicht, 2024; Burdon, Hoon, Johnson, Chapman, & O'Connor, 2013).

Previous studies have indicated that the timing of water ingestion is an essential factor in determining the reduction of T_c. In this study, the ingestion of ice slurry begins right after the completion of Exercise 1 and was followed by a 30-minute recovery period. To prevent gastrointestinal discomfort, the participants were required to finish ingesting the ice slurry within 10 minutes before Exercise 2 began. Previous studies have indicated that an effective strategy to reduce T_c was to ingest a cold beverage during the resting phase before exercising or during the period separating two series of exercise (Iwata, Kawamura, Hosokawa, Chang, & Muraoka., 2021; Ihsan, Landers, Brearley, & Peeling, 2010; Lee, Shirreffs, & Maughan, 2008; Siegel et al., 2010). However, despite the recommended timing of ice slurry ingestion being followed, the reduction of Tc was not drastically decreased. A possible explanation was that the body produces more heat as performance increases. Thus, given the enormous magnitude of heat production that may have occurred in this study, the ice slurry ingestion was insufficient to drastically reduce the T_c (Ng & Wingo, 2023; Riera, Trong, Sinnapah, & Hue, 2014). Cold fluid ingestion introduces a new avenue of heat transfer (internal heat transfer) for an athlete exercising in the heat in addition to four avenues of heat transfer (evaporation, convection, radiation, and conduction) at the skin surfaces (Lee, Shirreffs & Maughan, 2007; Morris, Coombs & Jay, 2016; Siegel et al., 2010). The reduction of skin temperature was due to the evaporated sweat. A study measuring sweat loss during exercise has shown that ingestion of crushed ice influenced the internal thermoreceptors, reducing sweat rate in the early stages of exercise (Zimmermann, Landers, Wallman, & Saldaris, 2017). Therefore, the skin temperature was increased. Nevertheless, the reduction in sweat rate during the early stages of exercise did not significantly reduce overall sweat loss but did allow for increased heat storage (Zimmermann et al., 2017).

This study showed no significant difference in RPE between control and ice slurry trials, $p = 0.540$. This finding is supported by Saldaris, Landersm & Lay (2019), with similar results where there was no significant difference in RPE between ice and control (Choo, Choo, Chang, Chow, & Lee, 2023; Saldaris et al., 2019). Despite the nonsignificant difference in mean between trials, the RPE seemed lower throughout the subsequent exercise after ice slurry ingestion. A previous study found that cooling during exercise improved RPE, and ice slushy tended to lower the rating of perceived exertion (Naito, Saito, Morinaga, Nobuhiko, & Yohei, 2024; Burdon et al., 2013). Decreased perceived exertion and improved maintenance of power output were observed and support the reduction of central fatigue similar to previous investigations, which also report lowered perception of effort (Lee et al., 2008) or improved ability to maintain power output (Ihsan et al., 2010). In the study of Siegel et al. (2010), the subjects' RPE was also lower throughout the exercise after consuming the ice slurry. The subjects likely perceived exercise after ice slurry ingestion to be more accessible at each time point because of the lower thermal strain and T_c. Indeed, it has previously been shown that increases in RPE during exercise in the heat are predominantly due to increases in T_c. Following ice slurry ingestion, the combination of extensive sensory stimulation and cooling of the gastrointestinal tract should have elicited a more significant reduction in RPE and improved thermal comfort (Burdon et al., 2013). However, the present study proved otherwise.

CONCLUSION

Consuming sports drinks ice slurry improved cycling performance in subsequent exercise compared to plain water. In addition, ice slurry also attenuated skin temperatures during subsequent exercise in a warm and humid environment. However, ice slurry ingestion during recovery did not affect core temperature, heart rate, RPE, thermal discomfort, or thermal sensation in subsequent exercise.

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CONFLICT OF INTEREST

The authors have no conflicts to declare.

AUTHORS CONTRIBUTIONS

All authors participated in the final approval of the manuscript.

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