Journal of Thermal Biology 65 (2017) 26–31

Contents lists available at ScienceDirect

Journal of Thermal Biology

journal homepage: www.elsevier.com/locate/jtherbio

Effect of the timing of ice slurry ingestion for precooling on endurance exercise capacity in a warm environment

Keisuke Takeshima[a], Sumire Onitsuka[a], Zheng Xinyan[b], Hiroshi Hasegawa[a,*]

[a] Graduate School of Integrated Arts and Sciences, Hiroshima University, Japan
[b] Department of Sport Science, Shanghai University of Sport, Shanghai, China

ARTICLE INFO

Keywords:
Ice slurry
Precooling
Thermoregulation
Endurance exercise

ABSTRACT

It has been demonstrated that precooling with ice slurry ingestion enhances endurance exercise capacity in the heat. However, no studies have yet evaluated the optimal timing of ice slurry ingestion for precooling. This study aimed to investigate the effects of varying the timing of ice slurry ingestion for precooling on endurance exercise capacity in a warm environment. Ten active male participants completed 3 experimental cycling trials to exhaustion at 55% peak power output (PPO) after 15 min of warm-up at 30% PPO at 30 °C and 80% relative humidity. Three experimental conditions were set: no ice slurry ingestion (CON), pre-warm-up ice slurry ingestion (−1 °C; 7.5 g kg^{-1}) (PRE), and post-warm-up ice slurry ingestion (POST). Rectal and mean skin temperatures at the beginning of exercise in the POST condition (37.1 ± 0.2 °C, 33.8 ± 0.9 °C, respectively) were lower than those in the CON (37.5 ± 0.3 °C; $P < 0.001$, 34.8 ± 0.8 °C; $P < 0.01$, respectively) and PRE (37.4 ± 0.2 °C; $P < 0.01$, 34.6 ± 0.7 °C; $P < 0.01$, respectively) conditions. These reductions increased heat storage capacity and resulted in improved exercise capacity in the POST condition (60.2 ± 8.7 min) compared to that in the CON (52.0 ± 11.9 min; effect size [ES]=0.78) and PRE (56.9 ± 10.4 min; ES=0.34) conditions. Ice slurry ingestion after warm-up effectively reduced both rectal and skin temperatures and increased cycling time to exhaustion in a warm environment. Timing ice slurry ingestion to occur after warm-up may be effective for precooling in a warm environment.

1. Introduction

Prolonged exercise in the heat can cause excessive increases in core body temperature and impair exercise performance (Brotherhood, 2008; Galloway and Maughan, 1997; Parkin et al., 1999). Precooling is a popular strategy for preventing reductions in exercise performance in such conditions. The rationale behind this approach is that decreasing the initial core body temperature can increase heat storage capacity during exercise and delay hyperthermia-induced fatigue and the attainment of critically high core body temperatures (Ross et al., 2011).

A variety of precooling techniques exist, and they are divided into external body cooling and internal body cooling techniques. While external body cooling techniques such as cold-water immersion have traditionally been used for precooling, they are associated with some logistical issues (Kay et al., 1999; Wilson et al., 2002; Siegel et al., 2012). These include the necessity for bulky facilities and the requirement for an extended period of time over which to achieve a sufficient reduction in core body temperature (Siegel and Laursen, 2012). Internal body cooling techniques, such as the ingestion of cold water or ice slurry, are not subject to such shortcomings; consequently, such techniques have recently attracted significant attention (Burdon et al., 2014; Pryor et al., 2015; Stevens et al., 2016, 2013; Zimmermann and Landers, 2015; Tan and Lee, 2015). The effectiveness of ice slurry, in particular, is based on the law of enthalpy of fusion (Ross et al., 2011). Siegel et al. (2012) reported that the improvement in endurance exercise capacity with 7.5 g kg^{-1} of ice slurry ingestion was similar to that achieved with 30 min of cold-water immersion. Similarly, Yeo et al. (2012) reported that ice slurry ingestion before exercise improved 10-km running performance in the heat.

Several studies (Ross et al., 2011; Siegel et al., 2010, 2012; Yeo et al., 2012) have previously demonstrated the beneficial effects of ice slurry ingestion before exercise on endurance exercise in the heat; however, no studies have examined the optimal timing for ice slurry ingestion. Until recently, precooling has typically been administered prior to warm-up in studies where a warm-up was included (Siegel et al., 2012; Yeo et al., 2012). This approach is a relic of traditional external body precooling. Due to the decrease in muscle temperature

---

* Corresponding author.
E-mail address: hasehiro@hiroshima-u.ac.jp (H. Hasegawa).

http://dx.doi.org/10.1016/j.jtherbio.2017.01.010
Received 8 August 2016; Received in revised form 23 January 2017; Accepted 23 January 2017

with external body cooling, reductions in-high intensity exercise performance have been observed (Sleivert et al., 2001); therefore, with external techniques, precooling must be applied prior to warm-up. With external cooling techniques, the need to apply precooling prior to warm-up may result in loss of the benefit during the warm-up itself.

In contrast, internal body cooling techniques, such as ice slurry ingestion, can be performed either before or after warm-up, as the decrease in core body temperature observed with internal cooling techniques is independent of muscle temperature. Indeed, ice slurry ingestion after warm-up shortens the interval between the precooling period and exercise; therefore, it is possible that internal precooling could more directly contribute to exercise performance and persist for a greater period of time than traditional external techniques. However, no studies have yet evaluated the optimal timing for precooling.

Therefore, this study aimed to evaluate how varying the timing of ice slurry ingestion for precooling (ingestion before or after warm-up) affects endurance exercise capacity in a warm environment.

2. Materials and methods

2.1. Participants

This study included 10 healthy non-heat-acclimatised male participants (age: 20.3 ± 1.6 years; height: 170.4 ± 4.2 cm; body mass: 60.1 ± 4.9 kg; peak power output (PPO): 242 ± 27 W). The study procedures were approved by the Ethics in Human Research Committee of Hiroshima University and all participants signed an informed consent form before the start of the study.

2.2. Overview

The participants completed a progressive exercise test, familiarised themselves with the exercise, and performed 3 experimental trials to exhaustion at 55% PPO on a cycle ergometer (POWERMAX-V2, COMBI, Japan). This intensity was chosen so that participants could continue to exercise for 1 h in a warm environment; this was based on our previous laboratory study (Hasegawa et al., 2006) indicating that the effectiveness of ice slurry ingestion on exercise performance was established within approximately 40–80 min of exercise (Ross et al., 2011; Siegel et al., 2010, 2012; Yeo et al., 2012). The environmental conditions for the experimental trials were set at 30 °C and 80% relative humidity to simultate the environmental conditions of future summer Olympic Games such as 2020 Tokyo. The 3 experimental trials included a trial involving no ice slurry ingestion (CON), a trial involving ice slurry ingestion (−1 °C) before warm-up (PRE), and a trial involving ice slurry ingestion after warm-up (POST). Throughout the study period, the participants were asked to maintain their normal lifestyle activities at a stable level, including their physical activity and nutritional habits. During the 24-h period prior to the trials, the participants were asked to avoid consuming alcohol and caffeine. The 3 experimental trials were performed with an interval of by at least 4 days in a counterbalanced order. All trials were performed at the same time of the day for each participants (between 16:00 and 19:00) to eliminate any effects of circadian variations.

2.3. Preliminary measurements

Before participating in the 3 trials, the participants familiarised themselves with the cycling exercise and performed a maximal exercise test to determine their PPO. This test consisted of a 5-min warm-up at 60 W followed by increases of 20 W every 2 min until volitional exhaustion. PPO was determined using the following formula:

$$\mathrm{PPO} = W_{\mathrm{out}} + (t/120) \times 20$$

where W_{out} is the wattage of the last completed stage, and t is the time spent in the final stage. Heart rate (HR) was continuously monitored using short-range radio telemetry (RS800CX, Polar Electro, Finland).

2.4. Experimental protocol

Upon arrival at the laboratory, a small urine sample was collected, and 1 ml of the urine sample was used for urine specific gravity (USG) measurement. Then, nude body mass was measured. A rectal thermistor (LT-ST08-21, Nikkiso-Therm Co. Ltd., Japan) was self-inserted 12 cm past the anal sphincter with a disposable rubber sheath (11Y24, Nikkiso-Therm Co. Ltd.). Then, skin thermistors and an HR monitor were attached. The participants then entered a climate chamber (29.7 ± 0.4 °C, 78.8 ± 3.5% Rh) and were kept at rest for 5 min to measure baseline data. The participants then ingested 7.5g kg^{-1} of thermoneutral fluid (37 °C) or ice slurry over a period of 15 min before and after a 15-min warm-up at 30% PPO. Specifically, the participants ingested thermoneutral fluid both before and after warm-up in the CON condition, ingested ice slurry before warm-up and thermoneutral fluid after warm-up in the PRE condition, and ingested thermoneutral fluid before warm-up and ice slurry after warm-up in the POST condition. The ingestion volume of 7.5g kg^{-1} of ice slurry has previously been shown to elicit large reductions in core body temperature without inducing gastrointestinal distress (Siegel et al., 2012). Thermoneutral fluid (37 °C) was ingested to ensure similar hydration status between trials (Siegel et al., 2012) and served as a control to observe the physiological responses associated with ingestion of fluid without imposing a heat load or a heat deficit (Lee et al., 2008). To ensure a standardised ingestion rate, the participants were administered 2.5g kg^{-1} of the fluid every 5 min. All beverages were conventional sports drinks (Energen, Otsuka Pharmaceutical, Japan), and ice slurry was prepared using a slurry machine (DM1000, Margaritaville, Australia). The participants were kept at rest for 5 min before the exercise capacity test. Exhaustion was considered when participants could not maintain 60 rpm or their rectal temperature (T_{re}) reached 39.5 °C. A pre-exercise cutoff USG value of < 1.030 was used to ensure that all participants were adequately hydrated before starting each experimental trial.

2.5. Measurements

T_{re}, mean skin temperature (T_{sk}), HR, nude body mass, and USG were measured as physiological indices. Skin temperatures were measured at 3 sites (chest, upper arm, and thigh), and the thermistors were secured with micropore tape. All thermistors were connected to a data collection device (LT-8A, Gram Corporation, Japan), and temperatures and HR were recorded every 5 min. The T_{sk} was calculated using the following formula presented by Roberts et al. (1977):

$$T_{\mathrm{sk}} = 0.43 \times (T_{\mathrm{chest}}) + 0.25 \times (T_{\mathrm{arm}}) + 0.32 \times (T_{\mathrm{thigh}})$$

where T_{chest} is the skin temperature at the chest, T_{arm} is the skin temperature at the upper arm, and T_{thigh} is the skin temperature at the thigh. The rate of increase in the T_{re} during exercise (ΔT_{re}; °C 5 min^{-1}) was calculated using the following formula:

$$\Delta T_{\mathrm{re}} = 5 \times (\text{change in } T_{\mathrm{re}}\,[^{\circ}\mathrm{C}] \text{ during exercise}) / (\text{exercise time [min]})$$

Nude body mass was measured to the nearest 100 g using a digital scale (HBF-373, Omron, Japan), and USG was determined using a digital USG scale (UG-D, Atago, Japan) before and after each trial to assess the hydration states. Sweat rate was calculated using the following formula:

$$\begin{aligned}\text{sweat rate } (\mathrm{kg\ h}^{-1}) = {} & (\text{nude body mass before the trial [kg]} \\ & -\text{nude body mass after the trial} \\ & \text{[kg]} + \text{the amount of ingested drink [kg]})/ \\ & (\text{exercise duration [h]})\end{aligned}$$

Subjective thermal sensation (TS; 0 [unbearably cold] to 8 [un-