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The effect of ice slurry ingestion on body temperature and cycling performance in competitive athletes

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Abstract

The effects of pre cooling on endurance performance are widely known. In contrast, the approach of cooling during endurance exercise in combination with pre-exercise cooling has been poorly understood. The purpose of the present study was to determine whether the effects of precooling and cooling during exercise enhance exercise performance compared to the ingestion of a thermo-neutral beverage (20 °C) or precooling alone in cycling performance. This was an experimental study using a randomised crossover design in which 7 cyclists underwent three trials comprising of 45 minutes steady state cycling (SS) at 70% VO₂ max and a subsequent 10km time trial (TT) in hot conditions (32°C, 50% relative humidity). Rectal temperature (T_{re}), heat storage (HS), heart rate (HR), blood lactate concentration (BLA) and thermal sensation (TS) were measured. The intervention consisted of: (1) ingestion of thermo-neutral beverage before and during SS cycling (TN), (2) ingestion of ice slurry beverage and application of iced towels (precooling) prior to exercise, and then ingestion of thermo-neutral beverage during SS (PRE) and (3) precooling strategy as above plus ice slurry ingestion during SS cycling (PRE + MID). The intake of thermo-neutral or ice slurry beverage (14 g/kg) occurred over 30 min before and every 15 minutes during SS cycling. There was no significant difference in TT performance between all the conditions (P=0.72). However, PRE and PRE + MID caused a significant decrease in

T_{re} ($P < 0.05$) from TN during exercise. Accordingly, both precooling and a combination of precooling and mid-cooling during exercise in hot conditions may be a practical and effective way of reducing core temperature. Future studies should investigate longer distance events and timing of ice slurry ingestion.

Keywords: Thermoregulation, physiology, ice slurry, cycling.

1. Introduction

Athletes experience thermoregulatory strain during exercise in a hot and humid environment, leading to decreased central neurological drive and reduced skeletal muscle activation (Nybo et al., 2014; Ament et al., 2009; Morris et al., 2016). Excess generated body heat must be dissipated in order to maintain homeostasis during exercise in thermo-neutral or hot conditions (Ament & Verkerke, 2009). Two strategies to reduce core temperature include pre-cooling and cooling the body during exercise (mid-cooling). Reducing initial temperature gives the body an increased capacity to store metabolic and environmental heat (Noakes, 2000; Ross et al., 2013). Pre-cooling may produce a heat 'sink', allowing the athlete to exercise for longer before reaching a high core temperature that may be associated with reduced exercise intensity or the cessation of exercising altogether ($\sim 40^{\circ}\text{C}$) (Nielsen et al., 1993). Moreover, mid-cooling may allow for continual maintenance and/or enhancement of the positive effects associated with pre-cooling for endurance performance in hot conditions (Burdon et al., 2013; Tyler et al., 2015; Munir et al., 2013). Cooling the body using external devices (i.e. cooling jackets, cold-water immersion, cold-air exposure) presents practicality issues for athletes in the field, whereas, ice slurry ingestion and iced-towels may present an accessible alternative to these methods (Lee et al., 2008).

Ice slurry ingestion is an effective pre-cooling strategy for reducing rectal (Siegel et al., 2012), gastrointestinal (Ihsan et al., 2010), skin temperatures (Siegel et al., 2010), and improving exercise performance (Steven et al., 2016; Maunder et al., 2017). It further

assists nutrient (carbohydrate and electrolytes) delivery and sustains hydration status. However, Morris et al. (2016) recently expressed reservation regarding ice slurry ingestion since it may lead to a lower net heat loss during exercise in warm conditions. Moreover, an improvement in exercise performance has not always been consistently demonstrated. This is the case of Stevens et al., (2016) when measuring effects with runners using two different techniques; menthol mouth rinse and ice slurry ingestion. The lacking effect of ice slurry may be a consequence of a shorter exercise protocol inducing lower levels of heat stress, as previous studies that also reported no improvements Levels et al. (2013) with slightly shorter protocols.

Fewer studies have been conducted examining the effect of a combination of pre and mid-cooling (Stevens et al., 2017). Some studies have demonstrated improved endurance performance using the combination method (Tran Trong et al., 2015) whereas others have reported no benefit (Schultze et al., 2015). Furthermore, Stevens et al. 2017 reported no added benefit of pre-cooling in addition to mid-cooling in isolation for short duration endurance performance. Therefore, further research is required to elucidate the effect of a combined approach to cooling for the enhancement of performance in hot conditions. The aim of the study was to assess the effectiveness of a combined approach of pre- and mid-cooling upon cycling performance in hot conditions. Therefore, we hypothesised that a combined approach of pre-cooling and ice slurry ingestion during exercise, will improve cycle time trial performance in the heat compared to consumption of a thermo-neutral drink.

2. Methods

2.1. Participants

Seven well trained and unacclimatized, male road cyclists (age 34.7 ± 6.3 y, height 178.6 ± 6.7 cm, weight 77.1 ± 8.4 kg, $\dot{V}O_2$ max 59.54 ± 6.7 ml/kg/min) volunteered to participate in the study. The participants were accustomed to prolonged and intensified

exercise in training and competition with a minimum of seven years of cycling competition experience. All of them participated in national events in Australia during the year of study and two of them participated in international championships. Prior to the experiment, participants underwent a health screening questionnaire that identified any contraindications to exercise. This ensured that participants were free of injury or illness and had no prior history of heat stress. Participants were provided written informed consent documents before participating and were able to withdraw at any time. The study was approved by the University of Adelaide Human Research Ethics Committee and performed according to the Helsinki Declaration.

2.2. *Preliminary Measures*

Body mass (in cycling shorts) was measured to the nearest 0.1 kg using an electronic floor scale (Tanita, Tokyo, Japan). VO_{2max} was determined by a maximal incremental exercise test to exhaustion on a cycle ergometer (Wattbike, Nottingham, UK). The test comprised 3 minute stages and commenced at a workload of 1.5 W/kg of body mass, and increased by 30 W at the completion of each stage. The test was terminated when the participant could no longer maintain the required workload or reported volitional exhaustion. Pulmonary ventilation (VE), oxygen uptake (VO_2) and carbon dioxide production (VCO_2) were recorded through a fully automated indirect calorimetry system (K4b2, Cosmed, Rome, Italy).

2.3. *Experimental Design*

Participants attended four separate sessions: a preliminary and three experimental trials. Participants were allocated an order of experimental trials in a randomised crossover design. Trials were (1) thermo-neutral trial with no cooling before or during exercise (TN), (2) pre-cooling before exercise (PRE), or (3) pre-cooling and mid-cooling during exercise (PRE+MID). Before each trial participants undertook a 15 minute warm up at 1.5W/kg in temperate conditions (23°C, 50% relative humidity). The experimental

trials took place in hot conditions (32°C, 50% relative humidity) within an environmental controlled chamber. Participants exercised on a cycle ergometer (Wattbike, Nottingham, UK) at 70% VO_{2max} steady state (SS) for 45 min, followed by a 10 km time trial (TT), using self-selected cadence and intensity (see Figure 1). The only information available to participants during the TT was the distance covered (m). Participants maintained and recorded regular training commitments during the period and were asked to refrain from exercise during the preceding 24 hours of each session.

2.4. *Cooling methods*

The pre-cooling procedure followed the protocol outlined by Ross et al. (2011). This involved the ingestion of ice slurry (-1°C) made from a commercially available 7.4% carbohydrate-electrolyte sports beverage (Powerade Isotonic, Coca-Cola Amatil, Australia) at 14g/kg of body mass in combination with the application of iced towels to the torso in the half hour before cycling. Cooling during exercise involved the ingestion of ice slurry while cycling. The amount and timing for ingestion was modelled on the study by Burdon et al. (2013) in which participants consumed 260 ± 38 g of ice slurry made from sports beverage every 15 min throughout steady state cycling. Participants during the TN trial ingested an identical quantity of sports beverage (14g/kg) at 20°C as the PRE and PRE+MID protocols to ensure total fluid consumption and carbohydrate ingestion was the same across all trials. This acted as a control to observe the physiological responses associated with sports beverage ingestion without imposing a heat load or deficit.

2.5. *Physiological and exercise performance measures*

Ambient temperature (°C) and relative humidity (%) were monitored using an electronic thermometer with a hygrometer (TA298, Chengdu, China) during each trial. Before and after each trial participants (in cycling shorts) were weighed and total body water (%) assessed using an electronic floor scale (Tanita, Tokyo, Japan). Physiological

measures were recorded every 5 min during the half hour before cycling, every 15 min during SS cycling, and every 5 min during the TT. Participants self-inserted a rectal probe thermometer (Monatherm Thermistor, Covidien, USA) to 10 cm past the anal sphincter. The rectal probe was attached to a temperature monitor (DUOTEMP Fisher and Paykel Healthcare, Oakland, New Zealand) for measurement of rectal temperature (T_{re}). Heat storage (HS) was calculated by $HS=0.965 \times m \times \Delta T_b/A_D$, where 0.965 is the specific heat storage capacity of the body ($W \cdot kg^{-1} \text{ } ^\circ C$), m the mean body mass (kg), and A_D is body surface area (m^2) ($A_D=0.202m^{0.425} \times \text{Height}^{0.725}$) (Dubois and Dubois, 1989; Adams et al., 1992). A chest strap and corresponding heart rate monitor were secured to measure heart rate (HR) (b/min) (Polar, Kempele, Finland). Blood (40 uL) was collected via finger tip sampling at baseline, the beginning, end, and every 15 minutes during SS cycling, and the conclusion of the TT. This was used for measurement of blood lactate concentration (BLA) (mM) using a portable analyser Lactate Scout (EKF Diagnostics, Berlin, Germany). Rating of thermal sensation (TS) (Toner et al., 1985) was recorded every 5 minutes over the half hour before cycling and every 15 minutes during SS.

2.6. Data Analysis

Mean (95% confidence intervals) and standard deviations were calculated for each variable. Cycle TT performance was compared using an analysis of variance (ANOVA). The effects of the different cooling strategies on each physiological variable were assessed using a two way ANOVA (trial x time). Post-hoc Student's t-test with Sidak-Bonferroni adjustment was used to define differences when a significant main effect was found. For all comparisons, significance was set at $P < 0.05$. Cohen's d effect sizes for the TT performance results were calculated with descriptive thresholds of small ($d=0.2$), moderate ($d=0.6$), large ($d=1.2$), and very large ($d=2.0$) (Hopkins 2010).

3. Results

3.1. Performance

A two-way ANOVA indicated there were no significant differences in 10km TT performance between the three conditions [(TN: 945 ± 89 s, PRE: 920 ± 65 s, PRE + MID: 929 ± 68), $P=0.72$]. Effect size calculations identified a small ($d=0.28$) performance benefit in the PRE trial in comparison to the TN trial, whereas there were only trivial differences between TN vs PRE + MID ($d=0.18$), and PRE vs PRE + MID ($d=0.10$).

3.2. Core Temperature

Participants commenced each test with a similar T_{re} (TN: 37.2 ± 0.70 °C, PRE: 37.4 ± 0.58 °C, PRE + MID: 37.3 ± 0.20 °C, $P=0.86$). There was no significant difference during the pre-exercise phase T_{re} between the three trials ($P=0.48$), but there were significant differences during the SS cycling and TT between TN vs. PRE + MID and TN vs. PRE, being $P<0.05$ respectively (Figure 2).

3.3. Heart Rate

There were no significant differences in HR during SS cycling (TN: 156 ± 17 bpm, PRE: 148 ± 20 bpm, PRE + MID: 150 ± 20 bpm, $P=0.26$). However, at the end of the TT, the increase of HR was significantly lower in the PRE + MID: 166 ± 2 bpm than TN: 182 ± 10 bpm ($P<0.05$) and PRE: 175 ± 9 bpm ($P<0.05$) (Figure 3).

3.4. Blood Lactate

The BLA concentration increased over time in all three trials ($P<0.05$), but was similar at each time point, except at 15 min into SS cycling, where PRE was significantly lower than TN ($P<0.05$) (Figure 4).

3.5. *Subjective responses to heat*

Thermal sensation was lower in PRE (1.3 ± 0.9 au) and PRE + MID (1.6 ± 0.8 au) than (3.6 ± 0.5 au) TN ($P < 0.05$) during the pre-exercise stage. Ratings were also significantly lower in PRE and PRE + MID than TN during the SS cycling ($P < 0.05$).

4. Discussion

The study examined the effect of pre-cooling in isolation in comparison to a combination of pre- and mid-cooling during a cycling protocol in hot conditions. The main finding was that there was no improvement in cycling performance despite participants displaying lower T_{re} during the PRE and PRE + MID trials in comparison to TN. In addition, rating of TS was lower in both PRE and PRE + MID during the intervention and SS cycling. These findings partially support our hypothesis as PRE + MID blunted an exercise induced rise in T_{re} , although this was not associated with improved cycle TT performance.

It has been proposed that ice slurry ingestion is associated with the formation of a heat sink and cooling of core temperature (Siegel et al., 2010). This allows for greater heat storage during exercise, delaying the attainment of high internal temperatures (Tyler et al., 2015). However, the present study failed to show an improvement in endurance performance across any of the interventions. This is consistent with the similar ratings of perceived exertion across interventions before the TT, indicating there was no difference in perceptual strain during SS cycling. These findings contrast studies gathered in systematic reviews (Burdon et al., 2010; Ross et al., 2011) which report ice slurry ingestion and other pre-cooling strategies to improve endurance performance in the heat.

The failure to find any effects of the cooling measures on performance may be due to the exercise protocol not being of sufficient length to detect changes. In fact, thermal strain is not likely to be key determinant in shorter events like running (Guy et al.,

2015). The present study examined 45 minutes of SS cycling at 70% VO_{2max} followed by a 10km TT. This may have not generated sufficient heat stress and therefore stunting the potential effect of the cooling interventions. Ihsan et al. (2010) reported that pre-cooling via ingestion of an ice slurry beverage before a 40km cycle time trial (~85 min) improved subjects performance compared to the ingestion of cold water alone. Ross et al. (2011) showed that pre-cooling via the application of ice towels to the body and ingestion of ice slurry allowed improved performance on a 46 km cycling TT (~80 min) compared to *ad libitum* consumption of cold water. Similarly, Burdon et al. (2013) found that ice slurry ingestion (4 kJ/kg body mass) during 90 min of SS cycling at 62% VO_{2max} was associated with improved performance during a time trial. Therefore, it is likely that a longer TT duration than the current study is required for the cooling interventions to provide a positive performance effect.

In our study, T_{re} was lower in PRE and PRE + MID than TN ($P < 0.05$) during the TT. Ice slurry ingestion has the advantage in that it does not greatly impact the reflex control of body temperature potentially due to the combination of two different factors. Firstly the amount of slurry taken and on the other hand, the time elapsed between the ingestion and the sampling. Concerning cardiovascular responses, HR was reduced in PRE + MID compared to TN and PRE during SS cycling. This is supported by the decreased ratings of TS at the end of the resting period and throughout SS exercise. Greater sweat loss during exercise in the heat leads to dehydration and decreases in cardiac output, which is compensated for by an increase in HR. The potential heat sink created by ice slurry ingestion may allow for more metabolic heat to be produced without compromising cardiovascular dynamics (Kay et al., 1999), leading to an attenuated rise in HR. This is supported by studies investigating the effect of pre-cooling on thermoregulatory responses during exercise (Tyler et al., 2015). When exercising in hot conditions (~40°C) muscle glycogenolysis, BLA accumulation and RER increase above that of exercise in moderate conditions (~20°C) (Febbraio et al., 1994). This may be

due to attenuation in muscle blood flow and to an increase in the skin blood flow, in heat stress (Nybo, 2008). However, BLA levels were lower for PRE 30 minutes into steady state than TN. This may be because pre-cooling attenuates the change in blood flow from the muscle to the skin. Cooling may indirectly influence performance due to an alteration in the level of perceived thermal strain experienced by the individual (Hessemer et al., 1984). Past research has shown that the sensory effect of presenting cold stimuli in the mouth may be associated with a reduction in the perception of effort and improved thermal comfort (Burdon et al., 2013). The significant difference in TS during the cooling interventions may influence cognitive functioning, being beneficial for sport performance.

The study is not without limitations. Firstly, the different protocols used for each trial cannot be blinded to the participants. The possibility that the participants believed the cooling interventions should be beneficial may have influenced their motivation, subjective thermal sensation, and subsequent performance. However, the use of a randomised crossover design lessened the ability for a participant to prepare for a particular trial, and mitigated potential learning effects. Participants were also well trained cyclists who were accustomed to the requirements and pacing of a 10km time trial event. Another important limitation it is the fact that during laboratory sessions, the fanning effect to simulate outdoor cycling was not implemented. In recent studies, the influence of the airflow has been demonstrated to exaggerate the benefits of pre-cooling (Morrison et al., 2014). Future research should be conducted using this combined approach on exercise performance using longer distance exercise protocols with real simulation of ice slurry availability.

5. Conclusions

In conclusion, the combined approach of pre- and mid-cooling did not enhance cycling performance (10 km TT) compared to a TN trial (ingestion of a thermo-neutral

beverage) or pre-cooling alone. Interestingly, PRE and PRE + MID were able to reduce T_{re} compared to TN and this was perhaps associated with lower perceptions of TS. Therefore, the ingestion of ice slurry may be a practical and effective way of cooling the body before and during exercise.

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Conflict of interest

None.

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Figure 1. Design for the three experimental trials.

Figure 2. Core Temperature during the whole protocol. Mean (\pm SD) core temperature taken at 5 minute intervals during pre-exercise and 15 minute intervals during steady state cycling (SS), and 5 minute intervals during the time trial (TT). (*) PRE < TN (P<0.05), (#) PRE+MID < TN (P<0.05). TN: ingestion of thermo-neutral beverage before and during SS cycling; Pre: ingestion of ice slurry beverage and application of iced towels prior to exercise, and then ingestion of thermo-neutral beverage during SS; PRE +MID: precooling strategy as PRE plus ice slurry ingestion during SS cycling.

Figure 3. Heart rate (HR) during Steady state cycling (SS) and Time Trial (TT). Mean (\pm SD) . (*) PRE + MID < TN and PRE (P<0.05). TN: ingestion of thermoneutral beverage before and during SS cycling; Pre: ingestion of ice slurry beverage and application of iced towels prior to exercise, and then ingestion of thermo-neutral beverage during SS; PRE+MID: precooling strategy as PRE plus ice slurry ingestion during SS cycling.

Figure 4. Blood lactate concentration (BLA) during Steady state cycling (SS) and Time Trial (TT). Mean (\pm SD) . (*) PRE < TN (P<0.05). TN: ingestion of thermo-neutral beverage before and during SS cycling; Pre: ingestion of ice slurry beverage and application of iced towels prior to exercise, and then ingestion of thermo-neutral beverage during SS; PRE +MID: precooling strategy as PRE plus ice slurry ingestion during SS cycling.

HIGHLIGHTS

Pre cooling and pre + mid-cooling reduced rectal temperature compared to a control group but no performance benefit was observed.

The ingestion of ice slurry may be a practical and effective way of cooling core temperature before and during exercise.

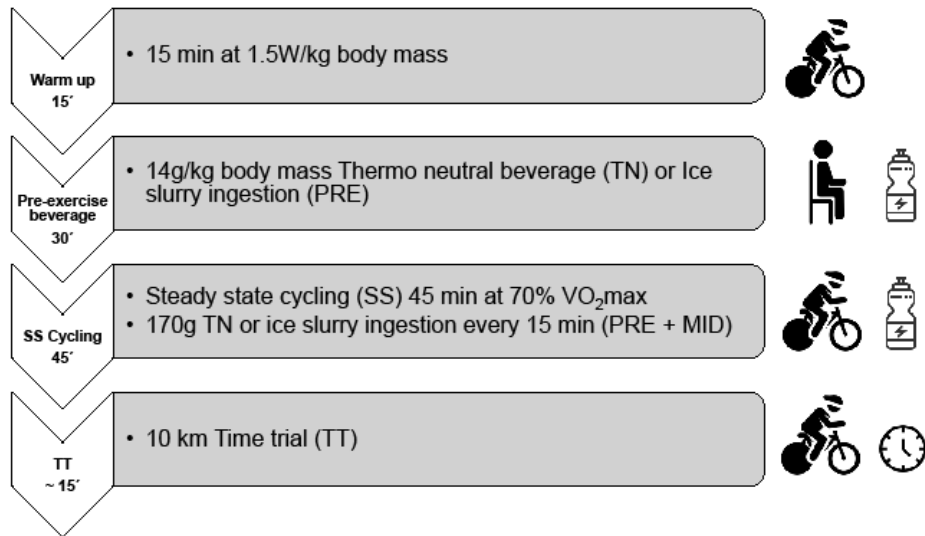


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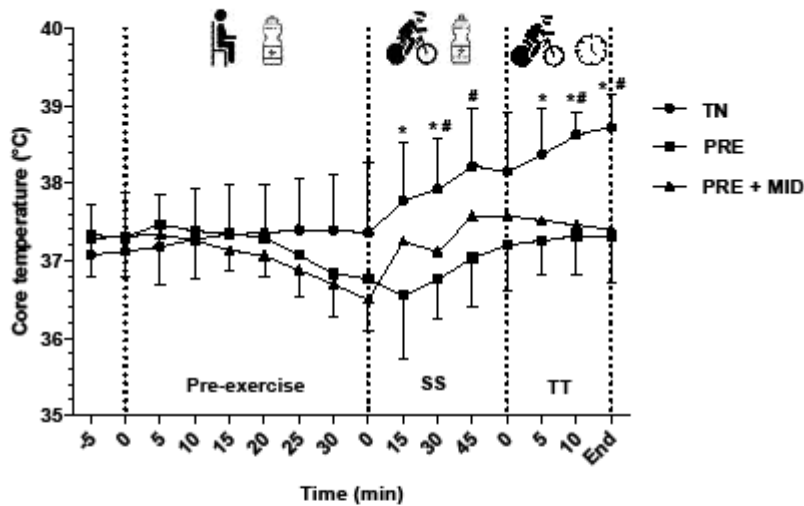


Figure 2. Core Temperature during the whole protocol. Mean (\pm SD) core temperature taken at 5 minute intervals during pre-exercise and 15 minute intervals during steady state cycling (SS), and 5 minute intervals during the time trial (TT). (*) PRE < TN ($P < 0.05$), (#) PRE+MID < TN ($P < 0.05$). TN: ingestion of thermo-neutral beverage before and during SS cycling; Pre: ingestion of ice slurry beverage and application of iced towels prior to exercise, and then ingestion of thermo-neutral beverage during SS; PRE +MID: precooling strategy as PRE plus ice slurry ingestion during SS cycling.

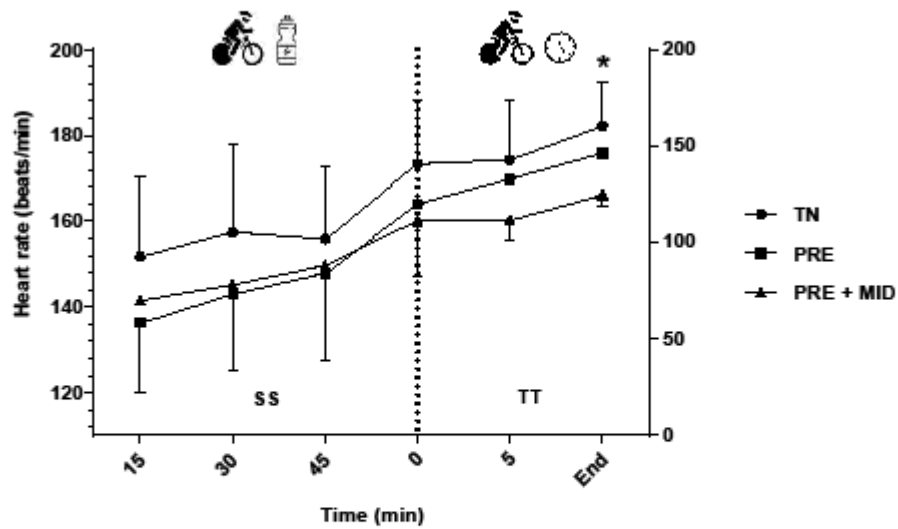


Figure 3. Heart rate (HR) during Steady state cycling (SS) and Time Trial (TT). Mean (\pm SD). (*) PRE + MID < TN and PRE ($P < 0.05$). TN: ingestion of thermo-neutral beverage before and during SS cycling; Pre: ingestion of ice slurry beverage and application of iced towels prior to exercise, and then ingestion of thermo-neutral beverage during SS; PRE+MID: precooling strategy as PRE plus ice slurry ingestion during SS cycling.

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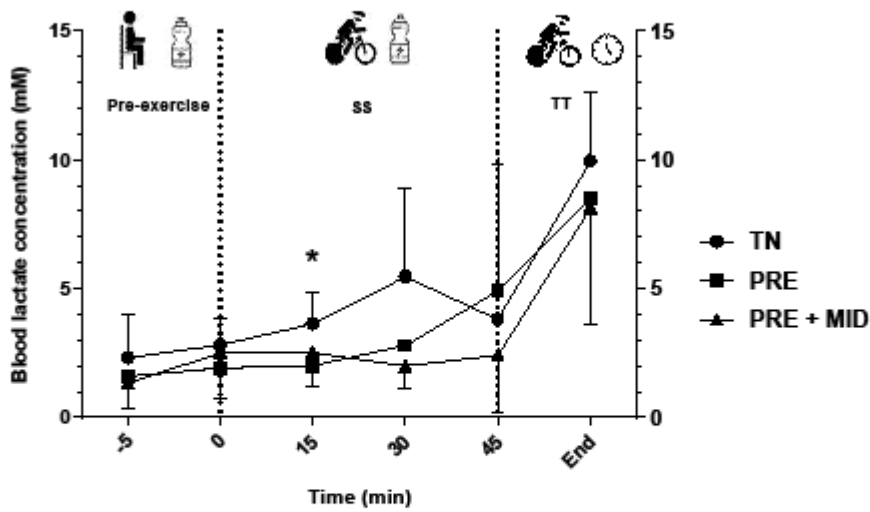


Figure 4. Blood lactate concentration (BLA) during Steady state cycling (SS) and Time Trial (TT). Mean (\pm SD). (*) PRE < TN ($P < 0.05$). TN: ingestion of thermo-neutral beverage before and during SS cycling; Pre: ingestion of ice slurry beverage and application of iced towels prior to exercise, and then ingestion of thermo-neutral beverage during SS; PRE +MID: precooling strategy as PRE plus ice slurry ingestion during SS cycling.

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