The Effect of Ice Slushy Ingestion and Mouthwash on Thermoregulation and Endurance Performance in the Heat

Catriona A. Burdon, Matthew W. Hoon, Nathan A. Johnson, Phillip G. Chapman, and Helen T. O’Connor

Purpose: The purpose of this study was to establish whether sensory factors associated with cold-beverage ingestion exert an ergogenic effect on endurance performance independent of thermoregulatory or cardiovascular factors.

Methods: Ten males performed three trials involving 90 min of steady state cycling (SS; 62% VO$_{2\text{max}}$) in the heat (32.1 ± 0.9 °C, 40 ± 2.4% relative humidity) followed by a 4 kJ/kg body mass time trial (TT). During SS, participants consumed an identical volume (260 ± 38g) of sports beverage (7.4% carbohydrate) every 15 min as either ice slushy (–1 °C; ICE), thermoneutral liquid (37 °C; CON), or thermoneutral liquid consumption with expectorated ice slushy mouthwash (WASH).

Results: Rectal temperature, hydration status, heart rate, and skin blood flow were not different between trials. Gastrointestinal (pill) temperature was lower in ICE (35.6 ± 2.7 °C) versus CON (37.4 ± 0.7 °C, $p = .05$). Heat storage tended to be lower with ICE during SS (14.7 ± 8.4W.m$^{-2}$, $p = .08$) and higher during TT (68.9 ± 38.6W.m$^{-2}$, $p = .03$) compared with CON (22.1 ± 6.6 and 31.4 ± 27.6W.m$^{-2}$). ICE tended to lower the rating of perceived exertion (RPE, 12.9 ± 0.6, $p = .05$) and improve thermal comfort (TC, 4.5 ± 0.2; $p = .01$) vs. CON (13.8 ± 1.0 and 5.2 ± 0.2 respectively). WASH RPE (13.0 ± 0.8) and TC (4.8 ± 0.2) tended to be lower versus CON ($p = .07$ and $p = .09$ respectively). ICE improved performance (18:28 ± 1:03) compared with CON (20:24 ± 1:46) but not WASH (19:45 ± 1:43).

Conclusion: Improved performance with ICE ingestion likely resulted from the creation of a gastrointestinal heat sink, reducing SS heat storage. Although the benefits of cold-beverage consumption are more potent when there is ingestion, improved RPE, TC, and meaningful performance improvement with WASH supports an independent sensory effect of presenting a cold stimulus to the mouth.

Keywords: body core temperature, cycling, cold drink, beverage temperature

Exercise in the heat is known to exacerbate the rise in body core temperature that occurs with prolonged exercise (Armstrong et al., 1985); therefore, regular fluid consumption is recommended to maintain endurance performance and reduce thermoregulatory strain (Sawka et al., 2007). Early investigations of voluntary fluid consumption during exercise established that hydration is improved with cold versus warm or hot beverages (Boulize et al., 1983). It has been hypothesized that reduced body core temperature, heat storage, and an associated decline in cardiovascular strain may explain the reported performance benefit with ingestion of cold or ice-slushy beverages (Kay & Marino, 2000; Mündel et al., 2006; Siegel & Laursen, 2012). However, a sensory mechanism has also been proposed (Burdon et al., 2010b).

Previous studies reporting an improvement in exercise performance with cold beverage ingestion in hot environments attributed the benefit, in part, to a reduction in body core temperature and/or cardiovascular strain (Lee et al., 2008b; Mündel et al., 2006; Siegel et al., 2010). A majority of studies have observed a reduction in body core temperature and heat storage with cold beverage consumption before or during exercise in the heat (Lee et al., 2008a; Lee et al., 2008b; Siegel et al., 2010; Szlyk et al., 1989) and this may influence cardiovascular strain by redirecting blood flow from the skin to working muscles. A reduction in cardiovascular strain, as inferred by reduced heart rate (Lee et al., 2008a; Lee et al., 2008b; Mündel et al., 2006; Szlyk et al., 1989), or skin blood flow (Wimer et al., 1997), has been found in some but not all studies (Burdon et al., 2010a; Ihsan et al., 2010; Lee et al., 2007; Siegel et al., 2010) and therefore suggests another mechanism is the predominant contributor to fatigue. A reduction in body core temperature during exercise in the heat has previously been demonstrated to increase activation of the central nervous system and improve performance (Morrison et al., 2004; Skein et al., 2012; Thomas et al., 2006). This has not been measured in studies of beverage temperature, however improved force production and/or a reduction in perceived exertion...
for the same workload suggests central fatigue is reduced (Lee et al., 2008b; Siegel et al., 2010, 2011, 2012).

In addition to temperature and/or cardiovascular influences, the performance improvement from cold beverage consumption may be partly mediated by altered feedback from thermoreceptors in the mouth region and/or gastrointestinal tract (Sieg et al., 2011; Villanova et al., 1997). Villanova et al. (1997) established that cold and warm stimuli in the stomach were consciously perceived and suggests a role for the gastrointestinal tract in perception of temperature. It was subsequently documented that a small (3.5 ml) cold sensation in the mouth increased pleasantness and stimulated areas of the brain associated with reward/pleasure (Guest et al., 2007). It is therefore hypothesized that performance may be improved due to a reduced perception of body temperature and/or via increased central drive resulting from improved sensation of reward/pleasure. This sensory effect has been corroborated with evidence showing an improvement in endurance performance and associated reduction in perception of effort following menthol mouthwash to elicit a cold like sensation during exercise in the heat (Mündel & Jones, 2010). Furthermore, Siegel et al. (2011) observed that force production during a sustained (2 min) maximal voluntary contraction was improved following endurance exercise in the heat with ingestion of a small quantity of ice slushy (Siegel et al., 2011). We previously examined the effect of ice slushy ingestion on prolonged exercise performance in the heat. The observed tendency for performance benefit may have been confounded by systemic effects as a decreased body core temperature was observed before the time trial in the slushy versus thermoneutral trial (Burdon et al., 2010a).

The aim of this study was to examine whether there is an ergogenic benefit of cold beverage ingestion resulting from sensory factors independent of cardiovascular and/or body core temperature influences during endurance exercise performance in the heat. To delineate the effect of systemic and sensory factors, a randomized controlled trial was undertaken comparing ice slushy consumption with expectorated ice slushy mouthwash. We hypothesized that, when compared with a thermoneutral beverage, consumption of ice slushy would improve endurance performance and be associated with attenuation of thermoregulatory and cardiovascular strain. Furthermore, we hypothesized that a noningested ice slushy mouthwash would also improve endurance performance, in the absence of a change in thermoregulatory or cardiovascular strain. The latter would be consistent with the presence of an independent sensory-only effect.

**Method**

Healthy, naturally acclimatized male endurance cyclists were targeted for recruitment. Potential participants gave informed consent and completed a health screening to determine their eligibility for the study. Participants were excluded if they were taking medications known to influence metabolism or responses to exercise, had a current injury which would be detrimental to cycle ability, or had a measured VO2peak of <55 ml·kg⁻¹·min⁻¹. The study was approved by the University of Sydney human research ethics committee.

**Preliminary Measures**

Participants presented to the laboratory and were measured for stature (to nearest 0.5 cm) using a wall mounted stadiometer (Seca, Germany) and body mass (in swimwear) to 0.01 kg using an electric floor scale (Mettler ID 1, Albstadt, Germany).

Body composition was assessed via hydrostatic weighing with participants fasting 6 hr before measurement. Water temperature and tare weight were recorded before the participants entered the tank. Participants expired maximally, attached a nose clip, and were then submerged sitting on a chair suspended from a 15 kg scale (Chatillon, New York). Weight was recorded when participants were motionless and completely under water. Residual volume was estimated immediately after participants surfaced by having them rebreathe (8–10 breaths) a known volume (5 L) of pure oxygen. The composition of the expired oxygen and carbon dioxide (Pm1111E and Ir1507 sensors; Servomex, Crowborough, UK), and hence the dilution of the known volume of pure oxygen, was used to calculate residual volume according to previously established methodology (van der Ploeg et al., 2000). Body density was calculated (Goldman & Buskirk, 1961) and fat free mass and percent of body fat were determined using the Siri equation (Siri, 1956).

Peak aerobic capacity was measured during a continuous incremental test on a cycle ergometer (Lode Excalibur, Groningen, Netherlands) using methods outlined previously (Burdon et al., 2010a). The test consisted of four submaximal steady-state power outputs of 5 min each (100, 150, 200, 250 W) followed by an incremental increase in power (30 W·min⁻¹) until volitional fatigue. Maximal effort was defined as having a heart rate (HR) within 10% of predicted maximum (based on 220 beats per minute [bpm] minus age) or respiratory exchange ratio (RER) above 1.10. Power output and VO2 was used to calculate workload for the following trials using linear regression. At the end of the incremental exercise test, participants were familiarized with the time trial (TT) protocol.

**Experimental Design**

Participants attended four sessions: a preliminary (described above) and three experimental trials. Twelve participants were allocated to trials in a randomized, counterbalanced order. Trials were ice slushy consumption (−1 °C, ICE), thermoneutral beverage consumption (37 °C, CON), or ice slushy mouthwash with thermoneutral beverage consumption (WASH). The order of each trial was counterbalanced and upon satisfying fitness requirements participants were randomized to which trial they were to complete first. Each trial was separated by a minimum of 7 and no more than 21 days.
As participant blinding to beverage temperature was not possible, participants were informed that time trial purpose and outcome of interest was evolution of body core temperature during self-paced exercise not performance.

During the experimental trials participants exercised on a cycle ergometer (Lode Excalibur, Groningen, Netherlands) for 90 min at a power calculated to elicit 60% of VO2peak using self-selected cadence in a climate chamber at 32 °C, 40% relative humidity (RH), and wind speed set at 3.6 k·h⁻¹. A commercially available 7.4% carbohydrate-electrolyte sports drink (Powerade Isotonic, Coca-Cola Amatil, Australia) was consumed every 15 min at 3.5 g per kg body mass in all trials. Intermittent ice slushy mouthwash was given as 20-s rinse and expectoration of 25 g ice slushy every 5 min during 90 min of steady state exercise (SS). Participants were carefully monitored and expectorate volume examined to ensure that ice was not ingested in WASH. The temperature of CON was controlled by a thermostatic water bath (E-5A, Julabo, Germany), and ICE was made using a commercial “slush” machine (Iceotonic, Essential Slush, Australia). All beverages were consumed within 3 min of presentation from a bottle (CON) or insulated cup (ICE). Beverage temperature was checked before consumption using an electronic thermometer (Thermistor 400 series, Cole Parmer, Illinois, USA). Beverage composition and carbohydrate consumption was the same for all trials. There was no fluid ingestion during the TT and total fluid consumption and carbohydrate ingestion was identical across all trials.

Heart rate (S410, Polar Electro, Kempele, Finland) was taken every minute during SS. Expired air was collected using a Douglas bag for 1 min at 10, 30, 60 and 90 min. Participants self-inserted a rectal probe to 10 cm past the anal sphincter. The rectal probe thermocouple was attached to a custom-made data logger (TLogger, University of Sydney) for measurement of rectal temperature (Tre) every minute. Gastrointestinal temperature (Tpill), to measure the ice-slushy heat sink in the stomach, was monitored with a telemetric pill (CorTemp Sensor, HQInc. Palmetto, USA) swallowed immediately before exercise. Skin temperature was recorded every minute using four skin thermistors (DS1921H-F5 ibutton, Maxim, USA) placed on the left side (upper chest, mid humerus, mid-calf and mid-thigh) and were combined to give an overall temperature: \( T_{sk} = 0.3T_{chest} + 0.3T_{arm} + 0.2T_{thigh} + 0.2T_{leg} \) (Ramanathan, 1964). Skin blood flow (SBF) was measured using laser-Doppler flowmetry (mooLAB, Moor Instruments, Devon, UK) on the right side at four sites (upper chest, upper back, mid humerus and mid forearm) and calculated as a percent of rested SBF in the hot environment. After affixing leads to reduce artifact, resting SBF was checked to ensure stability before measurements and exercise commenced. Standardized locations for \( T_{sk} \) and SBF measurement were determined using anthropometric landmarks. Whole body skin blood flow was calculated from Tre and \( T_{sk} \) measurements using the following equation: \( Q_{sk} = \frac{1}{C} \frac{h}{T_{re} - T_{sk}} \), where \( Q_{sk} \) is skin blood flow, \( C \) is specific heat of blood (≈0.87 kcal·°C⁻¹·L⁻¹) and \( h \) is work measured by \( V_0_2 \) (L·min⁻¹; Rowell, 1986). Body heat storage (HS, W·min⁻²) was estimated as: \( 0.8 \cdot \Delta T_{re} + 0.2 \cdot \Delta T_{sk} \cdot C_p \), where \( C_p \) is specific heat of body tissue and was adjusted for percent fat mass (3.49 kJ·°C⁻¹·kg⁻¹; Havenith et al., 1995). This commonly used two-compartment model for HS was chosen and deemed appropriate due to the crossover/repeated measures study design (Sawka & Castellani, 2007). Ratings of perceived exertion (RPE; Borg, 1973) and thermal comfort (TC; Parsons, 2003) were recorded at 5min intervals during SS at least 2 min post ingestion and before ice slushy rinse in WASH. A 10cm visual analog scale was administered at 45 and 90 min to check participant gastrointestinal discomfort.

Participants and cycling shorts were weighed separately before exercise. During exercise, participants were weighed at 30, 60 and 90 min (to nearest ±0.05kg). Post TT body (after toweling off sweat) and clothing weight (to nearest ±0.05kg) was recorded. Sweat loss was estimated from the differences in body mass pre and post exercise, corrected for fluid consumption, urine output, blood drawn, saline flushing, substrate exchange, respiratory water loss, and metabolic water (Maughan et al., 2007).

Immediately before and after SS, blood was drawn to determine serum osmolality (S0smol). The participants were allowed 5 min rest to allow body mass measurement and the post SS blood sample to be taken. Participants then completed a 4 kJ per kg body weight TT as fast as possible so core temperature evolution at a self-selected work rate could be evaluated. All TT were conducted by the same unblinded investigator and participant encouragement was not given to avoid potential bias. Participants were informed about work remaining approximately each quarter and given a countdown from 25 kJ. To minimize disruption, only HR, Tre, and \( T_{sk} \) were monitored and expectorate volume examined to ensure that ice was not ingested in WASH. Participants were informed about work remaining approximately each quarter and given a countdown from 25 kJ. To minimize disruption, only HR, Tre, and \( T_{sk} \) were recorded during TT. Exercise capacity and performance was assessed using time and average power (AP) recorded in 50 kJ blocks.

Participants completed a 3-day food diary before commencement of the study. To control for the effect of diet and hydration status, guidelines to adjust usual diet to a minimum of 6g per kilogram of body mass of carbohydrate per day were provided and participants were instructed to replicate this for 24 h before each visit and consume 30ml per kilogram body mass of fluid. Dietary compliance was closely monitored through inspection of food diaries which were analyzed using Food Works Version 7.0.2921 incorporating the AusFoods (Brands) revision 11, AusNut (All Foods) revision 18 and Nuttab 2010 revision 13 databases. Participants were instructed to refrain from strenuous activity (no more than a 30-min walk), abstain from alcohol, and replicate caffeine consumption for 24 h before fasting for 6 h (except water consumption) before presenting to the laboratory. Participants commenced each trial at the same time each
day to control the effect of circadian rhythm on body temperature.

**Blood Analysis**

At rest, a cannula was inserted into the antecubital vein. Before exercise, at 90 min and post exercise, 4ml blood was collected and left to clot for measurement of serum osmolality. After centrifugation (Model TJ-6, Beckman Coulter, United States), the serum was removed and osmolality (SOsmol) determined with a freeze point depression osmometer (Osmomat 030, Gallay Scientific, Australia). The cannula was flushed every 20 min with 4 ml saline. Euthydration was considered to be a blood osmolality less than 290 mOsmol·L⁻¹, < 2%Δ 90 min exercise body weight (American College of Sports Medicine, 2007).

**Statistical Analyses**

Statistical analysis was performed with SPSS version 17.0 (SPSS Inc., Chicago, IL). Univariate analysis of variance (ANOVA) was used to evaluate differences in physiological variables between trials at single time points. Repeated-measures ANOVA was used to evaluate differences in physiological variables across time, within trials and Time × Trial effects. To determine which variables were statistically significant a Bonferroni post hoc test was applied. Effect sizes and mean differences with 90% confidence intervals (CI) were also calculated. An effect is considered unclear when the CI cross zero. Statistical significance was set at $p < .05$. Data are reported as mean $M ± SD$. Magnitude based inferences (Batterham & Hopkins, 2005) were used to determine the true effect of ICE and WASH on performance using 90% confidence limits as a measure of uncertainty. The effect was deemed unclear if the confidence interval overlapped the thresholds for substantial change (harm or benefit). Substantial change was defined for performance as 0.3 or 2% (Hopkins et al., 2001).

Post hoc power analysis revealed an achieved power of 0.9 using ICE vs. CON performance data based on an effect size of 1.49 and α=0.05.

**Results**

Thirteen participants were recruited for the study; after the preliminary visit, one participant was excluded on the basis of inadequate fitness ($VO_{2\text{max}} < 55 \text{ ml·kg}^{-1}·\text{min}^{-1}$) and two dropped out due to inadequate time availability after completion of the first trial. Ten participants (age 30.1 ± 7.0 years, body mass 75.1 ± 9.4 kg, fat mass 12.3 ± 4.8%, $VO_{2\text{max}}$ 61.8 ± 5.6 ml·kg⁻¹·min⁻¹) completed the study. Participants completed the 90 min steady state cycling at 62 ± 5% of their measured $VO_{2\text{max}}$. No significant differences were detected in any of the observed variables at baseline and no order effect was found ($p = .64$).

**Dietary Compliance and Hydration**

Participant food diaries confirmed compliance with dietary carbohydrate prescription. Participants consumed $186 ± 36\text{kJ}$ ($p = .38$) and $6.9 ± 1.2\text{g}$ ($p = .34$) of total energy and carbohydrate per kilogram of body weight respectively. The intraindividual variation in carbohydrate consumption was $0.3\text{g}$ per kg body weight.

Participants arrived hydrated to the laboratory for all trials with no observed difference between trials (Table 1, $p = .99$). Body mass percent change from rest to post SS was low (CON: $0.73 ± 0.50$, ICE: $0.66 ± 0.51\%$, WASH: $0.84 ± 0.34\%$, $p = .70$) but consistent resulting in a significant difference over time measured by weight change ($p < .01$) and SOsmol ($p = .03$), however no difference between trials was detected. A significant reduction in weight was observed during TT ($1.2 ± 0.6\%$, $p < .01$);

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Markers of Hydration Status (Body Mass and Serum Osmolality)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
<td>Rest Body mass (kg)</td>
</tr>
<tr>
<td></td>
<td>SOsmol (mOsmol/kg)</td>
</tr>
<tr>
<td>CON</td>
<td>$76.6 ± 9.5$</td>
</tr>
<tr>
<td></td>
<td>$288 ± 3$</td>
</tr>
<tr>
<td>ICE</td>
<td>$76.4 ± 9.6$</td>
</tr>
<tr>
<td></td>
<td>$285 ± 3$</td>
</tr>
<tr>
<td>WASH</td>
<td>$76.2 ± 9.0$</td>
</tr>
<tr>
<td></td>
<td>$289 ± 2$</td>
</tr>
<tr>
<td>Post SS*</td>
<td>$76.0 ± 9.5*$</td>
</tr>
<tr>
<td></td>
<td>$295 ± 7*$</td>
</tr>
<tr>
<td></td>
<td>$75.9 ± 9.6*$</td>
</tr>
<tr>
<td></td>
<td>$296 ± 7*$</td>
</tr>
<tr>
<td></td>
<td>$74.9 ± 8.9*$</td>
</tr>
<tr>
<td></td>
<td>$298 ± 10$</td>
</tr>
<tr>
<td>Post TT</td>
<td>$75.1 ± 9.4*$</td>
</tr>
<tr>
<td></td>
<td>$297 ± 5$</td>
</tr>
<tr>
<td></td>
<td>$74.9 ± 8.9*$</td>
</tr>
<tr>
<td></td>
<td>$298 ± 10$</td>
</tr>
</tbody>
</table>

*Significant change from previous time point ($p < .05$).

Note: Euthydration was considered to be a blood osmolality < 290 mOsmol/kg, < 2%Δ 90-min exercise body weight (American College of Sports Medicine, 2007).
however, no difference between trials existed ($p = .38$). No difference in SOsmol was detected upon completion of TT ($p = .32$). Participants rated gastrointestinal discomfort as low on all trials ($p = .57$) at least three on the visual analog scale.

**Thermoregulation**

**Rectal Temperature.** Rectal temperature (Figure 1) increased over time ($p < .001$); however, no Time x Trial difference was detected ($p = .87$). There was no difference in rectal temperature between trials at the end of SS (overall mean 37.7 ± 0.6 °C, $p = .49$) or in absolute change from rest to 90 min (overall mean 1.3 ± 0.4 °C, $p = .88$). No difference in rectal temperature was observed between trials following TT (overall mean 38.7 ± 0.3 °C, $p = .76$) or in change from end SS to end TT (overall mean 0.5 ± 0.4 °C, $p = .46$).

**Gastrointestinal (Ingested Pill) Temperature.** Pill temperature (Figure 1) increased significantly across time ($p < .001$) and a Time x Trial effect was observed between ICE vs. CON ($p = .01$) and ICE versus WASH ($p = .02$). The intermittent reduction in gastric temperature was evident in ICE after beverage ingestion time points with temperatures ranging from a SS average maximum of 36.9 °C to an average minimum of 19.3 °C. Average temperature during SS was lower with ICE (35.6 ± 2.7 °C) vs. CON (37.4 ± 0.7 °C, $p = .05$) and WASH (37.4 ± 0.5 °C, $p = .04$). Absolute change from rest to end SS was not significantly different between trials ($p = .34$). Upon completion of the time trial, no difference between trials was detected in absolute temperature (overall mean 38.4 ± 0.7 °C, $p = .61$) or change in temperature (CON: 0.8 ± 0.6 °C; WASH: 0.9 ± 0.3 °C, despite a greater increase with ICE (3.2 ± 4.7 °C, $p = .20$).

**Skin Temperature.** A significant decrease over time in skin temperature was detected (Figure 1, $p = .01$). During SS, skin temperature tended to be lower during ICE compared with CON and WASH and resulted in Time x Trial trend ($p = .07$; ES: 0.52, 0.06–0.98 90% CI). The decrease in skin temperature from rest to end SS was significantly greater with ICE (−1.2 ± 0.5 °C) vs. WASH (−0.6 ± 0.6 °C, $p = .04$) but not CON (−0.8 ± 0.5 °C, $p = .12$). No significant difference was detected between trials upon completion of TT in either absolute temperature (overall mean 33.3 ± 0.7 °C, $p = .28$) or change in skin temperature (0.2 ± 0.4 °C, $p = .19$).

**Heat Storage.** Heat production during SS was similar between trials (overall mean 396.2 ± 38.6 W·m⁻², $p = .9$). A tendency for ICE (14.7 ± 8.4 W·m⁻²) to lower heat storage versus CON (22.1 ± 6.7 W·m⁻²) and WASH (22.8 ± 8.4 W·m⁻²) was observed ($p = .08$) and resulted in a positive ES 7.4, 0.52–14 90% CI). Heat storage was substantially and significantly greater during TT with ICE (68.9 ± 38.6 W·m⁻²) vs. CON (31.4 ± 27.6 W·m⁻², $p = .03$) and WASH (35.0 ± 20.9 W·m⁻², $p = .05$). Heat production was greater with ICE (461.2 ± 32.8 W·m⁻²) versus CON (425.4 ± 37.5 W·m⁻²) and WASH (439.2 ± 37.3 W·m⁻²) but this was not significantly different ($p = .09$).

**Blood Flow, Heart Rate, and Subjective Measures**

**Skin Blood Flow.** A significant difference was observed in four site combined skin blood flow (Figure 2) over time ($p < .01$) during SS; however, there was no difference between trials ($p = .71$). Calculated whole body SBF (Figure 2) decreased during SS ($p < .01$); however, no significant difference between trials was detected ($p = .46$).

Heat rate (Figure 3) increased over time during SS ($p < .001$) but was not significantly different between trials ($p = .27$). However, 7 of 10 participants experienced lower heart rates with ICE (range 6–11 bpm) and this resulted in an unclear but toward positive mean difference (7.7, −4 to 19 90% CI). No significant difference in heart rate between conditions was detected during TT ($p = .55$).

A time and Time x Trial effect was observed for rating of perceived exertion during SS, (Figure 4, $p < .001$ and $p = .03$ respectively). Rating of perceived exertion was lower for ICE ($p = .05$) and WASH tended to be lower ($p = .07$) compared with CON. The effect size for ICE vs. CON was positive (ES: 0.8, 0.09–1.5 90% CI). Thermal comfort (Figure 4) did not increase over time ($p = .33$) however thermal comfort in ICE was lower than CON ($p = .01$) and there tended to be a lower rate of change in thermal comfort in ICE (Time x Trial, $p = .07$). WASH was lower than CON ($p = .09$) during SS but was not different to ICE ($p = .90$).

**Performance**

Participants completed the TT (Table 2) faster (10.5 ± 7.93% with ICE (18:28 ± 1:03) than CON (20:24 ± 1:46), which is an effect size of 1.2 (0.70–1.77 90% CI) and is considered very likely beneficial using magnitude based inferences. The performance difference with WASH (19:45 ± 1:43) vs. CON (3.3 ± 1.9%, ES: 0.41, 0.28–0.55 90% CI) is likely beneficial using magnitude based inferences. Furthermore, 9 of the 10 participants completed the TT faster in WASH versus CON and 7 exceeded the smallest worthwhile change (2%). Average power output was higher with ICE (258 ± 21W) and WASH (242 ± 23W) vs. CON (233 ± 25W). The effect for ICE vs. CON is likely beneficial (ES: 1.0, 0.2–1.9 90% CI) and possibly beneficial for WASH vs. CON (0.36, −0.02 to 0.74 90% CI). No difference between trials was observed for split time or average split power.

**Discussion**

Cold beverage ingestion has been reported to improve endurance performance in the heat in most studies; however, the underpinning mechanism remains debated. Consistent with existing literature, this study found a
Figure 1 — Measures of body temperature during 90-min steady state and upon completion of time trial. Time × Trial effect ICE vs. CON: * p < .05, # p < .1
Figure 2 — Skin blood flow measured (% of rest in hot environment) and calculated from VO₂ and rectal and skin temperatures.

Figure 3 — Heart rate during 90-min steady state exercise and upon completion of time trial.
performance benefit from cold beverage consumption (in this case, ICE slushy ingestion) during prolonged cycling in the heat. The ergogenic effect of ICE was associated with the formation of a heat sink and cooling of the gastrointestinal tract, although ICE ingestion failed to cause significant reduction to measures of cardiovascular strain (skin blood flow and heart rate) and body core temperature (rectal temperature). The primary aim of this investigation was to establish whether cold beverages elicit a sensory effect which is independent of their effect on thermoregulatory and/or cardiovascular factors. We also observed a practically meaningful performance benefit (3.3 ± 1.9%) from ice mouthwash (WASH), with a likely beneficial effect using magnitude based inferences in this small cohort of trained individuals. However, like cold beverage ingestion (ICE condition), the mere act of presenting of a cold beverage to the mouth via expecto-

Table 2  Mean and Individual Performance Times During TT With ICE, CON, and WASH

<table>
<thead>
<tr>
<th>Participant</th>
<th>ICE</th>
<th>WASH</th>
<th>CON</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16:35</td>
<td>19:19</td>
<td>20:07</td>
</tr>
<tr>
<td>2</td>
<td>18:16</td>
<td>21:30</td>
<td>22:14</td>
</tr>
<tr>
<td>3</td>
<td>20:09</td>
<td>21:16</td>
<td>22:05</td>
</tr>
<tr>
<td>4</td>
<td>17:18</td>
<td>17:27</td>
<td>18:16</td>
</tr>
<tr>
<td>5</td>
<td>19:23</td>
<td>23:03</td>
<td>23:30</td>
</tr>
<tr>
<td>6</td>
<td>18:02</td>
<td>18:10</td>
<td>18:24</td>
</tr>
<tr>
<td>7</td>
<td>19:31</td>
<td>20:01</td>
<td>21:16</td>
</tr>
<tr>
<td>8</td>
<td>18:52</td>
<td>19:14</td>
<td>19:12</td>
</tr>
<tr>
<td>9</td>
<td>18:25</td>
<td>18:32</td>
<td>19:27</td>
</tr>
<tr>
<td>10</td>
<td>18:12</td>
<td>19:03</td>
<td>19:32</td>
</tr>
</tbody>
</table>

Mean (SD) 18:28 (1:03) 19:45 (1:43) 20:24 (1:46)
rated ice mouthwash was associated with a reduction in perception of effort and improved thermal comfort during exercise in the absence of cardiovascular and temperature alterations. This finding is consistent with the suggestion that the benefit of cold beverages is, in part, a function of a sensory effect.

In practice, endurance athletes (e.g., triathletes during ironman races) often consume beverages in competition at close to thermoneutral temperatures (Burdon et al., 2010c), as aid stations in hot environments appear to find it challenging to dispense cool beverages on a consistent basis. Dispensing slushy type beverages to competitors may be impractical and limit fluid consumption, however the potential benefit of attenuated core temperature and sweat rate with ice slushy (Siegel et al., 2010; Siegel et al., 2012) may be more important than a potential increase in dehydration if fluid consumption was limited. In addition, top competitors are often the most dehydrated and therefore a reduction in body core temperature may be more important than the degree of dehydration (Rüst et al., 2012; Zouhal et al., 2011). Furthermore, the use of ice slushy or cold beverages may confer a practical benefit as this method of internal cooling is effective in reducing core temperature compared with external methods of cooling which may be less practical in the field, or less effective (Burdon et al., 2012; Quod et al., 2006; Ross et al., 2011; Siegel et al., 2012). An ergogenic effect was observed in ICE and while not as large, it is possible that the sensory stimulation is greater with WASH compared to bolus ingestion due to extensive contact with thermoreceptors (Villanova et al., 1997). The intermittent ingestion of small volumes may cause difficulty in detecting differences between trials, for example seven of ten participants experienced reduced heart rates (6–11 bpm) with ICE during SS. Although this was not statistically different to CON, the effect size is positive but unclear and more data are required to confirm the effect.

This study also presents evidence that endurance performance in the heat may be mediated by sensory mechanisms associated with cold beverage ingestion. Decreased perceived exertion and improved maintenance of power output was observed and supports reduction of central fatigue similar to previous investigations which also report lowered perception of effort (Lee et al., 2008b; Siegel et al., 2010) or improved ability to maintain power output (Ihsan et al., 2010; Ross et al., 2011). In addition, the observed decrease in reported thermal comfort/sensation of heat with ice slushy ingestion in this study is consistent with previous investigations (Lee et al., 2008a; Lee et al., 2008b; Siegel et al., 2010; Siegel et al., 2012). Rating of thermal sensation has been shown to be influenced by skin temperature (Schlader et al., 2011) which is consistently reported to reduce with cold beverage ingestion (Armstrong et al., 1985; Burdon et al., 2010a; Lee et al., 2008a; Lee et al., 2007; Lee et al., 2008b; Stanley et al., 2010; Wimer et al., 1997). Although ice mouthwash alone was observed in this study to reduce RPE and improve TC, thus imparting a sensory benefit, it is possible that the sensory stimulation is greater with ingestion due to extensive contact with thermoreceptors in the gastrointestinal tract (Villanova et al., 1997). The combination of extensive sensory stimulation and cooling of the gastrointestinal tract elicited a greater reduction in RPE and improved thermal comfort. However, a placebo effect may exist in this study. Unfortunately, as it is not possible to blind participants, the possibility that participants believed the ICE or WASH should be beneficial may have influenced their reported exertion, thermal comfort, and subsequent performance. To conclusively demonstrate a sensory mediated benefit of cold beverages, further studies are required using objective measures of fatigue including cognitive tests and muscle activation.

There are some limitations of this investigation including the small sample size, underpowered to detect performance improvement in the WASH trial. Allowing participants to consume fluid or have the ice mouthwash during the TT may have increased the effect of each trial.
on the performance results. Despite this, the WASH improved performance by 3.2% compared with thermonutral and had an effect size of 0.4 (90% CI: 0.27–0.55). This is comparable with carbohydrate ingestion improving performance using similar protocols (submaximal SS followed by TT) by 7.5% with an effect size of 0.53 (0.37–0.69; Temesi et al. 2011). The frequency of WASH presentation compared with ICE and CON may have had an influence on RPE and TC via added sensation of cold or carbohydrate. It has been demonstrated that a carbohydrate mouthwash has no benefit when participants are in a fed state as in this study where carbohydrate is available via the thermoneutral beverage (Beelen et al., 2009; Rollo et al., 2011). However, the different feeding schedules remain a possible confounder in the WASH trial and the potential for a placebo effect cannot be dismissed. Participants and researchers were not blind to the beverage temperature although participants were informed the time trial was to measure evolution of temperature during self-selected work.

The evidence presented in this study suggests that the mechanism by which cold beverage ingestion imparts an ergogenic benefit is by the combination of a reduction in core temperature (as measured by gastrointestinal temperature) and sensory stimulation of the gastrointestinal tract reducing central fatigue. A nonsignificant reduction in heart rate suggests that cardiovascular strain contributes to fatigue less than temperature directly. No difference in skin blood flow was observed, however measurement was influenced by significant noise and variability despite data smoothing. Therefore, additional and accurate measures of cardiovascular strain, such as measurement of cardiac output with CO₂ rebreathing, are required to dismiss the contribution altogether.

The reduction in heat storage failed to reduce core temperature as traditionally measured (rectal temperature) but was associated with a substantial reduction in gastrointestinal temperature. This may have implications for endotoxemia as a result of hyperthermia and heat illness (Lambert, 2008), where a reduction in gut temperature may reduce severity and symptoms. However, the gastrointestinal measurement is confounded by the direct presence of the ice slushy (Lee et al., 2010) and may not accurately reflect the temperature of the tissue.

**Conclusion**

Intermittent ice slushy ingestion improved endurance performance (10.5 ± 7.9%) when compared with consumption of a similar volume of thermoneutral beverage. The ice slushy was observed to create a heat sink and reduce heat storage but failed to significantly change traditional measures of body core temperature or cardiovascular strain. The heat sink and reduced gastrointestinal temperature likely contributed to improved performance; however, a sensory benefit via reduction in rating of perceived exertion and improved thermal comfort is also evident. The sensory benefit is further supported by data from the ice mouthwash trial which resulted in reduced RPE, improved thermal comfort, and a meaningful but nonsignificant improvement in endurance performance. This study provides support for use of cold beverages during endurance exercise and potentially for occupational settings where workers experience prolonged heat exposure. Further studies are required to refine the mechanisms underpinning the observed performance benefits.

**Acknowledgments**

The authors would like to thank the New South Wales Institute of Sport for providing equipment for the study. No authors have any conflict of interest to declare.

**References**


