Mixed-methods pre- and per-cooling strategies improve physiological, perceptual, and performance responses in elite team sport athletes

S P. Fenemor[a, c]*, N. D Gill[a, b], M. W. Driller[d], B. Mills[b], F. Sella[a], J. R. Casadio[c], C. M. Beaven[a].

[a]Te Huataki Waiora School of Health, University of Waikato Adams Centre for High Performance, Mt Maunganui, New Zealand; [b]New Zealand Rugby Union, Wellington, New Zealand; [c]High Performance Sport New Zealand, Auckland, New Zealand; [d]Sport and Exercise Science, School of Allied Health, Human Services and Sport, La Trobe University, Melbourne, Australia.

*Corresponding Author:
Stephen Fenemor
Faculty of Health, Sport and Human Performance
University of Waikato Adams Centre for High Performance
52 Miro Street
Mount Maunganui
Tauranga
New Zealand

Ph: +64 276970210
Email: sfenemor@waikato.ac.nz
https://orcid.org/0000-0001-6778-1671

Other Authors:
Nicholas Gill (nicholas.gill@nzrugby.co.nz)
Matthew Driller (M.Driller@latrobe.edu.au)
Blair Mills (Blair.Mills@nzrugby.co.nz)
Francesco Sella (fss4@students.waikato.ac.nz)
Julia Casadio (Julia.Casadio@hpsnz.org.nz)
Christopher Martyn Beaven (martyn.beaven@waikato.ac.nz)

Abstract

The ingestion of ice slurry and application of ice towels can elicit favourable physiological, perceptual, and performance benefits when used individually; however, the combined use and effectiveness of these practical cooling strategies have not been assessed using an ecologically valid performance test, based on actual match demands in an elite team sport context.

Ten non-heat acclimated elite male rugby sevens athletes undertook two cycling heat response tests (HRT) designed to be specific to the demands of rugby sevens in hot conditions (35 °C, 80% rH). In a crossover design, the HRTs were conducted with (COOLING) and without (HOT) the combined use of internal (ice slushy ingestion) and external (application of ice towels to the head, neck, and face) pre- and per-cooling strategies. Physiological, perceptual and performance variables were monitored throughout each HRT.

COOLING resulted in reductions in mean tympanic temperature (-0.4 ± 0.2 °C; *d* =1.18); mean heart rate (-5 ± 7 bpm; *d* =0.53); thermal discomfort (-0.5 ± 0.8 AU; *d* =0.48); and thirst sensation (-1.0 ± 1.0 AU; *d* =0.61) during the HRT. COOLING also resulted in a *small* increase in 4-min time trial power output (by 7 ± 27 W, ~3%; *d* =0.35) compared to HOT.

A combination of internal and external pre- and per-cooling strategies can result in a range of physiological, perceptual, and performance benefits during a rugby sevens specific HRT, compared to undertaking no cooling. Practitioners should include such strategies when performing in hot conditions.

Introduction

Rugby sevens is characterised by repeated bouts of high-intensity running, frequent contacts, sprints, skill, and spatial awareness, played over 2x 7-min halves, with seven players per team (Ross et al., 2015). International rugby sevens teams compete in the World Rugby Sevens Series, along with pinnacle events such as the Olympic and Commonwealth Games. Many of these events are scheduled in hot summer environments, for example, temperatures of 45 °C (113 °F) were recorded during a recent Sydney tournament (unpublished observations), and the (delayed) Tokyo 2020 Summer Olympics were predicted to, and realised to be, the hottest Olympics on record (Gerrett et al., 2019; Kakamu et al., 2017). These challenging environmental conditions, along with the repeated high-intensity nature of rugby sevens combine to present a thermoregulatory challenge that is likely to impact performance (Fenemor et al., 2021; Gonzalez-Alonso et al., 2008). In this regard, the importance of appropriate heat management strategies are well indicated (Racinais et al., 2015).

While heat acclimation is commonly considered the most important heat management strategy (Gibson et al., 2019), the application of pre- and/or per-cooling can alleviate environmental heat stress on the day of performance (Bongers et al., 2017; Douzi et al., 2019; Ruddock et al., 2017). Pre-cooling aims to lower core and skin temperature ($T_{c;}$ T_{skin}) prior to the onset of exercise, thereby attenuating the adverse effects of heat stress, and increasing the capacity for metabolic heat production and heat gain. Thus, pre-cooling enables athletes to perform more work before an individual 'critical T_c' is reached (i.e. >40 °C) (Bongers et al., 2017; Tyler et al., 2015). Per-cooling aims to mitigate the exercise-induced rise in T_c, thus delaying the onset of hyperthermia-induced fatigue, whilst also providing perceptual benefit (Bongers et al., 2017; Cao et al., 2022; Vargas et al., 2019). In terms of pre-cooling, the performance benefits of cold-water immersion (CWI) are well-established for both intermittent-sprint and prolonged endurance exercise (Bongers et al., 2017; Duffield et al., 2010). Despite these well-established benefits, CWI pre-cooling still requires significant logistical challenges to be overcome for application in a field setting (Gibson et al., 2019), and the practicalities within athletic training and performance require substantial thought, especially considering the positive effects of elevated muscle temperature on performance (Bergh & Ekblom, 1979; Racinais & Oksa, 2010). Accordingly, a mixed-methods approach, combining both internal cooling with practical localised external cooling (i.e. application of ice towels) may be more feasible, and preferable for athletes and practitioners (Aldous et al., 2018; James et al., 2015; Minett et al., 2011).

Typically, internal cooling strategies involve the consumption of ice slurry, with the bolus of ice being melted in the stomach and small intestine, causing a small decrease in T_c (Siegel et al., 2010). In order to avoid the negative effects of ingesting a large bolus of ice slurry (such as headache and gastrointestinal discomfort), recommendations suggest that ice slurry should be ingested at a rate of 1.25 $g \cdot kg^{-1}$ every 5 min for 30 min before a performance (equating to 600 g of slurry for an 80 kg athlete) (Racinais et al., 2015). External cooling strategies act to lower T_{skin}, which may be associated with reduced thermal discomfort and facilitate behavioural thermoregulation (Cao et al., 2022; Schlader et al., 2011b). An immediate reduction in thermal discomfort can result when a cold stimulus is applied to the head, face, and neck regions of a heat-stressed individual, due to these regions exhibiting greater alliesthesial sensitivity than the rest of the body (Cotter & Taylor, 2005). As such, cooling the head and neck regions has been demonstrated as an effective method to mitigate perceptual strain and improve performance in the heat in endurance (Schlader et al., 2011a; Tyler & Sunderland, 2011; Tyler et al., 2010), and repeated sprint contexts (Sunderland et al., 2015). Notably, Sawka et al. (2012) suggested that cooling the core (i.e. internal cooling) without a concurrent reduction in T_{skin} (i.e. external cooling) will decrease the core to skin thermal gradient, thus impairing the ability of a human body to dissipate heat to the environment; hence, combining internal and external cooling may act to provide an increased heat storage capacity, alongside a reduced rate of heat storage during exercise (James et al., 2015).

Each sport or athletic competition involves its own circumstances that determine per-cooling method practicality (Russell et al., 2015), for example, in rugby sevens only short breaks (i.e. ~ 2 min at halftime) provide the only planned opportunity for cooling strategies to be implemented. During such breaks, short, non-obtrusive interventions are the most practical, such as the application of ice towels, or ingestion of small amounts of ice slurry. Given the thermoregulatory challenge undertaking repeated high-intensity exercise in hot environmental conditions, specific evidence is needed to guide practitioners on the use of previously described cooling strategies (Bongers et al., 2017). Therefore, the aims of the current research were to evaluate the effectiveness of a combined internal and external cooling protocol using the ingestion of ice slurry, and the application of ice towels to the head and neck, before and during a repeated high-intensity heat response test, designed to simulate a game of rugby sevens. We hypothesised that combined internal and external pre- and per-cooling would result in enhanced physiological, perceptual, and performance responses during high-intensity repeated intermittent exercise in the heat.

Methods

Subjects

Data was collected from ten non-heat acclimated elite male rugby sevens athletes (mean ± SD, age: 25 ± 3 years; body mass 95.3 ± 6.5 kg; height 1.90 ± 0.03 m) of a single international team. Written informed consent was collected from all participants prior to the beginning of the study, and the procedures of the study were approved by the Human Research Ethics Committee at the University of Waikato (HREC2018#64). Athletes were asked to consume the same food and abstain from alcohol and caffeine in the 12 hours before each testing session. All trials took place in local springtime conditions (mean daytime high ~18 °C) throughout the teams' pre-season to avoid any natural heat acclimatisation. Participants were asked to refrain from strenuous exercise outside of the laboratory 48 h before each testing session.

Design

In a crossover design, participants undertook two heat response tests (HRT) across consecutive weeks (HOT; COOLING) in an environmental chamber maintained at 35 °C, 80% rH. Participants performed all testing sessions at the same time of day (Monday mornings) across two weeks to account for circadian rhythms (Reilly & Brooks, 1986). All participants were familiar with the testing protocol, as this has been evaluated recently from the same laboratory (Fenemor et al 2022). During both HRTs all participants consumed 640 mL of 6% carbohydrate sports drink (Gatorade, The Gatorade Company, Inc. Chicago, Illinois, United States) prepared as an either ice slurry during COOLING (1 °C; 200 ml pre-warm-up, 200 mL post warm-up, 120 mL at half-time, 120 mL pre time-trial), or at room temperature (22 °C) during HOT. Additionally, during COOLING, participants applied towels that had been immersed in ice water to the head and neck for 60 s.

<<Insert Figure 1 here>>

Methodology

Heat response test

Participants entered the environmental chamber and completed a 19-min progressive-intensity, standardised warm-up (see Figure 1) followed by a repeated interval protocol and a 4-min time trial (TT). The repeated interval protocol consisted of 30 s cycling at 3.0 $W \cdot kg^{-1}$, followed by 40 s rest, repeated 12 times with a 2-min half-time break after interval 6. Immediately following every 2nd interval, participants also performed six down-ups (to simulate rucking type movements in rugby sevens). The design and content of the repeated interval protocol was chosen as it replicates game average high-intensity running volume, work: rest ratios (30 s: 40 s), and dynamic rucking type movements in rugby sevens (~15 per match) (Ross et al., 2015). This protocol has recently been evaluated against a similar running-based protocol, indicating that it can replicate the perceptual but not physiological stress associated with repeated high-intensity running in the heat (Fenemor et al. 2022). During the 4-min TT the display monitor of the cycle ergometer was covered, and verbal cues given by a researcher at 1000, 2000, 2500, and 2800 m. A 4-min TT was chosen as participants were familiar with this cycle test as it is commonly used as an off-feet conditioning session during their normal training, and it has been shown to have high level of test-retest reliability (CV < 3%) (Driller et al., 2014). All cycling was performed on a calibrated cycle ergometer (WattBike Ltd, Nottingham, UK).

Physiological measurements

Tympanic Temperature (T_{Tymp}; Braun ThermoScan® 7 IRT6520, Braun GmbH, Kronberg, Germany) and Heart Rate (HR; Polar H10, Polar Electro Oy, Kempele, Finland) were sampled at 0 min, post warm-up, after intervals 3 and 6; at the end of half time; after intervals 9 and 12; Pre TT and End TT. The mean of values collected after intervals 3 and 6 was taken to calculate the first half measurement, likewise for the second half with intervals 9 and 12 (as shown in Figure 2). Each T_{Tymp} measurement was sampled in duplicate, the mean of which was recorded for analysis. T_{Tymp} was chosen as our method of assessing body temperature as it has been previously demonstrated acceptable agreement with assessment of core temperature via telemetry pill when exercising in the heat (Fenemor et al., 2020).

Before the start of each test the skin of the right shoulder blade was cleaned with distilled water and dried, before adhesive gauze sweat patches (Tegaderm+Pad, 3M, Loughborough, UK) were applied. At the completion of each test, sweat patches were immediately placed into sealed containers and frozen until analysis. Sweat sodium concentration was determined using absorbance photometry (Cobas C111 analyser, Roche, AG Basel Switzerland). To estimate sweat rate, towel-dried, nude body mass was recorded to 0.1 kg using digital scales (Seca 877, Seca, Hamburg, Germany) before and immediately after each session, this value was adjusted for ingested liquid during the test (640 mL) and then converted to a rate ($kg\cdot hr^{-1}$).

Perceptual measurements

Rating of perceived exertion (RPE; 6-20 scale) (Borg, 1970), thermal sensation (TS; 1-13 point scale) (Gagge et al., 1967), thermal discomfort (TDC; 1-10-point scale) (Gagge et al., 1967) and thirst sensation (Thirst; 1-9 point scale) (Riebe et al., 1997) were collected at the same time points described above for physiological measurements during the HRT’s.

Statistical analysis

Raw data in tables and text are presented as mean ± SD with the mean differences (MD) and uncertainty of estimates shown as MD ± 90% confidence limits (CL). The mean of all data points was calculated and used in the corresponding analysis, presented in Table 1. For all variables, two-way repeated measures ANOVA was used to determine if there were differences between conditions across time. The Šídák – Bonferroni correction was used to correct for pairwise multiple comparisons. Normality and homogeneity of variance of residuals were checked using quantile-quantile (Q-Q) and scatter plots, which were deemed plausible in each instance. Where there was a main effect, magnitudes between each measurement period were determined and expressed as both mean differences ± 90% confidence limits (CL) and standardised effect sizes (Cohen's *d*). If the 90% CL for Cohen's *d* overlapped positive and negative trivial (± 0.20) values, the effect was deemed *unclear*. Substantial clear effects were described using standard thresholds of < 0.20 *trivial*, 0.20 – 0.49 *small*, 0.50 – 0.79 *moderate*, and > 0.80 *large* (Cohen, 1988).

Results

The interaction effect between time and condition was not statistically significant for any variable. Therefore, an analysis of the main effects for time was performed for all variables; these indicated that the main effect was statistically significant for T_{Tymp} [$F(6, 54) = 209.5$, $p < .0001$]; HR [$F(3, 28) = 305.8$, $p < .0001$]; TS [$F(6, 54) = 37.3$, $p < .0001$]; TDC [$F(2, 16) = 53.3$, $p < .0001$]; and Thirst [$F(3, 23) = 16.1$, $p < .0001$]. There were no statistically significant main effects for any other variables. Pairwise comparisons were then run to determine any differences at each measurement timepoint between HOT and COOLING conditions. These indicated that COOLING resulted in significant reductions in T_{Tymp} during the First half, at End half-time, during the Second half, Pre-TT, and End-TT (all $p < 0.05$, Figure 2). These significant reductions in T_{Tymp} caused in a *large* significant reduction in overall mean T_{Tymp} across the entire HRT (Table 1). COOLING resulted in a *moderate* decrease in mean HR and Thirst sensation, a *small* decrease in mean TDC, and a *small* increase in TT power; however, these did not reach statistical significance ($p > 0.05$). Group mean differences (± 90% CL), effect sizes, and statistical significance for all variables are presented in Table 1.

<<Insert Figure 2 here>>

<< Insert Table 1 here>>

Discussion

The current study examined the combined use of internal and external cooling strategies delivered via the use of ice slurry ingestion and the application of ice towels to the head, neck, and face before and during a repeated high-intensity exercise heat response test. The findings indicated that COOLING resulted *moderate to large* beneficial physiological changes (T_{Tymp} and HR) and *small to moderate* beneficial changes in indices of thermal perception (TDC and Thirst). Furthermore, there was a *small* increase in mean TT power output (3%) during COOLING compared to HOT.

The beneficial physiological changes presented in the current study (Figure 2 and Table 1) support the contention that combined internal and external cooling are effective at blunting the thermal strain caused by repeated high-intensity exercise in the heat. In terms of T_{Tymp}, it was notable that the constant application of cooling stimuli had the most benefit towards the end of the HRT (Figure 2). A similar T_c profile was demonstrated by Naito et al. (2018) during simulated tennis match-play in the heat. The authors indicated that the consumption of 1.25 $g \cdot kg^{-1}$ ice slurry at every rest break was significantly more effective at attenuating the increase in T_c than the same volume of cold-water; however, the blunted increase in T_c was only evident during the second half of exercise. In the current study, COOLING resulted in a 0.4 °C mean reduction in T_{Tymp} across the entire HRT. Such reductions in body temperature arising from ice slurry consumption are thought to benefit performance due to enhanced absolute heat storage capacity that prevents or delays central fatigue, which results in greater exercise intensity being permitted (James et al., 2015). Furthermore, it has been indicated that ice slurry acts upon thermoreceptors within the splanchnic region (Guest et al., 2007) and the frontal cortex of the brain (Onitsuka et al., 2018). Both thermoreceptors may activate pleasure centres of the brain, possibly leading to athletes developing a false sense of the overall thermal strain they are experiencing (Guest et al., 2007; James et al., 2015).

A previous team sport investigation indicated that 30-min of mixed-method pre-cooling (combination of ice slurry and ice packs) can augment physical performance within the first half of a simulated soccer performance test in the heat (Aldous et al., 2018). Interestingly however, the authors revealed that the subsequent application of half-time cooling strategies (15-min break) had no effect on physiological, perceptual, or performance measures throughout the second half. The authors speculated that cooling-related perturbations in muscle temperature, acting to decrease muscle contractility, may have potentially decreased repeated-sprint ability during the second half. In the current study, physiological, perceptual, and performance benefit were evident after the half-time break, possibly related to the comparatively short half-time break (2 min), which would not allow significant reductions in muscle temperature. Similarly, Minett et al. (2011) had previously indicated that mixed-method external cooling (ice packs, towels and vest) between halves (5 min) significantly improved total distance covered (by 5%) during the second half of a self-paced intermittent sprint exercise protocol in hot conditions. Taken together, it seems that aggressive short-duration mixed-method half-time cooling strategies, that fit within the practical limits of the break interval, may be the most effective for physiological, perceptual, and performance benefit (Russell et al., 2015).

The results of the current study further support those of a recent meta-analysis, which indicated that per-cooling using a combination of internal cooling (i.e. ice slurry ingestion) and external cooling (particularly on the face, neck, and torso) provide the greatest benefit for aerobic performances when exercising in the heat (Douzi et al., 2019). Furthermore in the current study, COOLING resulted in less thermal discomfort compared to HOT, supporting the concept that alleviating perceived thermal stress during an exercise performance in the heat can increase work output during self-paced exercise (Cheung, 2010). In the current study, the same volume of fluid was ingested in both conditions; however, Thirst sensation was decreased in the COOLING condition, possibly due to the stimulation of sensory nerves on the tongue and oropharyngeal region (Saldaris et al., 2020). Although satiation of thirst can be beneficial for cognitive function and reaction time tasks (Edmonds et al., 2013), the current findings indicate that caution must be taken when athletes use ice slurry before and during exercise performances in the heat, due to the potential development of dehydration.

Practical applications and considerations

It was shown that the combined use of internal and external pre and per-cooling strategies were effective at blunting the physiological and perceptual heat stress associated with exercising in the heat, along with contributing to practically important increases in self-paced high intensity exercise performance. While these results are indicative of the importance for practitioners to include practical cooling strategies within a game-day program, the small enhancements observed indicate that the larger performance benefits of heat acclimation as a pre-competition heat management strategy must not be ignored (Fenemor et al 2022). In this way, future research should investigate the application of similar practical cooling strategies within an elite heat acclimated population. Per-cooling during team sports are likely to be opportunity-based (i.e. breaks in play); as such, the application of ad-libitum cooling strategies may induce different results than those demonstrated in the current study. Furthermore, despite the current internal and external cooling strategies being similar to those suggested as most beneficial in the meta-analysis of Douzi et al. (2019), it is unknown whether other similar cooling methodologies would have resulted in the same demonstrated effects. While the ecological validity and high calibre of athletes are strengths of the current study, it is acknowledged that research in such an elite sport setting precluded the use of a control group or a larger sample size.

Conclusion

The current study demonstrated that the combination of internal and external pre- and per-cooling strategies can result in physiological, perceptual and performance benefits, compared to undertaking no cooling when exercising in hot conditions (35 °C, 80% rH). It is recommended that practitioners include a combination of practical internal and external cooling strategies within their heat management plan when performing in hot conditions. Future research should consider the application of such strategies within an elite heat acclimated population, to determine the benefits of cooling over and above heat acclimation.

Tables

Table 1: Grouped mean (± SD) and mean differences [MD ±90% CL (Cohens *d*)] for all variables for HOT and COOLING Heat Response Tests.

	HOT	**COOLING**	**HOT - COOLING**
T_{Tymp} (°C)	37.9 ± 0.3	37.5 ± 0.3	-0.4 ±0.2 (1.18) *large**
Heart Rate (bpm)	155 ± 8	150 ± 10	-5 ±7 (0.53) *moderate*
TS (AU)	10.8 ± 0.7	10.6 ± 0.4	-0.1 ±0.5 (0.16)
TDC (AU)	6.6 ± 1.1	6.1 ± 0.9	-0.5 ±0.8 (0.48) *small*
RPE (AU)	16.2 ± 0.8	16.2 ± 0.8	0.0 ±0.6 (0.08)
Thirst (AU)	3.8 ± 1.4	2.9 ± 1.1	-1.0 ±1.0 (0.61) *moderate*
Sweat rate (kg·hr^{-1})	1.5 ± 0.3	1.5 ± 0.4	0.0 ±0.2 (0.06)
Sweat [Na^+] (mmol/L)	69.7 ± 20.1	69.4 ± 18.9	-0.3 ±15.2 (0.01)
4-min Time Trial (W)	290 ± 34	297 ± 36	-7 ±27 (0.35) *small*

Comparisons are represented as mean difference ±90% CL, brackets represent Cohen's *d* which are qualitatively described in italics. Significance is indicated as * $p < 0.05$; AU = arbitrary units; TS = Thermal sensation; TDC = Thermal discomfort; RPE = Rate of perceived exertion.

Figures

Condition		Warm Up		1st Half	H/T	2nd Half		Time-Trial
HOT	##	░	##	▓	#	▓	#	4-min
COOLING	**	░	**^	▓	*^	▓	*^	4-min

░	5-min DS, 4-min cycle at 1.5 W·kg^{-1}, 2-min DS, 2-min cycle at 2.0 W·kg^{-1}, 2-min DS, 30 s cycle at 3.0 W·kg^{-1}, 1-min rest, 30 s cycle at 3.0 W·kg^{-1}, 2-min rest
▓	30 s cycling @ 3 W·kg^{-1}: 40 s rest repeated six times. Six down-ups after every 2nd interval.

= 120 ml sports drink; ## = 200 ml sports drink; * = 120 ml ice slurry; ** = 200 ml ice slurry; ^ = ice towel (60s)
H/T = 2-min half time; DS = dynamic stretching

Figure 1: Schematic of the HOT and COOLING conditions

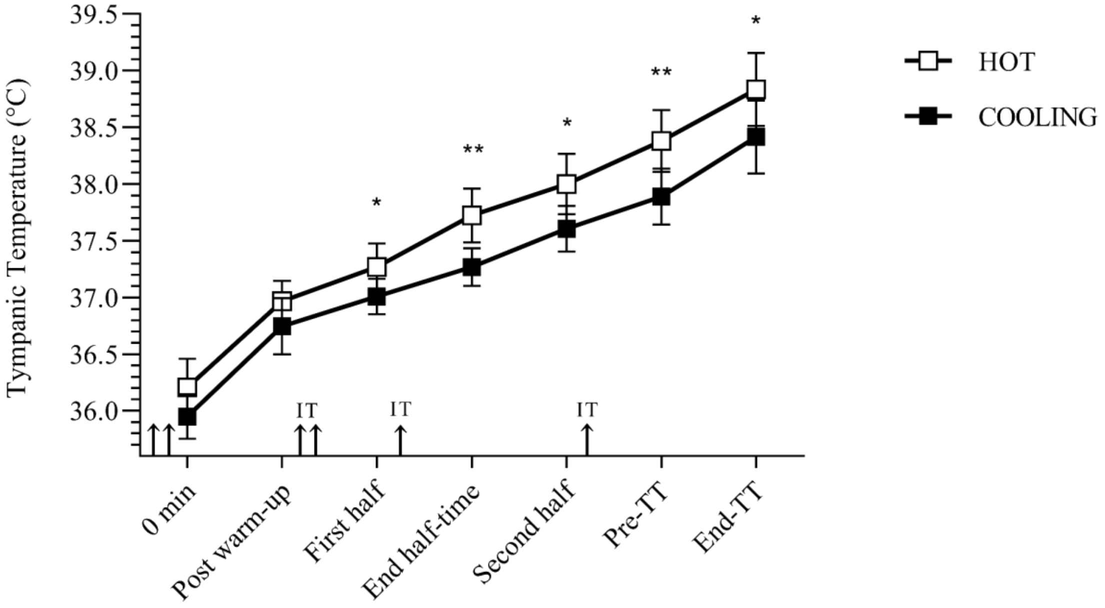

Figure 2: Mean (± SD) tympanic temperature (°C) at each measured timepoint for the two interventions. ↑↑ indicates where 200 mL ice slurry/room temperature fluid was ingested; ↑ indicates where 120 mL ice slurry/room temperature fluid was ingested; IT indicates where ice towels were applied to the head, neck, and face for 60 s. * = $p \leq 0.05$; ** = $p \leq 0.01$.

Figure captions

Figure 1: Schematic of the HOT and COOLING conditions

Figure 2: Mean (± SD) tympanic temperature (°C) at each measured timepoint for the two interventions. ↑↑ indicates where 200 mL ice slurry/room temperature fluid was ingested; ↑ indicates where 120 mL ice slurry/room temperature fluid was ingested; IT indicates where ice towels were applied to the head, neck, and face for 60 s. * = $p \leq 0.05$; ** = $p \leq 0.01$.

References

Aldous, J. W. F., Chrismas, B. C. R., Akubat, I., Stringer, C. A., Abt, G., & Taylor, L. (2018). Mixed-methods pre-match cooling improves simulated soccer performance in the heat. *European Journal of Sport Science*, 1-10. https://doi.org/10.1080/17461391.2018.1498542

Bergh, U., & Ekblom, B. (1979, Sep). Influence of muscle temperature on maximal muscle strength and power output in human skeletal muscles. *Acta Physiol Scand, 107*(1), 33-37. https://doi.org/10.1111/j.1748-1716.1979.tb06439.x

Bongers, C. C. W. G., Hopman, M. T. E., & Eijsvogels, T. M. H. (2017). Cooling interventions for athletes: An overview of effectiveness, physiological mechanisms, and practical considerations. *Temperature, 4*(1), 60-78. https://doi.org/10.1080/23328940.2016.1277003

Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Scandinavian Journal of Rehabilitation and Medicine, 2*(2), 92-98.

Cao, Y., Huan, L., Wang, F., Yang, B., & Mundel, T. (2022, 12/01). Head, Face and Neck Cooling as Per-cooling (Cooling During Exercise) Modalities to Improve Exercise Performance in the Heat: A Narrative Review and Practical Applications. *Sports Medicine - Open, 8*, 16. https://doi.org/10.1186/s40798-022-00411-4

Cheung, S. S. (2010). Interconnections between thermal perception and exercise capacity in the heat. *Scandinavian Journal of Medicine & Science in Sports, 20*(s3), 53-59. https://doi.org/10.1111/j.1600-0838.2010.01209.x

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Routledge. https://doi.org/https://doi.org/10.4324/9780203771587

Cotter, J. D., & Taylor, N. A. S. (2005). The distribution of cutaneous sudomotor and alliesthesial thermosensitivity in mildly heat-stressed humans: an open-loop approach. *The Journal of Physiology, 565*(Pt 1), 335-345. https://doi.org/10.1113/jphysiol.2004.081562

Douzi, W., Dugué, B., Vinches, L., Sayed, C. A., Hallé, S., Bosquet, L., & Dupuy, O. (2019). Cooling during exercise enhances performances, but the cooled body areas matter: A systematic review with meta-analyses. *Scandinavian Journal of Medicine and Science in Sports, 29*(11), 1660-1676. https://doi.org/10.1111/sms.13521

Driller, M. W., Argus, C. K., Bartram, J. C., Bonaventura, J., Martin, D. T., West, N. P., & Halson, S. L. (2014). Reliability of a 2-Bout Exercise Test on a Wattbike Cycle Ergometer. *International Journal of Sports Physiology and Performance, 9*(2), 340-345. https://doi.org/10.1123/ijspp.2013-0103

Duffield, R., Green, R., Castle, P., & Maxwell, N. (2010, Mar). Precooling can prevent the reduction of self-paced exercise intensity in the heat. *Med Sci Sports Exerc, 42*(3), 577-584. https://doi.org/10.1249/MSS.0b013e3181b675da

Edmonds, C., Crombie, R., & Gardner, M. (2013, 2013-July-16). Subjective thirst moderates changes in speed of responding associated with water consumption [Original Research]. *Frontiers in Human Neuroscience, 7*(363). https://doi.org/10.3389/fnhum.2013.00363

Fenemor, S. P., Gill, N. D., Driller, M. W., Mills, B., Casadio, J. R., & Beaven, C. M. (2021). The relationship between physiological and performance variables during a hot/humid international rugby sevens tournament. *European Journal of Sport Science*, 1-9. https://doi.org/10.1080/17461391.2021.1973111

Fenemor, S. P., Gill, N. D., Sims, S. T., Beaven, C. M., & Driller, M. W. (2020, 2020/01/02). Validity of a tympanic thermometer and thermal imaging camera for measuring core and skin temperature during exercise in the heat. *Measurement in Physical Education and Exercise Science, 24*(1), 49-55. https://doi.org/10.1080/1091367X.2019.1667361

Gagge, A. P., Stolwijk, J. A. J., & Hardy, J. D. (1967, 1967/06/01/). Comfort and thermal sensations and associated physiological responses at various ambient temperatures. *Environmental Research, 1*(1), 1-20. https://doi.org/10.1016/0013-9351(67)90002-3

Gerrett, N., Kingma, B. R. M., Sluijter, R., & Daanen, H. A. M. (2019). Ambient Conditions Prior to Tokyo 2020 Olympic and Paralympic Games: Considerations for Acclimation or Acclimatization Strategies. *Front Physiol, 10*, 414. https://doi.org/10.3389/fphys.2019.00414

Gibson, O. R., James, C. A., Mee, J. A., Willmott, A. G. B., Turner, G., Hayes, M., & Maxwell, N. S. (2019). Heat alleviation strategies for athletic performance: A review and practitioner guidelines. *Temperature (Austin), 7*(1), 3-36. https://doi.org/10.1080/23328940.2019.1666624

Gonzalez-Alonso, J., Crandall, C. G., & Johnson, J. M. (2008, Jan 1). The cardiovascular challenge of exercising in the heat. *The Journal of Physiology, 586*(1), 45-53. https://doi.org/10.1113/jphysiol.2007.142158

Guest, S., Grabenhorst, F., Essick, G., Chen, Y., Young, M., McGlone, F., de Araujo, I., & Rolls, E. T. (2007, Dec 5). Human cortical representation of oral temperature. *Physiol Behav, 92*(5), 975-984. https://doi.org/10.1016/j.physbeh.2007.07.004

James, C. A., Richardson, A. J., Watt, P. W., Gibson, O. R., & Maxwell, N. S. (2015). Physiological responses to incremental exercise in the heat following internal and external precooling. *Scandinavian Journal of Medicine & Science in Sports, 25*(S1), 190-199. https://doi.org/https://doi.org/10.1111/sms.12376

Kakamu, T., Wada, K., Smith, D. R., Endo, S., & Fukushima, T. (2017, 2017/09/19). Preventing heat illness in the anticipated hot climate of the Tokyo 2020 Summer Olympic Games. *Environmental Health and Preventive Medicine, 22*(1), 68. https://doi.org/10.1186/s12199-017-0675-y

Minett, G. M., Duffield, R., Marino, F. E., & Portus, M. (2011, Sep). Volume-dependent response of precooling for intermittent-sprint exercise in the heat. *Med Sci Sports Exerc, 43*(9), 1760-1769. https://doi.org/10.1249/MSS.0b013e318211be3e

Naito, T., Sagayama, H., Akazawa, N., Haramura, M., Tasaki, M., & Takahashi, H. (2018). Ice slurry ingestion during break times attenuates the increase of core temperature in a simulation of physical demand of match-play tennis in the heat. *Temperature (Austin), 5*(4), 371-379. https://doi.org/10.1080/23328940.2018.1475989

Onitsuka, S., Nakamura, D., Onishi, T., Arimitsu, T., Takahashi, H., & Hasegawa, H. (2018, 2018/02/09). Ice slurry ingestion reduces human brain temperature measured using non-invasive magnetic resonance spectroscopy. *Scientific Reports, 8*(1), 2757. https://doi.org/10.1038/s41598-018-21086-6

Racinais, S., Alonso, J. M., Coutts, A. J., Flouris, A. D., Girard, O., González-Alonso, J., Hausswirth, C., Jay, O., Lee, J. K. W., Mitchell, N., Nassis, G. P., Nybo, L., Pluim, B. M., Roelands, B., Sawka, M. N., Wingo, J. E., & Périard, J. D. (2015). Consensus recommendations on training and competing in the heat. *Scandinavian Journal of Medicine & Science in Sports, 25*(S1), 6-19. https://doi.org/doi:10.1111/sms.12467

Racinais, S., & Oksa, J. (2010, Oct). Temperature and neuromuscular function. *Scand J Med Sci Sports, 20 Suppl 3*, 1-18. https://doi.org/10.1111/j.1600-0838.2010.01204.x

Reilly, T., & Brooks, G. A. (1986, Dec). Exercise and the circadian variation in body temperature measures. *Int J Sports Med, 7*(6), 358-362. https://doi.org/10.1055/s-2008-1025792

Riebe, D., Maresh, C. M., Armstrong, L. E., Kenefick, R. W., Castellani, J. W., Echegaray, M. E., Clark, B. A., & Camaione, D. N. (1997, Jan). Effects of oral and intravenous rehydration on ratings of perceived exertion and thirst. *Medicine and Science in Sports & Exercise, 29*(1), 117-124. https://doi.org/10.1097/00005768-199701000-00017

Ross, A., Gill, N., & Cronin, J. (2015). The match demands of international rugby sevens. *Journal of Sports Science, 33*(10), 1035-1041. https://doi.org/10.1080/02640414.2014.979858

Ruddock, A., Robbins, B., Tew, G., Bourke, L., & Purvis, A. (2017). Practical Cooling Strategies During Continuous Exercise in Hot Environments: A Systematic Review and Meta-Analysis. *Sports Medicine (Auckland, N.z.), 47*(3), 517-532. https://doi.org/10.1007/s40279-016-0592-z

Russell, M., West, D. J., Harper, L. D., Cook, C. J., & Kilduff, L. P. (2015, Mar). Half-time strategies to enhance second-half performance in team-sports players: a review and recommendations. *Sports Med, 45*(3), 353-364. https://doi.org/10.1007/s40279-014-0297-0

Saldaris, J. M., Landers, G. J., & Lay, B. S. (2020). Physical and perceptual cooling: Improving cognitive function, mood disturbance and time to fatigue in the heat. *Scandinavian Journal of Medicine & Science in Sports, 30*(4), 801-811. https://doi.org/10.1111/sms.13623

Sawka, M. N., Cheuvront, S. N., & Kenefick, R. W. (2012, Mar). High skin temperature and hypohydration impair aerobic performance. *Exp Physiol, 97*(3), 327-332. https://doi.org/10.1113/expphysiol.2011.061002

Schlader, Z. J., Simmons, S. E., Stannard, S. R., & Mündel, T. (2011a, 2011/05/03/). The independent roles of temperature and thermal perception in the control of human thermoregulatory behavior. *Physiology & Behavior, 103*(2), 217-224. https://doi.org/https://doi.org/10.1016/j.physbeh.2011.02.002

Schlader, Z. J., Simmons, S. E., Stannard, S. R., & Mündel, T. (2011b, Aug). Skin temperature as a thermal controller of exercise intensity. *Eur J Appl Physiol, 111*(8), 1631-1639. https://doi.org/10.1007/s00421-010-1791-1

Siegel, R., Maté, J., Brearley, M. B., Watson, G., Nosaka, K., & Laursen, P. B. (2010, Apr). Ice slurry ingestion increases core temperature capacity and running time in the heat. *Med Sci Sports Exerc, 42*(4), 717-725. https://doi.org/10.1249/MSS.0b013e3181bf257a

Sunderland, C., Stevens, R., Everson, B., & Tyler, C. J. (2015, 2015-November-05). Neck-cooling improves repeated sprint performance in the heat [Original Research]. *Frontiers in Physiology, 6*. https://doi.org/10.3389/fphys.2015.00314

Tyler, C. J., & Sunderland, C. (2011, Jan-Feb). Cooling the neck region during exercise in the heat. *J Athl Train, 46*(1), 61-68. https://doi.org/10.4085/1062-6050-46.1.61

Tyler, C. J., Sunderland, C., & Cheung, S. S. (2015, Jan). The effect of cooling prior to and during exercise on exercise performance and capacity in the heat: a meta-analysis. *British Journal of Sports Medicine, 49*(1), 7-13. https://doi.org/10.1136/bjsports-2012-091739

Tyler, C. J., Wild, P., & Sunderland, C. (2010, Nov). Practical neck cooling and time-trial running performance in a hot environment. *Eur J Appl Physiol, 110*(5), 1063-1074. https://doi.org/10.1007/s00421-010-1567-7

Vargas, N. T., Chapman, C. L., Johnson, B. D., Gathercole, R., Cramer, M. N., & Schlader, Z. J. (2019). Thermal behavior alleviates thermal discomfort during steady-state exercise without affecting whole body heat loss. *127*(4), 984-994. https://doi.org/10.1152/japplphysiol.00379.2019