Man#6615-2020 in press at the Journal of Sports Science and Medicine

HEAD COOLING PRIOR TO EXERCISE IN THE HEAT DOES NOT IMPROVE COGNITIVE PERFORMANCE

Nur Shakila Mazalan[1,3], Grant J. Landers[1], Karen E. Wallman[1] and Ullrich K. H. Ecker[2]

1 School of Human Sciences, The University of Western Australia, Crawley, WA, Australia

2 School of Psychological Science, The University of Western Australia, Crawley, WA, Australia

3 Faculty of Education, National University of Malaysia, Bangi, Selangor, Malaysia

RUNNING HEAD: Head cooling and cognitive performance

ABSTRACT:

This study investigated the effectiveness of head cooling on cognitive performance after 30 min and 60 min of running in the heat. Ten moderately-trained, non-heat-acclimated, male endurance athletes (mean age: 22±6.6 y; height: 177.7±9.7 cm; body-mass: 75.7±15.6 kg; $\dot{V}O_{2peak}$: 51.6±4.31 $mL^{-1}\cdot kg^{-1}\cdot min$) volunteered for this study. Participants performed two experimental trials: head cooling versus no-cooling (within-subjects factor with trial order randomized). For each trial, participants wore a head-cooling cap for 15 min with the cap either cooled to 0°C (HC) or not cooled (22°C; CON). Participants then completed 2 × 30 min running efforts on a treadmill at 70% $\dot{V}O_{2peak}$ in hot conditions (35°C, 70% relative humidity), with a 10 min rest between efforts. Working memory was assessed using an operation span (OSPAN) task immediately prior to the 15 min cooling/no-cooling period (22°C, 35% RH) and again after 30 min and 60 min of running in the heat. Numerous physiological variables, including gastrointestinal core temperature (T_c) were assessed over the protocol. Scores for OSPAN were similar between trials, with no interaction effect or main effects for time and trial found ($p = 0.58$, $p = 0.67$, $p = 0.54$, respectively). Forehead temperature following precooling was lower in HC (32.4±1.6°C) compared with CON (34.5±1.1°C) ($p = 0.01$), however, no differences were seen in T_c, skin temperature, heart rate and ratings of perceived exertion between HC and CON trials at any time point assessed ($p > 0.05$). In conclusion, despite HC reducing forehead temperature prior to exercise, it did not significantly improve cognitive performance during (half-time break) or after subsequent exercise in hot environmental conditions, compared to a no cooling control.

KEYWORDS: running, precooling, thermoregulation, cognitive execution

INTRODUCTION

Resting core temperature (T_c) in humans is ~37°C (Casa, 1999), while a T_c of 38.3°C (proposed to be the point where hyperthermia begins) is associated with thermal strain and impaired physical performance (Faulds and Meekings, 2013). When T_c increases during exercise, particularly when performed in the heat, the temperature of arterial blood flow to the brain also increases, placing a thermal load on the brain, which in turn may result in central fatigue (Nybo and Neilsen, 2001). Furthermore, an increase in T_c during prolonged exercise in the heat results in a concomitant reduction in cerebral blood flow to the brain. This occurs due to the need for the body to direct blood flow to the periphery for cooling purposes (Nybo and Neilsen, 2001; Vanden Hoek et al., 2004), with blood flow to the brain further compromised if dehydration occurs as a result of sweating combined with minimal or no fluid replacement. Consequently, during exercise in the heat, less oxygen, glucose and other nutrients are supplied to the brain, which along with an already increased brain temperature is likely to have an adverse impact on cognitive function (Falkowska et al., 2015). This is an important issue for types of exercise that require strategic thinking or extended periods of concentration (i.e., team sports, cycling road-race events, etc.), as athletes need to be able to maintain a high level of cognitive function to assist in correct decision-making whilst exercising (Smits et al., 2014).

Previous studies by Hocking et al. (2001) and Hancock and Vasmatzidis (2003) noted that the deterioration of cognitive performance in the heat is dependent on the severity of the heat strain and the complexity of the task. Notably, T_c values >38.5°C have been found to impair complex cognitive functioning in respect to relatively difficult tasks such as those that require higher-level decision-making and problem-solving (Hancock and Vasmatzidis, 2003; Schmit et al., 2017). Such complex cognitive functions are highly dependent on working memory (Conway et al., 2007). According to Conway et al. (2007), working memory is a severely capacity-limited, short-term storage and processing system that is often termed the 'engine of cognition' (Conway et al., 2007). Previous studies have reported impaired complex cognitive performance (working memory) when participants either rested or exercised (walking, cycling or running) in hot environmental conditions (Gaoua et al., 2011; Racinais et al., 2008). As both studies by Racinais et al. (2008) and Gaoua et al. (2011) involved low-intensity exercise and a rest period, it is likely that higher-intensity exercise in the heat would result in greater thermal strain and consequently greater deterioration of complex cognitive function.

In order to address the negative effects of exercise in the heat, early research focused on reducing T_c using various precooling methods, which led to improved psychological parameters and physical performance, compared to no-cooling (Booth et al., 1997; Ihsan et al., 2010). Furthermore, precooling using ice ingestion (proposed to cool the carotid blood flow to the brain due to the close proximity of ice placed in the mouth and swallowed to these arteries) was found to result in lower forehead temperature (T_h) prior to exercise (and during), as well as lower thermal sensation during subsequent exercise in the heat (60 min cycling at 55% $\dot{V}O_{2peak}$; ~35°C and 50% relative humidity: RH), compared to no cooling (Saldaris et al., 2020). Other researchers have focused on cooling strategies designed to cool the brain region, with the aim to improve complex cognitive function during exercise in the heat (Gaoua et al., 2011; Ando et al., 2015; Lee at al., 2014; Onitsuka et al., 2015; Saldaris et al., 2020). In these studies, researchers typically use skin thermistors placed on the forehead to indirectly assess the temperature of the brain (Onitsuka et al., 2015; Saldaris et al., 2019, Saldaris et al., 2020). Notably, the use of either neck cooling (Lee at al., 2014) or the application of cold packs to the head (Racinais et al., 2008; Gaoua et al., 2011) during exercise and rest in the heat have been reported to improve working memory function (spatial span test) compared to no-cooling control trials. Of relevance, Racinais et al. (2008) and Gaoua et al. (2011) reported that T_c fell by ~0.6°C and T_h by ~1.9 - 2.0°C after head cooling (Racinais et al., 2008; Gaoua et al., 2011). Nonetheless, the effects of head cooling on cognitive function remain equivocal, as Ando et al. (2015) found that neck cooling and neck fanning (proposed to cool blood to the brain) during cycling in the heat (35°C, 70% RH) did not improve working memory performance (spatial delayed response task) or inhibitory control (go/no-go task), compared to a no-cooling control.

As there has been a minimal investigation into the effects of cooling on complex cognitive performance associated with exercise in the heat, further studies are warranted due to the many sporting events where decision making is paramount to success. Therefore, this study aimed to investigate whether 15 min of head cooling (HC) using a head-cooling cap applied prior to exercise in the heat could improve subsequent complex cognitive performance compared to a no-cooling control condition (CON). We hypothesized that HC would reduce T_h, as well as T_c and that this would result in improved subsequent cognitive performance assessed after 30 min (midway break) and 60 min of running performed in the heat, compared to a no-cooling control (CON).

METHODS

Participants

Ten moderately-trained, non-heat-acclimated, male endurance athletes, (age 22±6.6 y; height 177.7±9.7 cm; body-mass 75.7±15.6 kg; $\dot{V}O_{2peak}$ 51.6±4.3 $mL^{-1}\cdot kg^{-1}\cdot min$) volunteered to participate in this study. All participants reported training for a minimum of 4 × 60 min sessions each week. Based on a study by Barr et al. (2009), a G-power analysis (Faul et al., 2009) calculation showed that ten participants were needed for this study (effect size of 1.4 at an alpha level of 0.05, power of 0.80). Ethical approval was granted by the Human Research Ethics Office of The University of Western Australia. All participants gave informed written consent and completed the Adult Pre-exercise Screening System questionnaire (Norton et al., 2012) prior to participation in experimental protocols.

Preliminary session

Before the trial, body-mass (Sauter Multi-Range scales; Model ED3300, Ebingen, Germany) and height (Seca, Hamburg, Germany) were measured. Participants then completed a graded $\dot{V}O_{2peak}$ test on a motorized treadmill (H/P Cosmos, Quasar 3p Medical treadmill, Nussdorf-Traunstein, Germany) to determine aerobic capacity. A metabolic cart incorporating applied electrochemistry oxygen (SOV-S3A11) and carbon dioxide (COV CD-3A) analyzers (Pittsburgh, PA, USA) and ventilometer (VacuMed, Ventura, CA, USA) were used, with calibration performed prior to each test. The test began at 8 $km\cdot h^{-1}$ with a 1% incline, then increased by 1 $km\cdot h^{-1}$ every 3 min (with each stage separated by 1 min of recovery) until volitional exhaustion. Oxygen uptake ($\dot{V}O_2$), heart rate and ratings of perceived exertion (RPE) were measured at the end of every stage. Running speed during the subsequent experimental trials was performed at a speed eliciting 70% of each participant's $\dot{V}O_{2peak}$. Following the $\dot{V}O_{2peak}$ test, a familiarization session was completed, which required participants to complete a cognitive test (Automated Operation Span Task: OSPAN), which was installed on a laptop (HP Probook 440 G5, California, USA). The cognitive test was performed prior to wearing a head-cooling cap (Arctic Heat Pty Ltd, Gold Coast, Australia) for 15 min, with this followed by 2 x 30 min running bouts (at 70% $\dot{V}O_{2peak}$), on a treadmill in the heat chamber (35°C, 70% RH), with cognitive performance assessed again after each exercise bout.

Experimental design

In the 24 h before the first trial, exercise and food diaries were completed and participants were required to follow the same diet and physical activities prior to subsequent trials. Strenuous exercise, alcohol and caffeine were also avoided for 24 h prior to testing.

Following the familiarization session, two experimental trials were completed in a randomized order. The trials involved participants wearing a head-cooling cap that was either cooled to ~0°C or kept at room temperature (~22°C) prior to running in hot, humid conditions (35°C, 70% RH). Both trials were held at the same time of day, seven days apart. Participants ingested a telemetry capsule core body temperature sensor

(CorTemp® Ingestible Core Body Temperature Sensor, HQ Inc., Palmetto, FL, USA) 8 h prior to each experimental session to enable measurement of gastrointestinal (core) temperature.

Experimental protocol

On arrival to the laboratory, a mid-stream urine sample (1 ml) was collected to determine urine specific gravity (USG) using the refractometry method, in order to assess pre-exercise hydration status (~1.016±0.01 nmol/d), with no participants found to be hypohydrated (USG > 1.020, Volpe, Poule & Bland, 2009). A heart-rate monitor (Polar RS400, Kempele, Finland) was fitted to the participant's chest, and skin thermistors (Skin Sensor SST-1, Physitemp Instruments Inc, Clifton, NJ, USA) were taped (Fixomull Stretch Tape, BSN Medical GmBH, Hamburg, Germany) to the sternum (level of the second rib), left mid-anterior forearm, left mid-posterior calf and forehead to measure skin temperature (T_{sk}) via a computerized program (DASYLab Light, National Instruments, Ireland Resources Ltd, Dublin, Ireland). Mean T_{sk} was measured using the formula described by Burton (1935): $T_{sk} = (0.5 \text{ x } T_{sternum}) + (0.14 \text{ x } T_{forearm}) + (0.36 \text{ x } T_{calf})$. A baseline cognitive test (OSPAN) was performed on arrival to the laboratory (22°C, 35% RH), with this followed by 15 min of cooling or no-cooling wearing the head-cooling cap in a seated position whilst resting (0°C or 22°C). Participants then entered a custom-built 40 m^3 climate chamber (35°C, 70% RH) and performed a 5 min warm-up at 50% of $\dot{V}O_{2peak}$, followed by steady-state running at 70% of $\dot{V}O_{2peak}$ for 2 × 30 min on the treadmill with a 10 min break between each 30 min running bout. The endurance running protocol was performed at a constant relative speed so to reduce the number of possible cofounders introduced when attempting to determine the effect of cooling on cognitive performance. The cognitive test was re-administered after completing the first bout of the exercise protocol (30 min mark) and immediately after exercise, with this test performed in the climate chamber. Participants ingested 100 ml (~22°C) of tap water every 10 min during exercise. Every 5 min, T_c, T_h, T_{sk}, heart rate and RPE (Borg scale 6-10: Borg, 1982) were measured throughout the trial.

Head-cooling cap

A commercially available head-cooling cap (Arctic Heat Pty Ltd, Gold Coast, Australia; Figure 1) made from polyester material with four crystal-filled pockets were used for this study. The device covered the head from the forehead area to the nape of the neck (front to back). The head-cooling cap was secured with polyester laces that had an inbuilt wicking effect. Before the experimental trial, the headgear was soaked in water for 15 min to activate the crystals into gel form. It was then kept in a freezer at -10°C for at least 4 h. Five min before donning the headgear, it was removed from the fridge and placed in a cold box to maintain the temperature. The average temperature of the headgear after cooling was ~0.01±0.1°C.

Cognitive test

The OSPAN task (Unsworth et al., 2005) is a computerized cognitive test that was administered using Inquisit 5 software (Inquisit 5Lab, Millisecond Software, Seattle, USA) and took ~10 min to complete. The OSPAN is a complex cognitive task designed to assess working memory capacity. It requires participants to memorize sequences of letters in order, whereby presentation of each to-be-remembered letter is interleaved with a secondary processing task, which requires participants to judge a mathematical equation (e.g., 9*2 – 9 = 8) as being either correct or incorrect. Set sizes ranged from 3-7, with three trials per set size (i.e., 15 trials total). In total, there were 75 letters and 75 math problems to be solved. The order of set sizes was randomly and automatically set by the software for each session. The outcome measure was the sum of the total number of correct answers in the secondary task, with a total maximum mark of 75 (Bayliss et al., 2003). This test has previously been used in studies to test cognitive performance in education and work environments (Kraus and Porubanova, 2015; Miller et al., 2018) with this task having an internal consistency of $\alpha = 0.78$ and test-retest reliability of $r = 0.83$ (Unsworth et al., 2005).

Statistical analyses

All statistical data were analyzed using the IBM Statistical Package for Social Sciences version 23.0 (SPSS Inc, Chicago, IL, USA); descriptive statistics are presented as mean ± standard deviation unless otherwise stated. The data was assessed and met standards for normality (Shapiro-Wilk test) and sphericity (Mauchly’s test). Two-way, repeated-measures ANOVAs were performed on the data to test for interaction and condition differences. Statistical significance was set at $p \leq 0.05$. Where appropriate, posthoc comparisons using Bonferroni adjustments were conducted. Furthermore, effect sizes (Cohen's *d*) were calculated for all variables, with only moderate (0.5-0.79) and large (> 0.8) effect sizes and associated 95% confidence intervals (CI) reported if found.

RESULTS

There were no differences in temperature (34.5±0.8°C) and humidity (69.3±3.2% RH) in the environmental chamber between trials ($p = 0.75$ and $p = 0.82$, respectively).

The Automated Operation Span Task

There was no interaction effect for OSPAN absolute scores ($p = 0.58$), nor was there a main effect between trials ($p = 0.67$) or for time ($p = 0.54$). A moderate effect size was determined for the HC trial over time (d=0.51, 0.42 to 1.35 95% CI; Table 1).

Forehead temperature

There was an interaction effect for T_h values ($p < 0.01$) and a significant main effect for time ($p < 0.01$), with this supported by large ES for both trials (HC: d=8.41, 5.2 to 10.33 95% CI; CON: d=10.38, 6.48 to 12.67 95% CI). Precooling for 15 min significantly lowered T_h from 34.5±0.4°C to 32.4±1.6°C ($p < 0.01$), with this supported by a large ES in the HC trial (d=1.8, 0.65 to 2.68 95% CI). Furthermore, T_h in the HC trial was significantly lower than CON immediately following cooling ($p < 0.01$). Notably, T_h was similar at the start of the exercise for both trials (CON: 35.9±0.5°C; HC: 35.7±0.3°C) and increased in a similar manner over the exercise protocol, with results approaching significance ($p = 0.08$). Additionally, while there was no main effect found between trials ($p = 0.28$), large ES suggested a tendency for lower T_h values in the HC trial compared to CON at every time point during the cooling period (min 5, d=2.12, 0.89

to 3.02 95% CI; min 10, *d*=3.05, 1.58 to 4.05 95% CI; min 15 *d*=4.4, 2.54 to 5.61 95% CI; Figure 2).

Core and skin temperature

While there was no interaction effect (p = 0.84) or main effect for trial (p = 0.28), mean T_c increased progressively across the protocol, with this supported by a main effect for time ($p < 0.01$), as well as large ES (CON: *d*=15.30, 9.66 to 18.58 95% CI; HC: *d*=6.52, 3.96 to 8.07 95% CI; Figure 3). Further, in respect to T_{sk} responses, there was no interaction effect (p = 0.09) nor main effect for trial (p = 0.81). However, the main effect for time approached significance (p = 0.06), with this supported by large ES over time for both trials, (CON: *d*=3.79, 2.1 to 4.89 95% CI; HC: *d*=4.89, 2.86 to 6.16 95% CI; Figure 4).

Heart rate and rating of perceived exertion

There was no interaction effect for heart rate (bpm) (p = 0.32), nor was there a main effect for trial (p = 0.27). Heart rate values were similar between trials prior to exercise (CON: 60±13; HC: 59±10 bpm), and at the end of exercise (CON: 175±10; HC: 176±6 bpm). Notably, there was a main effect for heart rate over time ($p < 0.01$), with this supported by a large ES found for both trials (CON: *d*=9.92, 6.18 to 12.12 95% CI; HC: *d*=14.19, 8.94 to 17.24 95% CI). A similar pattern was observed for RPE, where values were similar for both trials at the start of exercise (CON: 7±1; HC: 7±1) and the end of exercise (CON: 18±2; HC: 18±2). While the interaction effect for RPE approached significance (p = 0.07), there was no significant main effect for trial found (p = 0.19).

There was however, a main effect for time ($p < 0.01$), with this supported by a large ES for both trials (CON, *d*=6.96, 4.25 to 8.95 95% CI; HC, *d*=6.96, 4.25 to 8.95 95% CI).

DISCUSSION

This study aimed to investigate the effect of precooling using a head-cooling cap on complex cognitive performance performed midway (during a rest break) and after 60 min of endurance running in the heat. The primary finding of this study was that while there was a tendency for improvement in OSPAN performance over time (moderate effect size), there were no significant differences in scores between trials for any time point assessed. Further, 15 min of wearing a cooling cap resulted in T_h being lower (~2.1°C) compared to baseline values, as well as being significantly different between trials immediately after cooling, however values were similar during the exercise protocol.

Thermal strain, where T_c is ≥38.5°C, has been found to impair complex cognitive performance (Schmit et al., 2017). In the current study, we were unable to determine whether cognitive performance was affected during and after exercise in the heat as no thermoneutral trial was performed to assess this effect. While initial/baseline cognitive performance was assessed in thermoneutral conditions (22°C, 35% RH), this assessment was performed while participants were at rest with no prior exercise in heat performed. Nonetheless, it was hypothesized that cooling applied to the head prior to exercise performed in the heat would reduce the temperature of blood flow to the brain, which in turn would result in better performance on the OSPAN task when compared to a no-cooling trial also performed in the heat. In the current study, the lack of significant difference between trials with respect to OSPAN performance is most likely due to similar

T_h and T_c values recorded for both trials at all-time points during the exercise protocol. Further, similar heart rate values recorded over the course of the protocol for both trials, suggest that heat strain was similar between trials.

Results for cognitive performance here are similar to those described by Ando et al. (2015) who assessed working memory (spatial delayed response task) and executive function (go/no-go task) in participants during cycling (10 min with heart rate maintained at 160 beats·min^{-1}) in hot and humid ambient conditions (35°C, 70% RH). These researchers reported no differences in either cognitive test between a cooling (neck cooling with a wet towel, 21°C and fanning of the back of the neck; both performed throughout the cycling protocol) and a no-cooling trial in the heat. Unfortunately, neither T_c nor T_h were assessed by Ando et al. (2015) meaning that it cannot be determined whether T_c was ≥38.5°C: a level reported to result in impaired complex cognitive performance (Hancock and Vasmatzidis, 2003). While the cooling methods in the study by Ando et al. (2015) were different to those used in the current study, the rationale for cooling the head whilst exercising in the heat was similar.

In contrast, Racinais et al. (2008) assessed complex cognitive performance (spatial span task) in three different environmental conditions: control/no-cooling (20°C, 40% RH; peak T_c ~37ºC), hot/no-cooling (50°C, 50% RH; peak T_c ~39°C) and hot/cooling (50°C, 50% RH; peak T_c ~38°C). The cooling trial involved three cold packs applied to the head and one pack to the back of the neck (frozen; -14°C), with packs replaced every 20 min throughout the entire exercise/rest protocol. Upon entering the chamber, participants performed 10-15 min of walking at 3-5 km.h^{-1} (duration based on the participant's fitness level) followed by rest for 45-50 min with total exercise/rest time being 60 min. Following this, the cognitive test was performed in the same environmental conditions for each trial. Racinais et al. (2008) reported that cognitive performance (spatial span test) was significantly lower/impaired ($p < 0.05$) in hot/no cooling (peak T_c: ~38.9°C) compared to control/no cooling (peak T_c: ~37°C) and hot/cooling conditions (peak T_c: ~38.1°C), where results between control/no cooling and hot/cooling were similar to each other. These researchers surmised that cooling the head during exercise in the heat helped prevent hyperthermia ($T_c \geq 38.5$°C) and consequently improved cognitive function. An issue with this study is that this form of head cooling is not practical in a real sporting world scenario.

These results by Racinais et al. (2008) were supported by Gaoua et al. (2011) who performed a similar experimental study protocol (three trials using the same environmental conditions and the same exercise/rest and cooling protocols with cognitive performance assessed following exercise/rest). Gaoua et al. (2011) observed a significant decrement in cognitive performance (spatial span test) in the hot/no-cooling trial (peak T_c: ~38.8°C) compared to control/no-cooling (peak T_c: ~37.1°C). Conversely, a significant improvement in cognitive performance was associated with hot/cooling (peak T_c: ~38°C) compared to the hot/no-cooling trial, but not when compared to control/no-cooling trial. Gaoua et al. (2011) also reported that cooling resulted in lower T_h values compared to hot/no-cooling condition by 1.9±0.4°C. In the current study, the difference reported in T_h values after cooling was similar to those reported by Racinais et al. (2008) and Gaoua et al. (2011), in the range of ~1.9- ~2.1°C. These results suggest that head cooling is effective in decreasing T_h.

As noted earlier, no differences were seen in cognitive performance between the cooling and no-cooling trials within the present study during and following exercise in the heat. Differences in results between the current study and the aforementioned studies may relate to cooling being performed for longer and continuously throughout the exercise period (i.e., 60 min) by Racinais et al. (2008) and Gaoua et al. (2011) compared to only 15 min of cooling performed prior to exercise in the current study. Additionally, a greater body surface area was covered by the cooling modalities used in these studies that either separately or combined with continuous cooling throughout exercise/rest may have contributed to keeping participants' T_c below hyperthermic levels, compared to the hot/no-cooling trials where T_c was ~39.0°C. These results compare to T_c values in the current study where T_c peaked at 39.18±0.53°C and 39.83±0.20°C in the control trial and 38.99±0.49°C and 39.64±0.40°C in the head cooling trial (end of the first and second bout of exercise, respectively), with all these values well exceeding a hyperthermic level of 38.5°C.

It is possible that a longer cooling period (involving precooling and mid-cooling) or a combination of wearing the cooling cap with another mode of cooling (e.g., neck cooling that specifically targets cerebral blood flow or ingestion of an ice slushy) may have resulted in significant differences in T_c (as well as in T_h, T_{sk} and heart-rate) and hence OSPAN scores between the cooling and no-cooling trials here. Importantly, Levels et al. (2013) reported that T_c was significantly decreased when mixed cooling (ice ingestion and scalp cooling) was employed compared to scalp cooling alone. Another consideration is that cooling may have reduced T_h for a longer period of time if the cap had been worn on a shaved head, as this would have improved the conduction properties of this process. Thick hair has been reported to increase the insulation capacity of the skull, thus restricting heat removal (Shin et al., 2015), while Cabanac and Brinnel (1988) reported a three times higher evaporation rate associated with bald scalps compared to hairy scalps.

This research has a number of limitations. Firstly, thermal sensation was not assessed during these trials. It is possible that feeling cooler may impact/improve complex cognitive function when undertaken in the heat. It has previously been reported that an increase in thermal sensation may lead to an increased RPE (Pandolf et al., 1978). In respect to the current study, RPE was assessed with no significant differences found between trials. Furthermore, as noted earlier, it would be advantageous to shave the head prior to wearing the head-cooling cap as this would result in better conduction between the cap and the head, which in turn may have a more profound effect on T_h and T_c. While some individuals may not wish to do this, it is probable that those competing at an elite level are more likely to comply with this suggestion. Finally, future research should consider cooling participants in the heat chamber, as this more closely mimics real-world scenarios where athletes participate in outdoor events and often do not have access to air-conditioned rooms (e.g., cyclists). Also, the wearing of the cooling cap during exercise should be explored.

CONCLUSION

While head cooling significantly reduced T_h immediately after cooling compared to baseline values, as well as between trials, this did not result in significant changes in T_c or OSPAN performance between trials. A longer cooling duration that uses a combination of cooling modalities (e.g., head cooling and neck cooling or ice slushy ingestion) where the head is shaved may result in significant outcomes in the variables measured here. This approach should be considered for future studies.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to the participants for their commitment and interest.

REFERENCES

1. Ando, S., Komiyama, T., Sudo, M., Kiyonaga, A., Tanaka, H., & Higaki, Y. (2015). The effects of temporal neck cooking on cognitive function during strenuous exercise in a hot environment: A pilot study. *BMC Research Notes* **8**:1.

2. Barr, D., Gregson, W., Sutton, L., et al. (2009). A practical cooling strategy for reducing the physiological strain associated with firefighting activity in the heat. Ergonomics **52(4)**, 413-420.

3. Bayliss, D. M., Jarrold, C., Gunn, D. M., Baddeley, A. D. (2003). The complexities of complex span: Explaining individual differences in working memory in children and adults. *Journal of Experimental Psychology Genetic* **132**, 71-92.

4. Booth, J., Marino, F. & Ward, J. J. (1997). Improved running performance in hot humid conditions following whole body precooling. *Medicine and Science in Sports and Exercise* **29**, 943–949.

5. Borg, G. A. (1982). Psychological bases of physical exertion. *Medicine and Science in Sports and Exerc*ise **14**, 377–381.

6. Burton, A. C. (1935). Human calorimetry II. The average temperature of the tissues of the body. *Journal of Nutrition* **9(3),** 261-280.

7. Cabanac, M., & Brinnel, H. (1988). Beards, baldness, and sweat secretion. *European Journal of Applied Physiology and Occupational Physiol*ogy **58**, 39–46.

8. Casa, D. J. (1999). Exercise in the heat. I. Fundamentals of thermal physiology, performance implications, and Dehydration. *Journal of Athletic Training* **34(3)**, 246-252.

9. Conway, A., Jarrold, C., Kane, M. J., Miyake, A., & Towse J. N. (2007). *Variation in working memory*. New York: Oxford University Press.

10. Falkowska, A., Gutowska, I., Goschorska, M., Nowacki, P., Chlubek, D., Baranowska-Bosiacka, I., & Falkowska, A. (2015). Energy Metabolism of the Brain, Including the Cooperation between Astrocytes and Neurons, Especially in the Context of Glycogen Metabolism. *International of Journal Molecular Sciences* **16(11)**, 25959–25981.

11. Faul, F., Erdfelder, E., Buchner A., et al. (2009). Statistical power analyses using G* Power 3.1: tests for correlation and regression analyses. Behavioral Research Method **41(4)**, 1149-1160.

12. Faulds, M., & Meekings, T. (2013). Temperature management in critically ill patients. *Continuing Education in Anesthesia Critical Care & Pain* **13**, 75-79.

13. Gaoua, N., Racinais, S., Grantham, J., & El, M. F. (2011). Alterations in cognitive performance during passive hyperthermia are task dependent. *International Journal of Hyperthermia* **27(1)**, 1-9.

14. Hancock, P., & Vasmatzidis, I. (2003). Effects of heat stress on cognitive performance: the current state of knowledge. *International Journal of Hyperthermia* **19(3)**, 355–372.

15. Hocking, C., Silberstein, R.B., Lau, W.M., Stough, C., & Roberts, W. (2001). Evaluation of cognitive performance in the heat by functional brain imaging and psychometric testing. *Computer Biochemical Physiology A Molecule Integrative Physiol*ogy **128**(4), 719-734.

16. Ihsan, M., Landers, G., Brearley, M. & Peeling, P. (2010). Beneficial Effects of Ice Ingestion as a Precooling Strategy on 40-km Cycling Time-Trial Performance. *International Journal of Sports Physiology and Performance* **5(2)**, 140-151.

17. Kraus, J., & Porubanova, M. (2015). The Effect of Binaural Beats on Working Memory Capacity. *Studia Psychologica* **57(2)**, 135–145.

18. Lee, J. K., Koh, A. C., Koh, S. X., Liu, G. J., Nio, A. Q., & Fan, P. W. (2104). Neck cooling and cognitive performance following exercise-induced hyperthermia. *European Journal of Applied Physiol*ogy **114(2)**, 375-384.

19. Levels, K., Teunissen, L. P., De, H. A., De, K. J., Van, O. B., & Daanen, H. A. (2013). Effect of warm-up and precooling on pacing during a 15-km cycling time trial in the heat. *International Journal of Sport Physiology and Performance* **8(3)**, 307–311.

20. Miller, Z., Fox, J., Moser, J., & Godfroid, A. (2018). Playing with fire: effects of negative mood induction and working memory on vocabulary acquisition. *Cognition and Emotion* **32(5)**, 1105–1113.

21. Norton, K., Coombes, J., Parker, R., Williams, A., Hobson-Powell, A., Knox, C. (2012). New Australian standard for adult pre-exercise screening. *Sport Health*, **30**, 12

22. Nybo, L., & Nielsen, B. (2001). Hyperthermia and central fatigue during prolonged exercise in humans. *Journal of Applied Physiology* **91**, 1055–1060.

23. Onitsuka, S., Zheng, X., & Hasegawa, H. (2015). Ice slurry ingestion reduces both core and facial skin temperatures in a warm environment. *Journal of Thermal Biol*ogy **51**, 105–109.

24. Pandolf, K. B., Kamon, E., & Noble, B. J. (1978). Perceived exertion and physiological responses during negative and positive work in climbing a ladder mill. *Journal of Sports Medicine and Physical Fit*ness **18(3)**, 227–36.

25. Racinais, S., Gaoua, N., & Grantham, J. (2008). Hyperthermia impairs short-term memory and peripheral motor drive transmission. *Journal of Physiology* **586(19)**, 4751-4762.

26. Saldaris, J. M., Landers, G. J., & Lay, B. S. (2019). Internal precooling decreases forehead and core temperature but does not alter choice reaction time during steady state exercise in hot, humid conditions. *Journal of Thermal Biology* **81**(77-72).

27. Saldaris, J. M., Landers, G. J., Lay, B. S. (2020). Enhanced decision making and working memory during exercise in the heat with crushed ice ingestion. *International Journal of Sport Physiology and Performance* **14**, 503-510

28. Schmit, C., Hausswirth, C., Le, M. Y., & Duffield, R. (2017). Cognitive functioning and heat strain: Performance responses and protective strategies. *Journal of Sports Medicine* **47(7)**, 1289-1302.

29. Shin, S., Park, J., & Lee, J. Y. (2015). Does the hair influence heat extraction from the head during head cooling under heat stress? *Industrial Health* ***53*(6)**, 533–541.

30. Smits, B., Pepping, G., & Hettinga, F. (2014). Pacing and Decision Making in Sport and Exercise: The Roles of Perception and Action in the Regulation of Exercise Intensity. *Journal of Sports Medicine* **44(6)**, 763–775.

31. Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavioral Research Methods* **37**, 498-505.

32. Vanden Hoek, T. L., Kasza, K. E., Beiser, D. G., et al. (2004). Induced hypothermia by central venous infusion: Saline ice slurry versus chilled saline. *Critical Care Medicine* **32**, S425–S431.

33. Volpe, S.L., Poule, K.A. & Bland, E.G. (2009) Estimation of pre-practice hydration status of National Collegiate Athletic Association Division I athletes. *Journal Athletic Training* **44**, 624-629.

Key points

- Wearing a cooling cap for 15 min significantly reduced forehead temperature compared to baseline, as well as compared to a no-cooling control.
- Despite forehead temperature being significantly lower after cooling, forehead temperatures were similar between the cooling and no-cooling trials during exercise in a hot environmental chamber.
- Cooling the forehead prior to exercise in the heat did not improve subsequent cognitive performance assessed midway and after exercise.

Figure 1: The Arctic Heat head-cooling cap. The cap is filled with crystallize beads that can be activated with water before usage.

Table 1 Absolute score for the automated operation span test of participants in experimental trials (n=10). The [a] indicates moderate ES for HC over time (*d*=0.51).

Time	**Control**	**Head cooling** [a]
OSPAN		
Before	60 ± 14.29	60.2 ± 8.49
First half	59.7 ± 13.57	62.3 ± 8.19
Second half	60.4 ± 13.13	63.9 ± 5.85

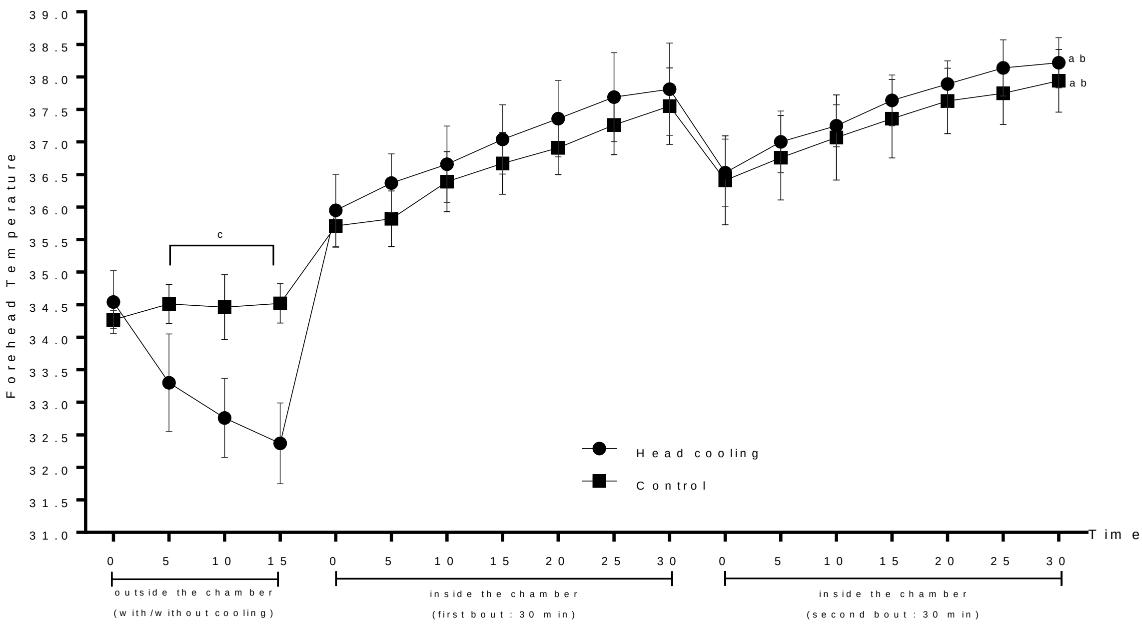

Figure 2 Forehead temperature (ºC) of participants in experimental trials. Mean forehead temperature was lowered in HC trial than CON trial during the precooling session (n=10). The [a] indicates a significant main effect for time for both trials (p<0.001). The [b] indicates large effect size (HC *d*=8.41.71, CON *d*=10.38) for both trials over time. The [c] indicates a large effect size between trials during cooling (*d*=2.12 – 4.4).

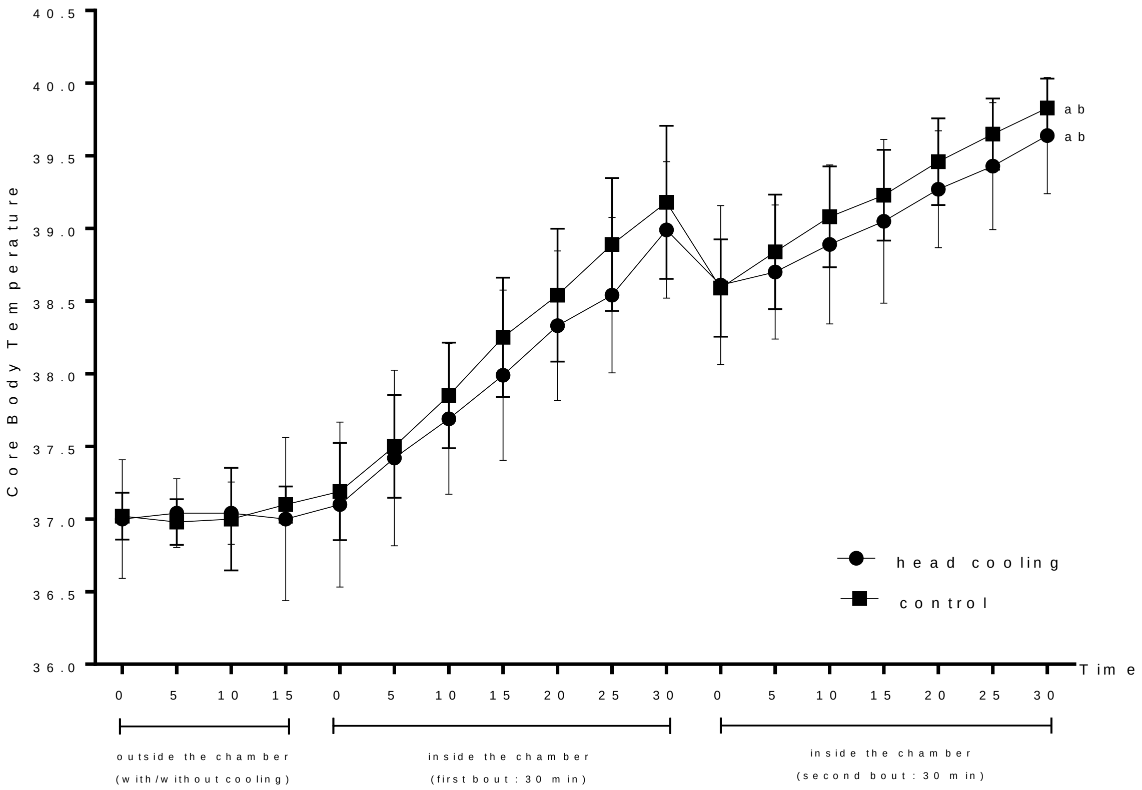

Figure 3 Core body temperature (ºC) of participants during the control and cooling trials (n=10). The [a] indicates a significant main effect for time for both trials (p=0.01). The [b] indicates large effect sizes over time for both CON and HC (*d*=15.30, 6.52).

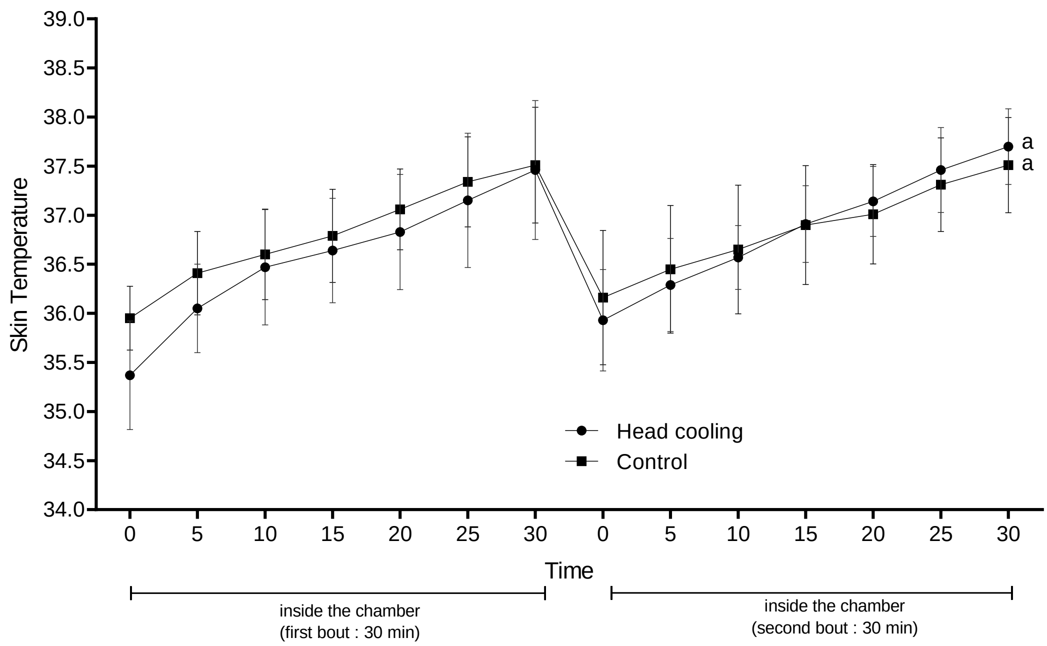

Figure 4 Skin temperature (°C) of participants during the control and cooling conditions (n=10). The [a] indicates large effect size for both trials over time (CON: *d*=3.79 and HC: *d*=4.89).