Abstract

This study compared the effects of a hand cooling glove (~16°C water temperature; subatmospheric pressure of -40 mmHg) and a cooling jacket (CJ) on post-exercise cooling rates (gastrointestinal core temperature, Tc; skin temperature, Tsk) and cognitive performance (Stroop Colour-Word test). Twelve male athletes performed four trials (within subjects, counterbalanced design) involving cycling at a workload equivalent to 75% $\dot{V}O_2$max in heat (35.7 ± 0.2°C, 49.2 ± 2.6% RH) until a Tc of 39°C or exhaustion occurred. A 30 min cooling period (in 22.3 ± 0.3°C, 42.1 ± 3.6% RH) followed, where participants adopted either one hand cooling (1H), two-hand cooling (2H), wore a CJ, or no cooling (NC). No significant differences were seen in Tc and Tsk cooling rates between trials, however moderate effect sizes (*d*=0.50-0.76) suggested Tc cooling rates to be faster for 1H, 2H and CJ compared to NC after 5 min; 1H and CJ compared to NC after 10 min and for CJ to be faster than 2H at 25-30 min. Reaction times on the cognitive test were similar between all trials after the 30 min cooling/no-cooling period ($p>0.05$). In conclusion, Tc cooling rates were faster with 1H and CJ during the first 10 min compared to NC, with minimal benefit associated with 2H cooling. Reaction time responses were not impacted by use of the glove(s) or CJ.

Keywords: *heat, thermoregulation, glove, core temperature, Stroop test*

Introduction

Exercise in the heat increases core temperature (Tc; resting: ~37°C), with ~39.4-40°C reported as a critical level, resulting in premature fatigue and possible exertional heat illness (Casa, 1999, Marino, 2002). Importantly, reducing Tc using cooling modalities during breaks in team-sport games played in a hot/humid environment has been found to improve subsequent exercise performance (Ranalli et al., 2010). Notably, cooling jackets (CJ; gel or ice) are currently used during team-breaks in many team-sports played in the heat (i.e., hockey, Australian Rules football; Brade et al., 2010), with Brade et al. (2010) reporting faster Tc cooling rates associated with a gel CJ (0.04±0.01/min) compared to no cooling (0.03±0.01/min; d=0.60) over a 30 min cooling period following exercise in the heat (peak Tc ~38.5°C). Other studies have also reported faster (but non-significant) Tc cooling rates associated with wearing a CJ for 10–30 min following exercise in the heat compared to a no-cooling control (Duffield and Marino, 2007, Lopez et al. 2008, Webster et al. 2005), with Duffield and Marino (2007) reporting that cooling with a CJ was also associated with lower Tsk and perceived thermal load compared to a no-cooling condition. The popularity of CJ relate to their ease of use, particularly when water and/or power sources are not available thus preventing the use of other superior cooling methods (i.e., water immersion; Proulx et al., 2003, or fan; Barwood et al., 2009). However, CJ need to be activated in icy water prior to use and kept in an ice chest over the course of a game in order to maintain effectiveness.

More recently, hand-cooling devices have been studied. The principle behind hand cooling relates to the packed vascular structures found in glabrous non-hairy palms of hands that facilitate heat loss faster when compared to non-glabrous body surfaces (Grahn et al., 2009). Studies have shown that immersing the hands in cold water of between 10-20°C significantly reduces an elevated Tc compared to a no-cooling control condition (Giesbrecht et al., 2007, Goosey-Tolfrey et al., 2008, Khomenok et al., 2008, Selkirk et al., 2004), with vasoconstriction reported to occur at temperatures below ~10°C, which can negatively interfere with cooling rates (Khomenok et al., 2008). This research prompted the creation of portable hand cooling 'gloves' such as CoreControlTM. This device utilises circulating cold water (~16°C, as set by the Manufacturers so to avoid vasoconstriction) in combination with negative subatmospheric pressure (-40 mmHg) to facilitate heat loss by increasing blood flow to the arteriovenous anastomoses underlying the palmar surfaces of the hand, thereby cooling blood returning to the core (Grahn et al., 2008). Studies have reported a range of Tc cooling rates (0.013 to 0.040°C/min over 10-60 min) when using these devices on one or two hands, with these rates being significantly greater when compared to control (Adams et al. 2016a, 2016b, Grahn et al., 2009, Hostler et al. 2010, Kuennen et al. 2010, Zhang et al. 2009). Importantly, these gloves represent a practical cooling method for sports played in hot environments due to their portability, battery operation and ease of application; however, Tc cooling rates associated with these gloves used on one compared to two hands have not been assessed in an athletic population. Compared to the CJ, which covers the torso - a larger non-glabrous body surface area (BSA: ~17% Young et al., 1987), the glove (~1% of average BSA per hand: Adams, et al. 2016a) targets a glabrous skin surface with cold water and negative subatmospheric pressure suggesting that Tc cooling rates may differ between the two modalities. Of issue, cooling the major muscle groups associated with a particular activity (i.e. quadriceps prior to sprinting) has been found to impair subsequent exercise that relies predominantly on the activation of these specific muscles (Sargeant, 1987, Sleivert et al., 2001). However, a short warm-up of these muscles prior to exercise has been reported to largely remove any detrimental impact of a cooler muscle temperature on subsequent performance (Sleivert et al., 2001). Moreover, the CJ and the CG only cool muscles surrounding the torso or the hands, with muscles in the lower limbs being predominantly activated in respect to cycling and running sprint performance.

Furthermore, optimal cognitive performance is important in team-sports (Lee et al., 2014), where decisions regarding movement and ball passing can impact scoring outcomes (Abernethy, 1991). Of relevance, the Stroop Colour-Word test assesses visual attention, reaction time and the level of interference caused by irrelevant stimuli (Macleod, 1991), with these factors making it applicable to a team-sport game. Notably, performance on the Stroop test has been found to improve following moderate (Sibley et al., 2006, Yanagisawa et al., 2010) and strenuous (Hogervorst et al., 1996) bouts of exercise, with this improvement associated with an increase in Tc that is proposed to result in faster neural conduction speed (Grether, 1973). Notably, the effect of cooling modalities (such as the CJ and cooling-glove) used during team-game breaks on reaction/attention time performance has not been previously assessed. This is an important issue if it is determined that these cooling modalities impair cognitive performance, which in turn will impact performance during a subsequent exercise bout.

Therefore, the main aim of this study was to assess Tc cooling rates associated with the cooling-glove (one or two hands) and a CJ to no-cooling following exercise in hot/humid environmental conditions. It was hypothesised that cooling rates would be faster when wearing cooling-gloves on both hands versus one hand and a no-cooling condition, but similar to the CJ. It was also hypothesised cooling rates would be faster with one hand cooling compared to no cooling. A second aim was to assess the effect of cooling (using methods outlined above) on the Stroop Colour-Word task following exercise in a hot/humid environment. It was hypothesised that cooling using the glove(s) or the CJ would impair cognitive performance compared to the no-cooling trial due to a greater decline in Tc when using these modalities.

Methods

Participants

Twelve, non-heat acclimatised (winter testing), male team-sport athletes (mean±SD: training status: 10±2 $h.wk^{-1}$ of moderate-high intensity exercise; age: 21.8±1.5 y; height: 183.9±11.2 cm; body-mass: 80.1±13.5 kg; body surface area [BSA; Dubois & Dubois, 1916]: 2.0±0.2 m^2; sum of six skinfolds: 39.5±4.4 mm; $\dot{V}O_2max$: 57.0±6.5 $mL \cdot kg^{-1} \cdot min^{-1}$) participated in this study. The Human Research Ethics Committee of the University of Western Australia granted ethical approval and informed consent was obtained from all participants prior to involvement in the study.

Experimental design

Participants attended five testing sessions; a familiarisation session followed by four experimental trials undertaken at the same time of day (a week apart) to control for circadian variability. Exercise during the experimental trials involved participants cycling in the heat at 75% $\dot{V}O_2max$ (35.7±0.2°C, 49.2±2.6% RH) until either a Tc (gastrointestinal) of ~39°C or volitional exhaustion occurred. Post-exercise cooling (30 min) followed, where participants sat quietly in a controlled laboratory environment (22.5±1.4°C, 43.3±6.9% RH) undertaking one of four trials in a randomised, counterbalanced order. This period is similar to the half-time break in Australian Rules football, with assessment of skin and Tc also being recorded every 5 min of this 30 min period allowing for further comparisons to be made and applied to shorter game breaks. Trials consisted of: (1) hand cooling glove on one hand, (2) hand cooling gloves on two hands, (3) wearing a CJ and (4) control (no cooling).

Familiarisation session

Anthropometric measurements of height (cm), body-mass (kg), sum of six skinfolds (Harpenden calipers; mm; bicep, tricep, subscapular, supraspinale, abdominal and calf) and BSA (m^2) were obtained. Participants then performed a graded cycle ergometer test to determine $\dot{V}O_2max$, beginning at a power output of 100 Watts (W) and increasing by 50 W every 3 min, until volitional exhaustion. A metabolic cart incorporating applied electrochemistry oxygen (SOV-S3A11) and carbon dioxide (COV CD-3A) analysers (Pittsburg, PA, USA) and a ventilometer (VacuMed, Ventura, California, USA) was used. After recovering, participants were familiarised to the procedures and equipment used in the experimental trials.

Cooling Interventions

CoreControl hand-cooling gloves (CoreControl™, AVAcore Technologies, Ann Arbor, MI) were used. As per manufacturer's instructions, participants placed their hand inside the glove, where cold circulating water (~16°C) and subatmospheric pressure (-40 mmHg) encapsulate the hand surface area (wrist to fingertips) (Adams et al., 2016a). For the single hand trial, the device was placed on the non-dominant hand. In order to promote venous return, the hand(s) for both trials using the glove was/were elevated to heart level. On another occasion, participants wore a CJ (Arctic Heat Products Pty Ltd, Queensland, Australia), which is manufactured from polyester and micromesh and contains four pockets, both anteriorly and posteriorly (eight in total), containing crystals. In accordance with the manufacturer's instructions, the jacket was first soaked in water for 15 min to activate the crystals to form a gel, and then frozen. Prior to use, the CJ was then soaked in an ice slushy (0-2°C) for 30 min before being wrung out to remove excess water, then was worn over the participant's bare chest. The control trial involved sitting in the same position/environment for 30 min.

Experimental Trials

Participants abstained from caffeine 3 h prior, and alcohol and vigorous activity 24 h prior to each experimental session; they also consumed 600 mL of water 1 h prior to arrival to ensure adequate hydration. They wore the same clothing (shorts and shoes) for each experimental session and replicated food and fluid intake prior to subsequent trials, with this checked by the researcher on arrival.

Eight hours prior to commencing exercise in the experimental sessions, participants ingested a radiotelemetry pill (CorTemp, HQ Inc., Palmetto, FL) to enable Tc (gastrointestinal) measurement (ingestion of the pill 8-12 hours prior to reading is recommended to allow passage of the pill from the stomach into the intestine, giving a more stable Tc reading; Byrne & Lim, 2007). Upon arrival, a mid-stream urine sample (1 mL) was used to determine urine specific gravity (USG) to assess pre-exercise hydration levels. In cases of hypohydration (USG>1.030), participants then consumed an additional 500 ml of water. Nude body-mass was then measured using a digital platform scale (Model ED3300; Sauter Multi-Range, Ebingen, West Germany) to the nearest 0.01 kg. A heart-rate monitor (HR: Polar RS400, Finland) was fitted and three skin thermistors (Skin Sensor SST-1, Physitemp Instruments Inc, NJ, USA) were taped to the sternum, left medial forearm and left mid-posterior calf to measure skin temperature (Tsk) via a computerised program (DASYLab Light, National Instruments, Ireland Resources Ltd.). Mean Tsk was calculated using the formula of Burton (1935): Tsk = (0.5 x Tsternum) + (0.14 x Tforearm) + (0.36 x Tcalf). Participants then completed a modified version of the Stroop Colour-Word Test (Inquisit 5 Lab, Millisecond Software, Seattle, USA) (Stroop, 1935). Colour names were presented in an incongruent colour, and participants needed to indicate the colour the word was presented in (not it's meaning) by key press. Speed and accuracy were equally emphasised. Baseline measurements for Tc, Tsk and HR were then recorded.

Next, participants entered the climate chamber and cycled continuously (model Ergomedic 818; Monark Exercise AB, Sweden; mean exercise time = 39.3±5.6 min) at a workload equating to 75% $\dot{V}O_2max$ in hot/humid conditions (35.8±0.6°C, RH: 49.0±0.5%). For safety reasons, participants drank 100 mL of water (~23°C) every 10 min with this standardised for each trial. Measurement of Tc and HR occurred every 5 min and Tsk every 10 min, while ratings of perceived exertion (RPE; Borg, 1970; 6-20 scale) and thermal sensation (TS; Young et al., 1987; 0=unbearably cold to 8=unbearably hot) were recorded every 10 min. Exercise was terminated when Tc reached 39°C degrees or volitional exhaustion occurred.

Participants then exited the climate chamber, were towel dried, had nude body-mass recorded to determine sweat loss (pre–post nude body-mass + fluid ingested and any urinary output), re-dressed in the same clothing and repeated the Stroop Test. Within 5 min of completing exercise, one of the cooling or no-cooling conditions was applied for 30 min; participants sat in the air-conditioned laboratory and drank 100 mL of water every 10 min, with Tc and HR being measured every 5 min and Tsk and TS every 10 min. After this the Stroop test was performed again.

Statistical Analysis

Analysis was conducted using IBM SPSS Statistics (Version 23.0 for Windows; SPSS Inc, Chicago, IL). Two-way repeated measures (RM) ANOVA were used to assess Tc, Tsk, HR, TS, RPE, and Stroop performance across the four trials for all time points noted for each variable in the methods section, while one-way RM ANOVAS assessed sweat loss and environmental conditions, with significance accepted at p≤0.05. Where appropriate, post-hoc comparisons using Bonferroni adjustments were conducted. All results presented are expressed as mean ± SD. Cohen's *d* effect sizes (ES) were also performed for analysis of Tc, mean Tsk, TS and Stroop, with ≥0.8 representing large, 0.5-0.79 moderate and ≤0.49 small effects respectively (Cohen, 1988). Only moderate to large ES are reported. Mean difference ± 95% confidence intervals (CI) were also calculated to assess the magnitude of these differences.

Results

For all experimental trials there were no differences in pre-exercise USG levels (1.013±0.01, p=0.17), exercise duration (39.3±5.6 min, p=0.83), end of exercise HR (171±10 bpm, p=0.18), ratings of perceived exertion (RPE: 17±1, p=0.92), sweat loss (0.73±0.26 kg, p=0.74) or environmental conditions (exercise: 35.8±0.6ºC, p=0.23, RH: 49.0±5.0%, p=0.11, cooling: 22.5±1.4 ºC, p=0.43, RH: 43.6±6.7 %, p=0.08).

Core temperature was similar at baseline (36.96±0.42ºC, p=0.86), and increased by ~1.9°C over the exercise period in all trials (p=0.65, Table 1). During cooling there was a significant main effect for time (p<0.001), as Tc gradually declined over the 30 min by ~1.3°C from peak exercise values (Table 1). However, there was no significant interaction effect for the change in Tc from the end of exercise (peak Tc) to the 5, 10, 15, 20, 25 and 30 min time points of cooling existed between the four trials (Table 1; p=0.189). Despite this, moderate ES were noted for change in Tc over the first 5 min for the glove on one hand (*d*=0.62, mean difference [95%CI] 0.14°C [-0.24, 1.39]) and two hands (*d*=0.76, 0.15°C [-0.12, 1.53]) and the CJ (*d*=0.68, 0.14°C [-0.19, 1.45]) trials compared to control, as well as for the glove on one hand (*d*=0.50, 0.16°C [-0.35, 1.27]) and the CJ (*d*=0.54, 0.20°C [-0.32, 1.31]) compared to control after 10 min of cooling, with changes in Tc being lower in control at these time points (Table 1). Moderate ES were also calculated between the CJ and glove (two hands) at 25 (*d*=0.55, 0.18°C [-

0.31, 1.32]) and 30 min (*d*=0.60, 0.18°C [-0.26, 1.37]) of cooling, suggesting greater cooling with the CJ. The Tc cooling rate (°C/min) for each 5 min interval of cooling also resulted in a significant main effect for time ($p<0.001$), recording a rate of ≈0.095°C/min in the first 5 min and slowing to ≈0.044°C/min by 30 min, however no significant interaction effect was found ($p=0.18$, Table 1). Moderate ES also showed a tendency for the glove on one hand (*d*=0.59, 0.03°C [-0.27, 1.36]), two hands (*d*=0.74, 0.03°C [-0.14, 1.51]) and the CJ (*d*=0.67, 0.03°C [-0.20,1.44]) trials to have a faster cooling rate (°C/min) than control after 5 min of cooling. Further, there was a tendency for the glove on one hand (*d*=0.50, 0.02°C [-0.35, 1.27]) and the CJ (*d*=0.54, 0.02°C [-0.32, 1.31]) trials to have faster cooling rates at 10 min compared to control. Moderate ES also showed faster cooling rates for the CJ compared to the glove (two hands) at 25 (*d*=0.53, 0.01°C [-0.32, 1.30]) and 30 min (*d*=0.60, 0.01°C [-0.26, 1.37]).

****Table 1 near here****

Mean Tsk values were similar at baseline (33.41±0.80°C $p=0.92$) and increased in a comparable manner across exercise (by ~3.0°C, $p=0.92$; Table 2) in all trials. During cooling, there was a significant main effect for time as Tsk progressively declined by ~4.0°C ($p<0.001$) over 30 min, but no significant interaction effect was found for changes in in mean Tsk (Table 2, $p=0.524$). However, change in Tsk values with cooling resulted in a tendency for higher temperatures for the CJ at 10 min compared to control (*d*=0.67, 0.51°C [-0.20, 1.44]). Similarly, the Tsk cooling rate (°C/min) showed a significant main effect for time ($p<0.001$), being ~0.272°C/min, ~0.182°C/min and ~0.134°C/min at 10, 20 and 30 min respectively, however there was no significant interaction effect found ($p=0.314$ Table 2). Notably, Tsk cooling rate (°C/min) at 10 min tended to be greater for the CJ when compared to control (*d*=0.68, 0.05°C [-0.19, 1.45]).

****Table 2 near here****

Ratings of thermal sensation (TS) at the end of exercise were similar between trials, with a mean value of '7' ('very hot'). During cooling, TS progressively decreased over time (p=0.012) and a significant main effect for trial was found (p=0.001), with TS for the CJ being lower compared to control (p=0.039). Specifically, the control displayed greater perceived TS after 10 (p=0.002, *d*=1.24, 1.0 [0.28, 2.01]) and 20 min (p=0.014, *d*=0.98, 0.5 [0.06, 1.74]) of cooling, however, at 30 min, results were similar for all trials ('3.5' = 'cool/comfortable', p>0.05).

No significant interaction effect was found for scores on the Stroop task (p>0.05; Table 3). However, a significant main effect for time indicated that incongruent reaction time was faster following exercise compared to baseline for combined trial scores (p=0.001), with this supported by moderate to large ES found for each trial (*d*=0.57-0.80, 64.69-95.01 s [-0.29 to -0.05, 1.34 to 1.61]). Further, a significant main effect for time was found after 30 min of cooling/no-cooling compared to baseline (overall scores higher) and post-cooling/no-cooling to post-exercise scores (overall scores lower; p=0.001, p=0.013, respectively).

While there was no significant interaction effect for HR (p=0.302), mean HR decreased by ~90 bpm by the end of the 30 min (peak HR following exercise: 171±10 bpm; post-cooling/no-cooling: 81±14 bpm; significant main effect for time, p<0.001).

****Table 3 near here****

Discussion

The primary aim of this study was to assess post-exercise cooling rates (Tc, Tsk) associated with hand cooling (one or two hands) compared to torso cooling (CJ) or no cooling following strenuous exercise in heat. While no significant differences were found between trials for any physiological variable measured, post-exercise cooling rates and changes in Tc were greater (moderate ES) for CJ and glove(s) (one and two hands) at 5 min and for CJ and glove (one hand) at 10 min compared to no cooling. Further, cooling rates and change in Tc for the CJ were greater at 25 and 30 min (moderate ES) compared with gloves (two hands only), but were similar between CJ and glove (one hand). Moreover, there was a tendency for cooling rates and change in Tsk to be greater in the CJ (moderate ES) at 10 min compared to no cooling. These results are in contrast to our hypotheses apart from all cooling modalities being better than a no-cooling trial.

To date, only Grahn et al. (2009) has assessed Tc cooling rates whilst wearing the glove on one or both hands, reporting significantly faster cooling for the glove compared to control 5-60 min into cooling (cooling rates at 60 min: two hands = 0.022°C/min, one hand = 0.017°C/min, no cooling = 0.007°C/min) and for the glove on two hands compared to one hand 25-55 min into cooling (two hands = ~0.022°C/min, one hand = ~0.016°C/min at 55 min), following exercise in heat (until oesophageal temperature; $T_{oes} \geq 39$°C). Similar results were expected here, with differences between outcomes possibly related to methodological variances. Specifically, participants recruited by Grahn et al. (2009) wore heavily insulated military clothing, impermeable boot covers, gloves (when not wearing the cooling-glove/s) and a balaclava during cooling whilst seated in a hot environment (41.5°C, 20-30% RH). This would have restricted overall heat loss, particularly in the no-cooling trial, with the cooling-glove(s) representing the only avenue for heat loss when worn. This may have accentuated the gloves' effect on cooling rates compared to control. In contrast, our participants wore only shorts and shoes during cooling (except when wearing the CJ), and were removed from heat, thus exposing a large skin surface area to a cooler environment (22.5±1.4°C, 43.3±6.9% RH). This most likely enhanced cooling in all trials, possibly limiting the specific effect of the glove(s) and CJ on Tc and Tsk cooling, ultimately resulting in higher and similar cooling rates and change in Tc between all trials. This premise is supported by lower overall Tc cooling rates and significant differences found between the glove(s) and control trials reported by other researchers compared to here (Adams et al., 2016a, 2016b, Grahn et al., 2009, Kuennen et al., 2010). Of relevance, participants in these studies wore more clothing and/or 'cooled' in hot ambient conditions: with these factors affecting effective heat exchange from the body to the environment, particularly in the no-cooling trials. Specifically, when calculating changes in T_{oes} at 30 min of the 60 min cooling period in the study by Grahn et al. (2009), a decline in T_{oes} of ~0.70°C and ~0.94°C for the glove (one and two hands, respectively) versus control (~0.30°C; $p<0.05$) were reported. Here, a non-significant fall in Tc of 1.32±0.35°C and 1.24±0.27°C for the glove (one and two hands, respectively) versus 1.26±0.46°C for control were recorded, highlighting the marked effect of clothing and ambient conditions on cooling rates between trials. Further evidence is provided by Adams et al. (2016a), who (post-exercise) cooled participants in heat (40°C, 40% RH) reporting greater rectal cooling rates ($p=0.035$) for the glove (one hand: 0.020±0.003°C/min) compared to control (0.013±0.003°C/min) after 10 min. Here, our values were 0.084±0.032°C/min for glove (one hand) and 0.068±0.031°C/min for control ($p>0.05$) at the same time. We opted to cool participants in the laboratory to replicate conditions for elite athletes who often have access to air-conditioned clubrooms during half-time and after games.

Notably, changes in Tsk and Tc cooling rates for the glove on two hands were not greater than for one hand here. Further, Tc cooling rates and changes in Tc were similar between the CJ and the glove (one hand) at 25 and 30 min, but tended to be greater (moderate ES) for the CJ compared to the glove (two hands) at these time points. These results were surprising with reasons underpinning these outcomes being unclear. Wearing the CJ here also resulted in a significant main effect for thermal sensation, where participants overall felt cooler compared to all other trials. This result may be due to the jacket being soaked in icy water prior to application over the chest, coupled with the larger BSA for heat exchange that the jacket covers compared to the hands when wearing the glove(s).

Results from this study suggest that the glove (one hand) may be beneficial during the first 10 min of cooling for team-game players who have access to air-conditioning during breaks in a game. This is pertinent in games such as indoor basketball (15 min half-time breaks and short substitution periods) when players sit/stand near or on the court, and where the use of fans for cooling can be cumbersome due to the need for power, cords and space. Moreover, as the CJ needs to be immersed in an icy slurry prior to use and then kept in an ice chest, the glove may be more practical for use in a sporting setting, as it is battery operated and easy to apply. Importantly, the glove may be of practical benefit when breaks are taken during team-games played outdoors or in a non-air-conditioned venue (where water or power sources are unavailable or restricted), as studies have reported significantly faster Tc cooling rates for the glove compared to no cooling when assessed in a hot environment (Adams et al., 2016a, 2016b, Grahn et al., 2009).

In respect to cognitive performance, scores were faster on the Stroop Colour-Word test following exercise compared to baseline for all trials as demonstrated by moderate to large ES as well as a significant main effect for time. These results are similar to those reported in other studies (Hogervorst et al., 1996; Sibley et al., 2006, Yanagisawa et al., 2010) and may be due to faster neural conduction speed as a result of an elevated Tc (due to a hot environment and/or exercise) or an exercise induced arousal effect (Tomporowski, 2003). However, we cannot be certain whether this faster performance time represented an improvement, as a control trial was not included here, as this was not the main focus of this study. In contrast to our second hypothesis, there were no significant differences between the cooling trials (glove on one or two hands and CJ) and the no cooling trial for Stroop performance after 30 min, suggesting no detrimental effect associated with use of these cooling devices on cognitive performance. This result may be due to similar Tc values recorded at this time point between all trials. Further, significant main effects for time demonstrated that while post-cooling/recovery scores in all trials for the Stroop task were higher than baseline, these scores were lower compared to post-exercise scores, suggesting that passive recovery (i.e. with or without the glove(s) or the CJ) diminishes the effects of exercise on this particular cognitive test. This outcome may be related to the overall decline in Tc for this period and/or the cessation of exercise that may have impacted processes associated with performance on the Stroop test. A limitation to this study was that cognitive performance was not assessed at every 5 min interval of the cooling period, as participants would have had to remove the CG in order to access the keyboard, thus defeating cooling benefits associated with the CG. Future studies should use a shorter cooling period where the effects of the CG on cognitive performance can be assessed.

Conclusion

Core temperature cooling rates were faster (moderate to large ES) with the glove (one hand) and CJ compared to a control trial during the first 10 min of cooling, with minimal benefit associated with wearing the glove on two hands. This suggests that it is beneficial to employ either the glove or a CJ during short team-game breaks, with the glove representing a less cumbersome modality to use. Further, 30 min of cooling using the glove(s) or the CJ did not result in slower Stroop Colour-Word performance compared to a control trial.

Disclosure statement

The authors reported no potential conflict of interest.

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Table 1. Mean (± SD) core temperature (°C) responses to exercise in the heat and during a 30 min post-exercise cooling/no-cooling period (n = 12).

1H = 1 hand cooling, 2H = 2 hand cooling, CJ = cooling jacket, NC = no cooling

	1H	2H	CJ	NC
Exercise Period				
Baseline	36.87 ± 0.34	36.86 ± 0.39	37.20 ± 0.45	36.93 ± 0.42
Peak	38.85 ± 0.30	38.72 ± 0.41	39.07 ± 0.22	38.78 ± 0.47
Δ Tc	1.98 ± 0.36	1.86 ± 0.38	1.87 ± 0.42	1.85 ± 0.48
Cooling Period				
Δ Tc				
5 min	0.51 ± 0.23 [a]	0.52 ± 0.17 [a]	0.51 ± 0.19 [a]	0.37 ± 0.22
10 min	0.84 ± 0.32 [a]	0.81 ± 0.23	0.88 ± 0.42 [a]	0.68 ± 0.32
15 min	1.04 ± 0.32	1.01 ± 0.26	1.10 ± 0.44	0.93 ± 0.41
20 min	1.19 ± 0.34	1.11 ± 0.26	1.26 ± 0.37	1.11 ± 0.44
25 min	1.27 ± 0.35	1.18 ± 0.28	1.36 ± 0.37 [b]	1.21 ± 0.45
30 min	1.32 ± 0.35	1.24 ± 0.27	1.42 ± 0.33 [b]	1.26 ± 0.46
Cooling rate (ºC/min)				
5 min	0.101 ± 0.047 [a]	0.104 ± 0.035 [a]	0.102 ± 0.038 [a]	0.074 ± 0.045
10 min	0.084 ± 0.032 [a]	0.081 ± 0.023	0.088 ± 0.042 [a]	0.068 ± 0.032
15 min	0.069 ± 0.022	0.068 ± 0.018	0.073 ± 0.029	0.062 ± 0.027
20 min	0.059 ± 0.017	0.056 ± 0.013	0.063 ± 0.018	0.056 ± 0.022
25 min	0.051 ± 0.014	0.047 ± 0.011	0.054 ± 0.015 [b]	0.048 ± 0.018
30 min	0.044 ± 0.012	0.041 ± 0.009	0.047 ± 0.011 [b]	0.042 ± 0.015

Tc = core temperature

Δ Tc indicates change in Tc over exercise or from the peak Tc over 30 min of cooling

Note: There were no significant differences between trials ($p>0.05$)

[a] Indicates moderate effect size compared with no cooling (d=0.50-0.76)

[b] Indicates moderate effect size compared with 2 hand cooling (d=0.53-0.60)

Table 2. Mean (± SD) skin temperature (ºC) responses to exercise in the heat and during a 30 min post-exercise cooling/no-cooling period (n = 12).

1H = 1 hand cooling, 2H = 2 hand cooling, CJ = cooling jacket, NC = no cooling

	1H	2H	CJ	NC
Exercise Period				
Baseline	33.38 ± 0.81	33.31 ± 0.77	33.46 ± 0.67	33.49 ± 1.00
End exercise	36.28 ± 0.44	36.44 ± 0.60	36.49 ± 0.52	36.54 ± 0.64
Δ Tsk	2.90 ± 0.86	3.13 ± 0.93	3.03 ± 1.00	3.05 ± 0.93
Cooling period				
Δ Tsk				
10 min	2.82 ± 1.17	2.69 ± 0.60	2.94 ± 0.87 [a]	2.43 ± 0.64
20 min	3.78 ± 1.07	3.52 ± 1.00	3.74 ± 1.28	3.48 ± 0.66
30 min	3.99 ± 1.09	3.89 ± 1.29	4.19 ± 1.87	3.98 ± 0.90
Cooling rate (ºC/min)				
10 min	0.282 ± 0.117	0.269 ± 0.060	0.294 ± 0.087 [a]	0.242 ± 0.063
20 min	0.189 ± 0.054	0.176 ± 0.050	0.187 ± 0.064	0.174 ± 0.033
30 min	0.133 ± 0.036	0.130 ± 0.043	0.140 ± 0.062	0.133 ± 0.030

T_{Sk} = skin temperature

ΔT_{Sk} indicates change in T_{Sk} over exercise or from the end of exercise over 30 min of cooling

Note: There were no significant differences between trials (p>0.05)

[a] Indicates moderate to large effect sizes from no cooling (d=0.67-0.68)

Table 3. Stroop Colour-Word Test mean latency of all correct incongruent trials, mean (± SD) in milliseconds (ms) at baseline, post exercise in the heat and following a 30 min cooling period (n = 12).

1H = 1 hand cooling, 2H = 2 hand cooling, CJ = cooling jacket, NC = no cooling

	Baseline	Post Exercise [ab]	Post Cooling [a]
1H	730.94 ± 99.56	656.47 ± 97.64	697.75 ± 97.13
2H	689.40 ± 138.83	624.71 ± 79.12	637.09 ± 80.43
CJ	691.94 ± 101.72	615.67 ± 76.94	667.10 ± 89.01
NC	708.98 ± 138.11	613.97 ± 94.60	649.55 ± 77.11

[a] Main effect, significantly different to baseline ($p \leq 0.05$)

[b] Main effect, significantly different to post cooling ($p \leq 0.05$)