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Research article

Effects of Half-Time Cooling Using A Cooling Glove and Jacket on Manual Dexterity and Repeated-Sprint Performance in Heat

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Abstract
This study aimed to assess the separate and combined effects of a cooling glove (CG) and a gel-cooling jacket (CJ) used during a half-time break on manual dexterity performance (Purdue Pegboard test) and subsequent repeat-sprint cycling performance in hot conditions. Twelve male athletes performed four experimental trials (within subjects, counterbalanced design) that consisted of: wearing a CG, wearing a CJ, combination of CG and CJ (CG+J) or a no-cooling control (NC) for 15 min during a 20 min half-time break performed between 2 x 30 min repeated-sprint cycling bouts in heat (35.0 ± 1.2°C and 52.5 ± 7.4% RH). Manual dexterity (dominant and non-dominant hand) was assessed immediately before and after the first-half of exercise, then immediately after cooling and the second-half of exercise. No differences were found for manual dexterity performance between trials or over time ($p > 0.05$). Additionally, no differences were found for power and work performance variables assessed during the second-half of exercise ($p > 0.05$), however participants felt 'cooler' wearing CG+J compared to NC (Thermal Sensation scale; $p = 0.041$). Further, no differences were found between trials for changes in gastrointestinal core temperature for any time period assessed ($p > 0.05$). In conclusion, the cooling trials did not affect manual dexterity or second-half repeated-sprint cycling performance compared to NC.

Key words: Core temperature, cooling modalities, cycling performance, Purdue pegboard test.

Introduction

Team-sports (requiring multiple short sprints) played for 60+ min in heat can increase core temperature (Tc) by 2+°C (Duffield et al., 2009). Importantly, when hyperthermia (Tc >38.0°C; Faulds and Meekings, 2013) occurs, heat strain may begin to manifest, with a Tc >39.4°C during exercise linked to an increased risk of heat illness (Casa, 1999), impaired central nervous system motor drive, reduced force output (Kay et al., 2001; Morrison et al., 2004) and premature fatigue during exercise (Gonzalez-Alonso, 1999). Consequently, team-sport players often utilise cooling modalities prior to and during breaks in play to reduce Tc (Marino, 2002) and hence limit the effects of heat on subsequent exercise performance (Bongers et al., 2014; Ranalli et al., 2010). However, a limitation of many cooling modalities (e.g. cold water immersion/fans) is their impracticality, particularly for field-sports, where water and/or power sources may be restricted.

As such, the use of cooling jackets (CJ) are popular in many field team-sports (i.e., Australian football, hockey) due to their practicality and ease of use. Notably, Brade et al. (2010) reported higher T_c cooling rates (d=0.60) associated with a gel CJ compared to no-cooling (0.040 ± 0.009°C/min versus 0.034 ± 0.010°C/min after 30-min) following exercise in heat. Wearing a CJ prior to exercise in the heat has also been reported to improve subsequent exercise performance compared to no-cooling (5 km time-trial running, Arngrimsson et al., 2004; 40-min of repeat-sprint cycling, Castle et al., 2006; incremental run to exhaustion time, Ückert and Joch, 2007). Further, wearing a CJ during a 10-min half-time break was found to improve subsequent exercise performance (power/work; d>0.50) in hyperthermic athletes compared to ingestion of an ice slushy (Brade et al., 2014). However, while practical, the CJ need to be soaked in icy water before use and kept cold (ice chest) throughout the match in order to maintain effectiveness.

Another cooling modality that could be used in team-sports is a cooling glove (CG), which uses cold circulating water (~16°C, as set by the manufacturer to avoid vasoconstriction) in combination with negative subatmospheric pressure (-40 mmHg) to increase blood flow to the arteriovenous anastomoses underlying the glabrous (non-hairy) palm of the hand, and in turn, cool blood returning to the core (Grahn et al., 2005). Notably, glabrous skin surfaces contain packed vascular structures that facilitate heat loss faster than non-glabrous body surfaces (Grahn et al., 2009). To date, significantly faster Tc cooling rates have been reported for the CG compared to no-cooling in hyperthermic individuals by Adams et al. (2016; 0.020°C/min versus 0.013°C/min for 10-min), Grahn et al. (2009; 0.017°C/min versus 0.007°C/min for 60-min), and Kuennen et al. (2010; 0.0076°C/min versus 0.0006°C/min for 50-min) when cooling was performed in the heat. Recently, Maroni et al. (2018) reported faster Tc cooling rates (d=0.50-0.54) over 10-min for the CG (one hand; 0.084°C/min) compared to CG (two hands; 0.081°C/min) and no-cooling (0.068°C/min), with cooling performed in an air-conditioned lab (22.3°C). Notably, Maroni et al., (2018) also reported comparable cooling rates between the CG (1 hand) and the CJ (0.044 versus 0.047ºC/min respectively after 30 min of cooling) with similar effects possibly being due to the CG targeting a small but glabrous skin surface area (~1% per hand; Adams et al., 2016), while the CJ targeted a larger but non-glabrous skin surface area (~17%; Young et al., 1987). As the CG is easily transported and applied, and does not require power (i.e., battery operated),

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immersion in icy water or cold storage, it may represent a better alternative to CJ for use in field-sport events played in heat.

Importantly, the effect of using the CG on subsequent exercise performance is unknown; similarly, the combined effect of using CJ and CG together has not been studied. This is of relevance, as using multiple cooling methods can result in greater cooling rates than when undertaken in isolation (i.e; CJ and ice slushy: Brade et al., 2014; hand/head/torso and thigh cooling using ice packs and cold towels; Minett et al., 2011). Furthermore, as many team-sports represent multi-million dollar businesses where winning is paramount, the assessment of the effects of different cooling modalities on subsequent exercise performance would be of interest to coaches and players, particularly if the aid can also reduce the risk of heat illness.

A potential issue relating to the use of the CG, and of importance to team-sport athletes, is that manual dexterity has been found to be significantly impaired after 5 min of hand immersion in 10°C water compared to no-cooling (Cheung et al., 2003). As the CG leaves the hand cold after use, it is important to determine whether this impairs subsequent dexterity, as ball throwing, catching and holding a bat/ball are integral to success in many sports.

Therefore, the aims of this study were to assess the effects of cooling (CG, CJ and CG+CJ) and no-cooling on manual dexterity performance and on subsequent repeat-sprint performance (work and power) in the heat. It was hypothesised that Tc cooling rates would be significantly higher in CG and CJ combined, compared to these conditions alone and to NC, and that cooling rates for the CG and CJ alone would be higher than NC yet similar. Consequently, it was further hypothesised that manual dexterity would be impaired following use of the CG and that the trial with the highest cooling rates would result in greater power and work output during subsequent exercise performance compared to a no-cooling control.

Methods

Participants

Male, team-sport players [n = 12, mean ± SD: training status: 7.7 ± 4.4 h/wk of moderate-high intensity exercise; age: 20.5 ± 1.9 y; height: 1.83 ± 0.07 m; body-mass (BM): 76.7±7.8 kg; sum of six skinfolds: 49.0 ± 8.3 mm] participated in this study. Testing was performed during the winter months; therefore participants were not heat acclimatised. All provided informed consent and the Human Research Ethics Committee of the University granted ethical approval.

Experimental design

After familiarisation, four experimental trials were performed in a randomised, counterbalanced manner, at the same time of day (a week apart) to control for circadian variability. The exercise component of each trial comprised 2 x 30 min halves of repeat-sprint cycling, separated by a 20 min half-time break, all performed in heat (35.0 ± 1.2°C, 52.5 ± 7.4% RH). Players cooled in the heat in order to simulate situations where access to air-conditioned rooms and powered cooling methods are not available. The repeat-sprint cycling protocol has been previously used to simulate the intermittent and variable intensity efforts typical of team sports (Brade et al., 2014; Duffield et al., 2003). During half-time, participants cooled for 15 min using either: (1) the CG, (2) the CJ, (3) the CG and CJ (CG+J) and (4) a NC control. This half-time duration is similar to that used in Australian football, rugby union, soccer and hockey. Prior to exercise, immediately pre- and post-cooling, and on completion of exercise the Purdue Pegboard test (Model 32020, J.A. Preston Corporation, New York) (3 min) was performed. Participants abstained from alcohol and vigorous activity for 24 h and caffeine 3 h prior to testing, and replicated food and fluid intake in the 24 h prior to testing.

Familiarisation session

Anthropometric measurements (as above) were first obtained. Participants then performed 10 min of the repeated-sprint cycling protocol in heat in the climate chamber and were familiarised to all other tests and equipment to be used in the experimental trials.

Exercise protocol

On entering the climate chamber, a 5-min cycling warm-up was performed comprising 3 min at 75 W and 2 min at 100 W, with 2 x 5 s maximal sprints also undertaken at 3.5 and 4.5 min. The repeated-sprint cycling test followed, with a 20 min break separating the two 30 min halves. Each half comprised 30 x 5 s cycle sprints interspersed by 55 s of cycling performed at prescribed (varying) intensities (25, 50, 75, 100 W). In addition, 6 extra sprints were performed at 2.5, 7.5, 12.5, 17.5, 22.5 and 27.5 min to induce a greater physiological demand, similar to what is experienced during (unpredictable) team-sport scenarios (Brade et al., 2014; Duffield et al., 2003; Figure 1). All trials were performed on a front-access air-braked cycle ergometer (Model EX-10, Repco, Australia) connected to a computer system designed to calculate power/work generated during each flywheel revolution for each 30 min exercise period (Cyclemax, UWA, Australia). For safety, participants ingested 100 mL of water (23°C) every 10 min, with 200 ml of a sports drink (23°C) (Gatorade^{TM}) consumed during half-time to replenish sweat electrolyte and energy loss. The same clothing (shorts, socks and running shoes) was worn for all trials, and there was no active airflow on the participants within the climate chamber.

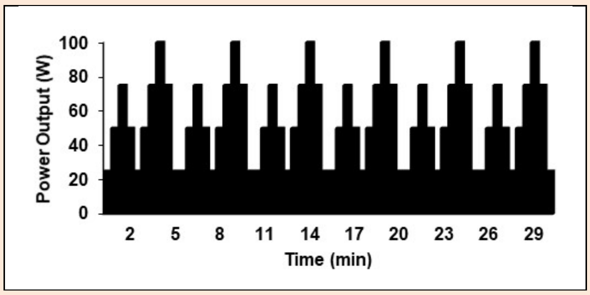

Figure 1. Intermittent repeat sprint cycling protocol. Black shading represents the submaximal exercise intensities performed following each maximal 5 s sprint (additional sprints not shown).

Cooling interventions

During half-time, participants cooled (CG, CJ, CG+J or NC) for 15 min whilst seated in the chamber. In the CG trial (CoreControl^{TM}, AVAcore Technologies, Ann Arbor, MI), participants placed their dominant hand inside the glove, where cold circulating water (~16°C) and subatmospheric pressure (-40 mmHg) encapsulate the hand surface area (wrist to fingertips), as per manufacturer's instructions. The CG was placed at heart level to assist venous return. Participants also wore the CJ (not activated) during this trial. In the CJ trial, participants donned a gel CJ (Arctic Heat Products Pty Ltd, Queensland, Australia), which has four anterior and posterior pockets containing crystals. In accordance with manufacturer's instructions, the jacket was first soaked in water to activate the crystals into a gel. Prior to use, the jacket was placed in cold water (0-2°C) for 30 min, then wrung out and worn over the participant's bare chest. Participants also wore the CG (not activated) for this trial. During the CG+J trial, both cooling modalities were activated for cooling (as described). During the NC trial, participants wore the CG and CJ (not activated) to enable a true laboratory-controlled comparison between trials.

Assessment of manual dexterity

The Purdue Pegboard test, used to assess fine manual dexterity (Tiffin and Asher, 1948), was performed prior to exercise (baseline), immediately after the first half of exercise, post-cooling and immediately after the second half of exercise (all in the heat). Here, participants had 30 s to place as many pins into a row of holes, one at a time, using their dominant and non-dominant hands in turn.

Measures

Prior to arrival (6-8 h) participants ingested a radiotelemetry pill to measure T_g (CorTemp, HQ Inc., USA) and 1 h before consumed 600 mL of water for pre-test hydration purposes. On arrival, a mid-stream urine sample (1 mL) was collected to determine urine specific gravity (U_{SG}) to assess pre-exercise hydration status (~1.016±0.01), with no participants found to be hypohydrated (U_{SG}>1.030). Nude BM was then measured to the nearest 0.01 kg using a digital platform scale (Model ED3300; Sauter Multi-Range, Ebingen, Germany); this was repeated immediately after exercise (towel dried) for the calculation of sweat loss (pre - post nude BM + fluid ingested). A heart-rate monitor (HR: Polar RS400, Finland) was fitted to the chest and thermistors (Skin Sensor SST-1, Physitemp Instruments Inc, NJ, USA) taped to the sternum, left mid-anterior forearm and left mid-posterior calf to measure skin temperature (T_{sk}) via a computerised program (DASYLab Light, National Instruments, Ireland Resources Ltd.). Mean T_{sk} was calculated using the formula of Burton (1935): $T_{sk} = (0.5 \times T_{sternum}) + (0.14 \times T_{forearm}) + (0.36 \times T_{calf})$. Temperature measurements (T_g and T_{sk}) and HR were recorded at baseline and every 5 min throughout the entire trial. Changes (Δ) in T_g, T_{sk} and cooling rates (°C/min) over half-time were also calculated (from the peak T_g and T_{sk} reached at the end of the first half of exercise). Ratings of perceived exertion (RPE; 6-20 scale, Borg, 1970) and thermal sensation (TS; 0=unbearably cold to 8=unbearably hot; Young et al., 1987) were measured every 10 min during exercise, with TS also measured after the cooling period. Performance variables measured for each sprint (excluding the six extra maximal sprints), comprised peak power (W), peak power per kilogram BM, mean power, work (kJ) and work per kilogram BM, averaged for each 30 min exercise half.

Statistical analysis

Data analysis was conducted using IBM SPSS Statistics (Version 20.0 for Windows; SPSS Inc, Chicago, IL). Two-way repeated measures (RM) ANOVAs were used to assess exercise and manual dexterity performance, T_g, T_{sk}, HR, RPE and TS across the four trials for all time points noted for each variable described in the Methods section, while one-way RM ANOVAs assessed sweat loss and environmental conditions. Statistical significance was accepted at $p \leq 0.05$. Where appropriate, post hoc comparisons using Bonferroni adjustments were used. In addition, Cohen's *d* effect sizes (ES) calculated meaningful differences in the data (Cohen, 1988) with only moderate (0.5-0.79) and large (>0.8) ES reported. Mean difference ±95% confidence intervals (CI) were also calculated to assess the magnitude of these differences. All values are expressed as mean±SD.

Results

No differences were found for environmental conditions between any trial or at any time point of the experimental protocol (all $p > 0.05$).

For manual dexterity performance, the dominant hand (~17 pieces) was consistently better than the non-dominant hand (~16 pieces) throughout all trials ($p < 0.01$). Pegboard performance pre-cooling (dominant: 17.8 ± 2.0 vs. non-dominant 16.3 ± 1.9 pieces) and post half-time cooling (dominant: 17.3 ± 1.8 vs non-dominant 16.5 ± 1.7 pieces) did not differ between trials, nor did pegboard performance differ from any other time points (baseline and post exercise) (all $p > 0.05$).

In respect to exercise performance, no differences ($p > 0.05$) or moderate-large ES were found between the first and second-half of exercise for any performance variable (work and power) assessed. Further, there were no significant differences ($p > 0.05$) or moderate-large ES found between any trials for any of the performance variables assessed during the second-half of exercise following the cooling/control period (Table 1).

In respect to T_c responses, absolute T_g increased by 1.04-1.17°C over the first-half of exercise ($p < 0.001$; peak T_g ~38.26 ± 0.46°C) then decreased by 0.51-0.77°C ($p < 0.001$) over the half-time break across all trials, with no differences found between trials for any time point assessed (all $p > 0.05$, Table 2). Notably, during the half-time break, ΔT_g tended to be greater for CJ; compared to NC after 5 min (*d* = 0.53, mean difference [95%CI], 0.1°C [-0.33,1.30]); compared to all other trials at 10 min (*d* = 0.57-0.72, 0.16-0.19°C [-0.29 to 0.16, 1.34-1.48]); and compared to CG (*d* = 0.50, 0.18°C [-0.35,1.27]) and NC (*d* = 0.74, 0.26°C [-0.14,1.51]) at 15 min. Also, during half-time, there was a tendency for cooling rates to be greater

Table 1. Performance variables during the 1st and 2nd half of 30 min repeat sprint cycling (CG = Cooling Glove, CJ = Cooling Jacket, CG+J = Cooling Glove and Jacket, NC = No Cooling). Values expressed in mean (±SD).

	Peak Power (W)		Peak Power (W/kg)		Mean Power (W)		Work (kJ)		Work (J/kg)	
	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half	1st Half	2nd Half
CG	963 (148)	979 (134)	12.7 (1.8)	12.9 (1.6)	733 (123)	746 (115)	109.9 (18.5)	111.9 (17.2)	1444 (216)	1473 (211)
CJ	961 (177)	945 (169)	12.6 (2.2)	12.4 (2.1)	728 (145)	720 (146)	109.2 (21.8)	107.9 (22.0)	1430 (248)	1414 (257)
CG+J	964 (132)	974 (139)	12.6 (1.5)	12.8 (1.7)	741 (110)	739 (119)	111.4 (16.5)	110.8 (17.9)	1459 (189)	1452 (208)
NC	930 (148)	943 (141)	12.3 (2.0)	12.4 (1.9)	708 (125)	729 (121)	106.2 (18.8)	109.3 (18.2)	1400 (243)	1439 (231)

There were no significant differences (p > 0.05)

Table 2. Gastrointestinal core temperature (T_g) responses at baseline, after each half of exercise and during a 15 min half-time (HT) period (CG = Cooling Glove, CJ = Cooling Jacket, CG+J = Cooling Glove and Jacket, NC = No Cooling). Values expressed in mean (±SD).

		Baseline	End 1st Half *	HT 5 min *	HT 10 min *	HT 15 min *	End 2nd Half *
T_g	**CG**	37.29 (.40)	38.33 (.56)	38.08 (.56)	37.94 (.52)	37.74 (.40)	38.52 (.47
	CJ	37.17 (.32)	38.35 (.42)	38.00 (.38)	37.80 (.36)	37.58 (.32)	38.26 (.49) [a]
	CG+J	37.11 (.39)	38.19 (.43)	37.92 (.39)	37.81 (.34)	37.59 (.36)	38.16 (.21) [ac]
	NC	37.06 (.36)	38.19 (.45)	37.96 (.41)	37.83 (.45)	37.68 (.39)	38.43 (.42)
ΔT_g	**CG**		1.04 (.47)	.25 (.23)	.39 (.28)	.59 (.32)	.78 (.27)
	CJ		1.17 (.37)	.34 (.20) [c]	.55 (.28) [abc]	.77 (.40) [ac]	.68 (.45)
	CG+J		1.08 (.33)	.27 (.14)	.38 (.22)	.60 (.32)	.64 (.30)
	NC		1.13 (.47)	.24 (.18)	.36 (.25)	.51 (.29)	.75 (.33)
°C/min	**CG**			.050 (.046)	.039 (.028)	.039 (.021)	
	CJ			.069 (.040) [c]	.055 (.028) [abc]	.051 (.027) [ac]	
	CG+J			.054 (.028)	.038 (.022)	.040 (.021)	
	NC			.047 (.036)	.036 (.025)	.034 (.020)	

* Main effect (time); significantly different compared with previous time point (p < 0.05).[a] Moderate to large effect size compared with CG (*d*=0.50-0.99). [b] Moderate to large effect size compared with CG+J (*d*=0.68). [c] Moderate to large effect size compared with NC (*d*=0.53-0.81)

Table 3. Mean skin temperature (T_{sk}) responses at baseline, after each half of exercise and during a 15 min half-time (HT) period (CG = Cooling Glove, CJ = Cooling Jacket, CG+J = Cooling Glove and Jacket, NC = No Cooling). Values expressed in mean (±SD).

		Baseline	End 1st Half *	HT 5 min *	HT 10 min *	HT 15 min *	End 2nd Half *
Mean T_{sk}	**CG**	34.64 (.73)	36.28 (.75)	35.68 (.76)	35.37 (.82)	35.14 (.80)	36.34 (.71)
	CJ	34.77 (.73)	36.18 (.65)	35.38 (.66) [c]	35.14 (.52)	34.90 (.61)	36.18 (.71)
	CG+J	34.76 (.62)	36.31 (.53)	35.25 (.73) [ac]	34.97 (.73) [ac]	34.85 (.64) [c]	36.22 (.73)
	NC	34.54 (.64)	36.31 (.47)	35.69 (.48)	35.40 (.67)	35.14 (.69)	36.37 (.75)
Δ Mean T_{sk}	**CG**		1.64 (.74)	.60 (.28	.91 (.39)	1.14 (.36)	1.20 (.58)
	CJ		1.41 (.58)	.80 (.37) [ac]	1.04 (.29)	1.28 (.42)	1.28 (.30)
	CG+J		1.55 (.51)	1.06 (.43) [abc]	1.34 (.45) [abc]	1.46 (.42) [ac]	1.37 (.42)
	NC		1.77 (.58)	.62 (.35)	.91 (.54)	1.17 (.57)	1.22 (.47)
°C/min	**CG**			.120 (.056)	.091 (.039)	.076 (.024)	
	CJ			.160 (.073) [ac]	.104 (.029)	.085 (.028)	
	CG+J			.212 (.085) [abc]	.134 (.045) [abc]	.097 (.028) [ac]	
	NC			.124 (.069)	.091 (.054)	.078 (.038)	

* Main effect (time); significantly different compared with previous time point (p < 0.05). [a] Moderate to large effect size compared with CG (*d*=0.52-1.28). [b] Moderate effect size compared with CJ (*d*=0.65-0.79). [c] Moderate to large effect size compared with NC (*d*=0.50-1.14)

for CJ; compared to NC after 5 min (*d* = 0.58, 0.022°C/min [-0.28,1.35]); compared to all other trials at 10 min (*d* = 0.57-0.72, 0.016-0.019°C/min [-0.29 to 0.016, 1.34-1.48]); and compared to CG (*d* = 0.50, 0.012°C/min [-0.35,1.27]) and NC (*d* = 0.72, 0.017°C/min, [-0.16,1.48]) at 15 min; however, none of these differences were significant (p > 0.05). Over the second-half of exercise, T_g increased by 0.64-0.78°C across all trials (p < 0.001), with no differences noted between trials at exercise completion (p > 0.05; Table 2).

In respect to T_{sk} responses, during the first-half of exercise, mean T_{sk} increased by 1.41-1.77°C (p < 0.001; peak T_{sk} ~36.27 ± 0.59°C) then decreased by 1.14-1.46°C (p < 0.001) over the half-time break across all trials, with no differences found between trials at any time point (p > 0.05, Table 3). During half-time, the ΔT_{sk} tended to be greater for CG+J; compared to all other trials (*d* = 0.65-1.27, 0.26-0.46°C [-0.22 to 0.30, 1.42-2.04]) with CJ also greater than CG and NC (*d* = 0.50-0.61, 0.18-0.20°C [-0.35 to -0.25, 1.27-1.38]) at 5 min. Further, there tended to be a greater ΔT_{sk} in CG+J; compared to all other trials at 10 min (*d* = 0.79-1.02, 0.30-0.43°C [-0.10 to 0.10, 1.56-1.79]); and compared to CG and NC at 15 min (*d* = 0.58-0.82, 0.29-0.32°C [-0.28 to -0.07, 1.35-1.58]). Cooling rates also tended to be higher in CG+J compared to all trials (d = 0.66-1.28, 0.05-0.09°C/min, [-0.21 to 0.31, 1.42-2.05], and for CJ compared to CG and NC (d = 0.51-0.61, 0.04°C/min [-0.34 to -0.25, 1.28-1.38] at 5 min. Further, cooling rates tended to be greater for CG+J; compared to all other trials at 10 min (*d* = 0.79-1.02, 0.030-0.043°C/min [-0.10 to 0.10, 1.56-1.79]) and compared to CG and NC at 15 min (*d* = 0.57-0.81, 0.02°C/min [0.29 to -0.08, 1.34-1.58]). Over the second-half of exercise, T_{sk} increased by 1.20-1.37°C across all trials (p < 0.001) with no differences found between trials at exercise completion (p > 0.05; Table 3).

Mean HR at the start of cooling was 154±20 bpm.

Following the break, HR dropped to 91 ± 13 bpm and then reached 160±19 bpm on exercise completion. There were no differences between trials at any time point ($p > 0.05$). The RPE and TS values increased over the first-half of exercise (RPE: 6 to 15; TS: 4 to 6; $p < 0.05$). After half-time participants reported feeling ‘cooler’ wearing CG+J compared to NC (TS=4.0 ± 0.6 versus 4.5 ± 0.7, respectively, $p = 0.041$). Both RPE and TS increased in a similar manner during the second-half of exercise (RPE: 6 to 15; TS: 4 to 6.5; $p < 0.05$) with no differences found between trials on exercise completion ($p > 0.05$), where participants described exercise as ‘hard’ (15 ± 2) and felt ‘hot’ (6.5 ± 0.8). There were also no differences between trials for average BM pre or post exercise (76.32 ± 7.71 vs. 76.04 ± 7.58 kg, $p > 0.05$). However, post-exercise BM indicated that sweat loss and percentage (%BM loss) dehydration was less in CG+J compared to all other trials ($p = 0.022$; CG = 1.16 ± 0.28 kg, 1.52%; CJ = 1.07±0.34 kg, 1.40%; CG+J = 0.98 ± 0.30 kg, 1.28% and NC = 1.13 ± 0.26 kg, 1.48%).

Discussion

This study aimed to assess the effect of cooling hyperthermic athletes using a CG, CJ and CG+CJ compared to NC on subsequent manual dexterity and repeat sprint exercise performance. No significant differences were found between trials for manual dexterity or exercise performance following cooling. There were also no significant changes in T_g or cooling rates during the half-time cooling period between trials, however there was a tendency (moderate ES) for these variables to be more favourable in CJ compared to NC during this period.

In respect to the effects of cooling on manual dexterity performance, Cheung et al. (2003) reported significantly lower Purdue Pegboard scores after 5 min of cold water (10°C) hand immersion compared to no-cooling (40.2 ± 7.6 vs. 49.0 ± 6.4 pieces in 60-s, respectively), however this test was conducted in normothermic individuals (T_c~37°C), where maximal peripheral vasoconstriction is proposed to occur at water temperatures below 15°C (Davies, 1995). In hyperthermic individuals (Tc>38.0°C), researchers have reported water temperatures of 10°C to be optimal for removing excess body heat via hand immersion (House et al., 1997), without this cooling application resulting in peripheral vasoconstriction (Davies, 1995). Here, participants were hyperthermic (T_g>38.0°C) when wearing the CG (set at~16°C), which may explain why manual dexterity performance was not impaired between trials. In addition, manual dexterity performance did not differ over time and was not impacted following 2 x 30 min exercise bouts in the heat, (with half-time cooling performed in 3 of 4 trials). This suggests that athletes can wear the CG during breaks in exercise played in the heat without any detriment to manual dexterity performance.

No effect of cooling on subsequent exercise performance for any performance variable assessed was also found here. Brade et al. (2014) also reported no improvement in 30-min of repeated-sprint performance following 10-min of cooling using a CJ compared to NC in hyperthermic participants (peak T_g 38.5 ± 0.4°C), with this result likely due to similar cooling rates and final T_g values found for both trials during the cooling period. Another study by Hornery et al. (2005) consisted of exercise (peak T_c ~38.5°C) followed by 10-min of cooling using a CJ or NC, followed by 20-min of cycling at 75% $\dot{V}O_{2max}$ and a 10-min maximal effort. They also found no significant difference in T_c cooling rates and final T_c values between the CJ and NC trials after cooling, which may explain why no improvement in subsequent performance was found between trials. In respect to the CG, no previous studies have assessed the effect of cooling hyperthermic athletes using this modality on subsequent prolonged exercise performed in hot/humid conditions. For subsequent exercise performance to improve following cooling (compared to no-cooling), it may be necessary that cooling rates associated with a particular cooling modality (i.e. CJ, CG or CG+J) be significantly greater than a no-cooling trial, thereby resulting in significantly lower T_c values post-cooling. For this to occur it is also likely that a Tc >38.3°C (i.e., a greater hyperthermic state prior to cooling) may be required (resulting in a greater core-skin gradient), which in turn may impact final T_c values following cooling.

Of relevance, previous studies have reported significantly lower T_c values and significantly greater T_c cooling rates for the CG (one hand) compared to NC over various cooling time periods (10-min, Adams et al., 2016; at every 5 min of a 60-min period, Grahn et al., 2009; between 15-50 min, Kuennen et al., 2010; more details in Introduction) when cooling was performed in the heat (40-42°C) in hyperthermic participants. These outcomes suggest that the insignificant cooling results found here between the CG and NC were not due to the cooling period being too short. Possibly, differences in results between the current and previous studies may relate to clothing worn during the cooling period. Specifically, participants recruited by Grahn et al. (2009) and Kuennen et al. (2010) wore heavy insulated clothing covering the entire body, with cooling performed in hot/humid environmental conditions. This clothing ensemble would have restricted heat loss via sweat evaporation, with the CG then representing the main means for facilitating heat loss, accentuating the effect of the CG on Tc cooling compared to the control. In comparison, participants here wore shorts, shoes and the CG+J (either activated or not), therefore exposing a larger skin surface area to the environment, allowing for greater evaporative sweat loss (as would typically occur in the field in team sports at half-time). This may have dampened the effect of the CG on T_g cooling, resulting in similar cooling rates between the CG and NC. Notably, Grahn et al. (2009) reported a decline in T_c of 1.0±0.2°C and 0.4±0.2°C for the CG and NC trials respectively, following 60-min of cooling compared to 0.6±0.3°C (CG) and 0.5±0.3°C (NC) found in the current study after only 15-min of cooling. The higher cooling rate for NC found here compared to that reported by Grahn et al. (2009) highlights the body’s ability to cool faster when less clothing is worn, even when environmental conditions are hot/humid. Similar comparisons cannot be made with the study by Adams et al. (2016), as participant clothing was not described. Further, the lower peak T_g value achieved in the current study prior to cooling (38.19-38.35°C) compared to other studies (39.2°C, Adams et al., 2016; 39.0°C, Grahn et al., 2009; 38.8°C, Kuennen et al.,

2010) would have resulted in a smaller core-skin temperature gradient for cooling (range here of 2.01-2.04°C). This may have also contributed to the non-significant difference in T_g cooling values recorded here between CG and NC trials (Nb: T_{sk} not reported or assessed prior to cooling in studies by the aforementioned authors).

Similar to the current study, Brade et al. (2010) reported a tendency for higher T_g cooling rates for CJ compared to NC following exercise in heat (35°C, 52% RH; details in Introduction); however, cooling in this study was for 30-min compared to 15-min here. Unfortunately, T_g results for earlier time periods of this 30-min cooling period were not provided, preventing further comparison of cooling rates between this and the current study. Interestingly, a later study by Brade et al. (2014) reported no significant difference or moderate-large ES in post-cooling T_g values for CJ compared to NC after 10-min of cooling in hyperthermic athletes (cooling rates not reported). This suggests that the CJ may need to be used for longer than 10 min for a higher T_g cooling rate to be achieved compared to NC. Surprisingly, the combination of the CG+J did not result in faster T_g cooling rates compared to any other trial here, with reasons for this being unclear. However, for T_{sk} values, there was a tendency (moderate ES) for cooling rates and ΔT_{sk} to be greater in the CJ and the CG+J compared to the CG and NC at various time points during cooling. It is likely that these results reflect the greater skin surface area exposed to cooling.

Interestingly, thermal sensation was perceived as better following cooling with the CG+J, while sweat loss at exercise completion was lower here than in all other trials, indicating a lesser degree of dehydration occurring during the second-half of exercise (for the same rise in T_c). Although these effects did not improve subsequent exercise performance here, in more extreme circumstances (i.e., a higher peak Tc and/or longer exercise durations with associated higher HR and RPE values) these effects may potentially have greater thermoregulatory and performance benefits (Hasegawa et al., 2005). Of relevance, Burdon et al. (2013) and Schulze et al. (2015) reported improved subsequent cycling performance in the heat (4 kJ/kg BM time-trial following 90 min of steady state cycling at 60%$\dot{V}O2_{peak}$ and a 20 km time-trial performance following 60 min of steady state cycling at an RPE of 14, respectively) following cooling (ice slushy ingestion) compared to a control, with both results associated with improved thermal sensation in the cooling trial, compared to the control trial, despite non-significant changes in Tc between trials prior to time-trial performances.

Conclusion

In conclusion, use of the CG or CG+J for 15 min in-between 2 x 30 min bouts of repeated-sprint cycling in heat did not impair subsequent manual dexterity performance, nor improve exercise performance compared to a no-cooling control. These results may reflect the similar T_g values recorded after cooling compared to the NC trial.

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Key points

- Cooling with a cooling glove or jacket, alone or in combination, during a half time break did not further significantly decrease core temperature compared to no cooling.
- Cooling did not improve second half repeated-sprint cycle performance.
- The cooling glove did not impair manual dexterity performance of the dominant hand, which is important for skills involving use of this hand.

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