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ORIGINAL ARTICLE

The effects of lower body passive heating combined with mixed-method cooling during half-time on second-half intermittent sprint performance in the heat

Jacky Soo[1,2] · Gabriel Tang[1,2] · Saravana Pillai Arjunan[3] · Joel Pang[1] · Abdul Rashid Aziz[1] · Mohammed Ihsan[4]

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Abstract

Purpose This study examined the effects of combined cooling and lower body heat maintenance during half-time on second-half intermittent sprint performances.

Methods In a repeated measures design, nine males completed four intermittent cycling trials (32.1 ± 0.3 °C and 55.3 ± 3.7% relative humidity), with either one of the following half-time recovery interventions; mixed-method cooling (ice vest, ice slushy and hand cooling; COOL), lower body passive heating (HEAT), combined HEAT and COOL (COMB) and control (CON). Peak and mean power output (PPO and MPO), rectal (T_{re}), estimated muscle ($T_{es\text{-}Mus}$) and skin (T_{SK}) temperatures were monitored throughout exercise.

Results During half-time, the decrease in T_{re} was substantially greater in COOL and COMB compared with CON and HEAT, whereas declines in $T_{es\text{-}Mus}$ within HEAT and COMB were substantially attenuated compared with CON and COOL. The decrease in T_{SK} was most pronounced in COOL compared with CON, HEAT and COMB. During second-half, COMB and HEAT resulted in a larger decrease in PPO and MPO during the initial stages of the second-half when compared to CON. In addition, COOL resulted in an attenuated decrease in PPO and MPO compared to COMB in the latter stages of second-half.

Conclusion The maintenance of $T_{es\text{-}Mus}$ following half-time was detrimental to prolonged intermittent sprint performance in the heat, even when used together with cooling.

Keywords Intermittent sprint performance · Mixed-method cooling · Passive heating · Half-time intervention · Team sports

Abbreviations

MPO	Mean power output
COMB	Combined upper body cooling and lower body passive heating
CON	Control
COOL	Upper body cooling
HEAT	Lower body passive heating
HR	Heart rate
PPO	Peak power output
SS	Single sprint
RPE	Rating of perceived exertion
RS	Repeated sprint
T_B	Body temperature
T_C	Core temperature
$T_{es\text{-}Mus}$	Estimated muscle temperature
T_m	Muscle temperature
T_{re}	Rectal temperature
TS	Thermal sensation
T_{SK}	Mean skin temperature
USG	Urine-specific gravity
VO_{2peak}	Peak oxygen uptake

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✉ Jacky Soo
jackysds@gmail.com

1 Sport Physiology, Sport Science and Medicine, Singapore Sport Institute, 3 Stadium Drive, Singapore 397630, Singapore

2 Physical Education and Sports Science, Nanyang Technological University, Singapore, Singapore

3 Physical, Sports and Outdoor Education Branch, Student Development Curriculum Division, Ministry of Education, Singapore, Singapore

4 Athlete Health and Performance Research Centre, Aspetar Orthopedic and Sports Medicine Hospital, Doha, Qatar

Introduction

Intermittent team games are typically played for 60–90 min, with temporary breaks lasting between 10 and 20 min usually evident at every quarter or at the mid-way point (i.e. half-time). During this period, players engage in predominantly passive activities such as receiving tactical instructions, attending to injuries and consuming ergogenic aids (Russell et al. 2015b). Recent studies have highlighted several shortcomings associated with the passive nature of recovery during half-time intervals. Notably, this includes the decline in core (T_C) and muscle temperature (T_m) (Mohr et al. 2004), which has been shown to negatively influence sprint performances, especially during the period of match recommencement (Edholm et al. 2015; Mohr et al. 2004). Indeed, an elevated T_m is an important determinant of sprint performance, given that it has been shown to improve muscle contractility (i.e. shorter contraction and half-relaxation time) (Racinais et al. 2016; Sargeant 1987), as well as enhance anaerobic ATP turnover and muscle fibre conduction velocity (Gray et al. 2006).

Previous studies have demonstrated the effectiveness of heated or insulated clothing in preserving post-warm-up T_m and subsequently improved sprint exercise performance (Faulkner et al. 2012, 2013). For instance, Faulkner et al. (2012) demonstrated that the maintenance of T_m following warm-up using heated garments resulted in enhanced peak power output (~9%) during a subsequent 30-s sprint. Accordingly, the demonstrated importance of preserving T_m has led to several studies exploring the use of such strategies during half-time to minimise the decline in body temperatures. Kilduff et al. (2013) showed that attenuating the loss in post-warm-up T_C (and likely T_m) through the use of blizzard jackets led to an improvement in peak power output and repeated sprint (RS) performance (6 × 40 m) in rugby league players. In a subsequent study, the use of blizzard jackets in-between two bouts of RS sequences (6 × 40 m) resulted in improved performance within the second RS sequence, particularly within the first two sprints (Russell et al. 2015a). However, it must be noted that whilst heat maintenance strategies might be beneficial upon the moments of match recommencement, its efficacy can be contentious during prolonged intermittent sprinting/running typifying actual match durations. Given that team games typically last 60–90 min, and with several upcoming major competitions held in hot environments, such strategies will likely exacerbate the increase in body temperature (T_B), hastening the development of hyperthermia-related fatigue (González-Alonso et al. 1999). In support, Skein et al. (2012) demonstrated that whilst sprint performances during initial periods of a prolonged intermittent sprint protocol were enhanced following passive heating, performances during the latter stages of the exercise protocol were considerably impaired, with the excessive increase in T_C reasoned as the contributing factor. The mechanisms underpinning the decrease in exercise performance following hyperthermia may include a decrease in neural drive and subsequent failure to fully activate the exercising musculatures (i.e. central fatigue; Girard et al. 2011; Nybo 2008), as well as an increase in cardiovascular strain, characterised by an increase in heart rate and skin blood flow, with concomitant decreases in stroke volume and cardiac output (Périard et al. 2011; Shaffrath and Adams 1984). As such, the use of passive heat maintenance garments needs to be further deliberated to mitigate between the neuromuscular benefits conferred at the start of match recommencement, and the exacerbated increase in body temperatures that will likely ensue when exercise is prolonged.

One possibility would be to combine cooling and heat maintenance strategies, targeted at lowering T_C whilst maintaining the T_m of key musculatures involved in exercise. Precooling is a temperature regulation strategy undertaken to lower pre-exercise T_C, consequently increasing body heat storage capacity and ameliorating the development of hyperthermia-induced fatigue. Strategies such as cold water immersion, ice slurry ingestion and the use of cooling garments are some traditional methods shown to improve exercise performance across a variety of prolonged continuous and intermittent modalities (Castle et al. 2006; Ihsan et al. 2010; Siegel et al. 2010; Zimmermann et al. 2018). To improve the practicality of administering cooling interventions during half-time, some have proposed mixed-method modalities, which include possible combinations with the use of cooling vests (torso), cold towels (neck and head regions), ice slurry ingestion and hand immersion (Duffield et al. 2009; Minett et al. 2012). Such mixed modalities applied prior to exercise have been shown to improve running performances (i.e. maintained RS performances and improved self-paced running velocity) (Duffield et al. 2009; Minett et al. 2012) which paralleled the decrease in T_C and physiological strain following cooling.

A recent study by Beaven et al. (2018) demonstrated that combined ice slurry ingestion and passive heat maintenance prior to exercise improved sprinting performances (sprint timings and fatigue index) during a 5 × 40 m RS protocol. However, we are unaware of studies that have examined the effects of combined cooling and lower body heat maintenance as a half-time strategy on second-half performance during prolonged intermittent sprinting in the heat. Such combined treatment potentially minimises the decline in T_m, and hence muscle contractile function following half-time intervals, yet preserves/increases the capacity for heat storage (lower T_C) essential for maintaining prolonged exercise performance. Therefore, the purpose of this study was to investigate the effects of combined core cooling and lower body heat maintenance during a half-time interval on second-half intermittent sprint performance performed in the heat.

Methods

Participants

Nine male participants (age: 26.5 ± 4.2 years, height: 174.0 ± 5.9 cm, mass: 69.2 ± 13.8 kg, VO_{2peak}: 42.7 ± 3.9 $ml.kg^{-1}$ min^{-1}) participated in the present study. Participants were physically active and/or recreational intermittent team sports players without any previous history of heat illness and injuries. They were informed of the procedures and potential risks involved in this study, and a written informed consent was subsequently obtained. They were also instructed to refrain from strenuous physical activity, alcohol, and caffeine 24-h before all tests. This study was approved by the Human Research Ethics Committee of the Singapore Sport Institute. This study was conducted in Singapore during daytime, where the ambient temperature and relative humidity was ~ 30–33 °C and ~ 60–80%, respectively. Weather forecast was based on an online meteorological service (https://www.weather.gov.sg/climate-climate-of-singapore/).

Experimental overview

Each participant visited the laboratory on five separate occasions, which included one pre-experimental and four experimental sessions. During the pre-experimental session, participants performed a graded exercise test to determine their peak oxygen uptake (VO_{2peak}), followed by familiarisation to the main experimental protocol. During the experimental sessions, participants performed an intermittent sprint protocol consisting of two 33-min halves, separated by a passive rest interval of 15 min. Participants were administered either one of four different interventions in a crossover manner during the half-time interval, before undertaking the second-half of intermittent sprint activity. The experimental interventions included (1) lower body passive heating (HEAT), (2) upper body cooling directed at lowering T_C (COOL), (3) combined upper body cooling and lower body passive heating (COMB) or (4) control (CON). All sessions were separated by at least 72 h, conducted at the same time of the day.

Graded exercise test and familiarisation session

The graded exercise test and familiarisation session were performed in standard laboratory conditions of 23.4 ± 0.6 °C and 67.4 ± 2.7% RH. Participants performed the graded exercise test on a cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands) and expired air was analysed using an automated system (TrueOne 2400, Parvo Medics, Salt Lake City, UT). The test commenced at a power output of 100 W, with 20 W increments every minute thereafter until volitional exhaustion. After a 30-min recovery period, participants were familiarised to the intermittent sprint protocol (Wattbike Ltd., Nottingham, UK), as well to the general procedures and equipment involved in the experimental sessions. Participants completed four to five 4-s sprinting efforts where they were familiarised with the sequence of activity and the instructions of the tester. In addition, air resistance was adjusted to determine the optimal resistance that would achieve maximal power output. Seat and handlebar positions were adjusted according to preference, and replicated during all experimental trials. The same cycle ergometer was used throughout the experiment, and participants' attire (i.e. shorts, socks and sport shoes) was kept consistent as well.

Intermittent sprint protocol

Upon arrival to the laboratory, a urine sample was collected and nude body mass was measured. Participants then self-inserted a disposable rectal probe to a depth of 12-cm beyond the anal sphincter. Subsequently, participants were fitted with a heart rate (HR) monitor (Polar RS400, Polar Electro, Finland), and wireless skin temperature sensors. Following instrumentation, participants proceeded into a climate-controlled room maintained at 32.1 ± 0.3 °C and 55.3 ± 3.7% RH and performed a standardised 8-min warm-up. The warm-up consisted of 4-min of cycling at 50% VO_{2peak} followed by two 1-min blocks of 30 s at 70% VO_{2peak} and 30 s of passive rest. This was immediately followed by two 4-s maximal sprints separated by a 2 min of active recovery at 35% VO_{2peak}. Participants were then given 2 min of passive rest before commencing the intermittent sprint protocol adapted from previous research (Bishop and Maxwell 2009; Schneiker et al. 2006). This protocol was specifically designed to simulate the physiological demands of match-play in team sports (Bishop and Maxwell 2009; Schneiker et al. 2006). This test consisted of approximately two 33-min halves, separated by a 15-min recovery period. Specifically, each half consisted of 16 × 2-min blocks, which included a 4-s maximal sprint, 100 s of active recovery, and 20 s of passive recovery (Fig. 1). On two occasions during each half (following the 8th and 16th single sprint block), participants performed a RS sequence consisting of five 3-s

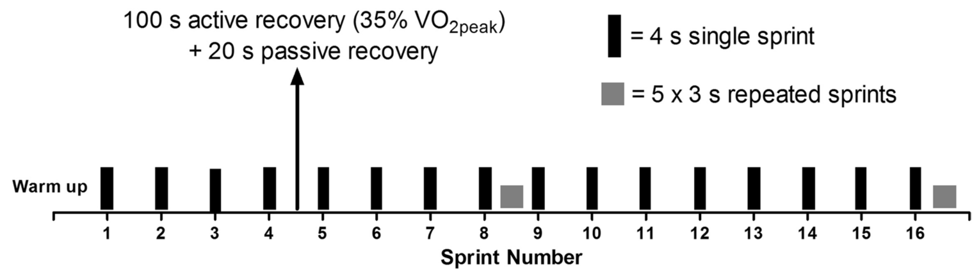

Fig. 1 Schematic representation of one half of the intermittent-sprint protocol. The protocol consisted of 16 single sprints (4 s) interspersed by 100 s of active recovery, followed by 20 s of passive recovery. Twenty seconds following the 8th and 16th single sprint, participants performed a repeated sprint sequence consisting of five 3 s sprints with 21 s of passive recovery in-between

sprints with 18 s of recovery between successive sprints. During the last 5 s of each passive recovery period, participants were instructed to assume a "ready" position, and a 3-s countdown was given prior to the start of each sprint. Cycling was performed in a seated position throughout the trial. Strong verbal encouragement was provided for every sprint effort. Participants were given 100 ml of water (29.0 ± 1.6 °C) to ingest at the 18th min during each halves for all conditions. Upon completion of the trial, another urine sample was collected. Participants then towelled themselves dry, and nude body mass was measured. Peak (PPO) and mean (MPO) power output (W) for every sprint effort was retrieved using the Wattbike software, and subsequently downloaded for offline analysis. The second-half single sprint (SS) data were subsequently grouped into representative SETS 1 (SS 1–4), 2 (SS 5–8), 3 (SS 9–12), and 4 (SS 13–16). Similarly, the first and second RS sequence (five 3-s sprints) during second-half was grouped as SETS 1 and 2, respectively.

Half-time interval

Immediately following the first-half, participants proceeded out of the climate room, and were administered with either HEAT, COOL, COMB or CON in standard laboratory conditions of 21.1 ± 0.3 °C and 71.4 ± 1.9% RH. The HEAT trial involved participants wrapping a blizzard blanket (Blizzard Survival Blanket, Blizzard Protection Systems Ltd, UK) around their lower body that covered the gluteus, quadriceps, hamstrings and gastrocnemius while being seated. The blizzard blanket was made from ReflexCell™ material. The material provides insulation by trapping warm still air, and its reflective surface acts to block radiated heat, while its elastic properties cause the material to clinch the body reducing convection (Allen et al. 2010). The COOL trial involved a combination of cooling modalities which included hand cooling, wearing an ice vest and consumption of an ice slushy (Duffield et al. 2009; Ihsan et al. 2010). Specifically, participants were instrumented with an ice vest (Artic Heat, Brisbane, Australia) covering the torso region. The ice vest was made from an inner polyester fabric and micromesh outer consisting of pockets filled with crystals. Prior to use, the ice vest was immersed in water to activate the crystals into a viscous gel and subsequently frozen at approximately −20 °C. Hand cooling was undertaken on the participants' non-dominant hand, immersed to the wrist level in a water bath maintained at ~ 9.0 °C (Minett et al. 2012). In addition, participants consumed 3.4 g kg^{-1} body mass of ice slushy (0.7 ± 0.6 °C) made using a commercially available ice slushy machine. Servings were provided in portions of 75–100 g at 4–5-min intervals over the 15-min half-time interval, ensuring the stipulated amount of ice to be consumed is reached. The COMB trial involved the combined administration of HEAT and COOL interventions. During the CON trial, participants rested passively in a seated position over the 15-min interval. In addition, participants in both the HEAT and CON trial consumed 3.4 g kg^{-1} body mass of tap water (20.2 ± 0.2 °C) served at similar proportions and timings in all other conditions. Participants returned to the climate room at the 14th min, and assumed position on the cycle ergometer in preparation for the second-half. Physiological measurements were also recorded prior to the start of the second-half.

Temperature measurements and calculations

Participants' T_{re} was monitored throughout via a data logger (Cole Parmer Thermistor Thermometer 8502-12, Cole Parmer Instrument Co., USA) connected to a disposable rectal probe (YSI401, Yellow Springs Instruments, Yellow Springs, OH, USA). Temperature sensors (iButton, DS1922L, Maxim Integrated Products Inc, Sunnyvale, CA, USA) were attached to the chest (mid-point of the pectoralis major at the underarm level; T_{chest}), arm (mid-belly of the lateral tricep; T_{arm}), thigh (lateral vastus lateralis, 15 cm superior to the patella; T_{thigh}), and calf (mid-belly of the lateral gastrocnemius; T_{calf}) on the right-hand side of the body using an adhesive dressing (Tegaderm, 3 M Healthcare, USA), and mean skin temperature (T_{SK}) was calculated using the following equation (Ramanathan 1964):

$$T_{SK} = 0.3 \times T_{chest} + 0.3 \times T_{arm} + 0.2 \times T_{thigh} + 0.2 \times T_{calf}. \quad (a)$$

Body temperature was calculated using the following equation (Burton 1935):

$$T_B = 0.65 \times T_C + 0.35 \times T_{SK}. \quad (b)$$

Quadriceps T_m was estimated using recent methods developed by Flouris et al. (2015). Briefly, an insulation disk (iDISK) was placed directly on top of a temperature sensor on the left lateral mid-thigh (vastus lateralis) at a distance of 15 cm superior to the patella, and secured with adhesive dressing. The iDisk was made by cutting a circle measuring 50 mm in diameter and 4.8 mm in thickness from an open cell foam neoprene material. Changes in T_m during exercise and post-exercise recovery were calculated by the following equations, respectively (Flouris et al. 2015):

$$\text{Estimated muscle temperature } \left(T_{es-Mus}\right) \text{ during exercise} = \text{iDISK} \times 0.599 - \text{iDISK}_{lag4} \times 0.311 + 15.63, \quad (c)$$

$$T_{es-Mus} \text{during post} - \text{exercise recovery} = \text{iDISK} \times 0.657 - \text{iDISK}_{lag4} \times 0.538 + 13.283, \quad (d)$$

where iDISK is the current temperature of the vastus lateralis as measured by the temperature sensor; iDISK_{lag4} is the difference in temperature between the current value and the temperature 4 min before.

Perceptual ratings

Rating of perceived exertion (RPE) and thermal sensation (TS) were recorded before the start of the intermittent sprint test and 9, 17, 25 and 33 min into each half. Rating of perceived exertion was assessed using Borg's 6-to-20 scale (Borg 1982). Thermal sensation was assessed using a 9-point scale ranging from 0 (unbearably cold) to 8 (unbearably hot) (Toner et al. 1986).

Hydration and fluid loss

Urine samples collected before and after the trial were used to determine urine-specific gravity (USG) using a clinical refractometer (Atago UG-1, Atago Co. Ltd, Japan). Changes in nude body mass were used to assess fluid loss or gain during the trial.

Statistical analysis

All within- and between-group comparisons were undertaken using magnitude-based inferences (Hopkins 2006). Changes in all variables were analysed in raw units relative to the smallest worthwhile change (SWC) with 90% confidence intervals. The SWC (0.2 × between-subject SD) for PPO and MPO during SS and RS, as well as temperature responses (T_{re}, T_{SK}, T_B, $T_{es\text{-}Mus}$) and other measures (i.e. HR, RPE, TS) were each determined from first-half (i.e. mean of all SWC within each of the four conditions). The SWC for changes in all temperature responses during half-time was determined from the CON group. Quantitative chances of higher or lower differences were evaluated qualitatively as: < 1%, almost certainly not; 1–5%, very unlikely; 25–75%, possible; 75–95%, likely; 95–88%, very likely; > 99% almost certain. In addition, differences were considered unsubstantial/unclear if the probability of the difference being substantially greater or lower were both > 5% (Hopkins et al. 2009). The magnitude-based inference statistics are also supplemented with repeated measures analysis of variance, where p values for all main effects are reported.

Results

Main effects for time, condition and interaction for changes in PPO during SS were $p = 0.003$, $p = 0.672$ and $p = 0.413$, respectively. Mean changes in PPO (90% CI) with quantitative chances are presented in Fig. 2. There were substantial decreases in PPO within all experimental conditions in the second-half (SETS 1, 3 and 4) compared with the first (Fig. 2a–d). Between conditions, COOL resulted in a smaller decrement in PPO compared with CON at SET 4 (Fig. 2h), and compared with COMB at SET 3 (Fig. 2g). In addition, COMB resulted in a greater decrease in PPO compared with CON at SET 1 (Fig. 2e).

Main effects for time, condition and interaction for changes in MPO during SS were $p = 0.002$, $p = 0.484$ and $p = 0.175$, respectively. Mean changes in MPO (90% CI) with quantitative chances are presented in Fig. 3. Substantial decreases in MPO during SS were observed within all experimental conditions, particularly during SET 1, 3 and 4 (Fig. 3a–d). Between conditions, COOL resulted in smaller decrements in MPO compared with CON (SET 4, Fig. 3h), HEAT (SET 4, Fig. 3h) and COMB (SETS 1, 3 and 4, Fig. 3e, g, h). The COMB treatment also resulted in a lower MPO compared with CON (SETS 1, Fig. 3e).

Time, condition and interaction effects for changes in PPO during RS were $p < 0.001$, $p = 0.273$ and $p = 0.384$, respectively. Substantial decreases in PPO were evident within all experimental conditions within the second, compared to the preceding half during RS (Fig. 4a–d). Between conditions, the decrease in PPO was substantially smaller in COOL compared with CON (SET 2, Fig. 4f) and COMB (SET 1 and SET 2, Fig. 4e, f). Time, condition and interaction effects for changes in MPO during RS were $p < 0.001$, $p = 0.076$ and $p = 0.093$, respectively. Substantial decrements in MPO were observed in the second-half within all

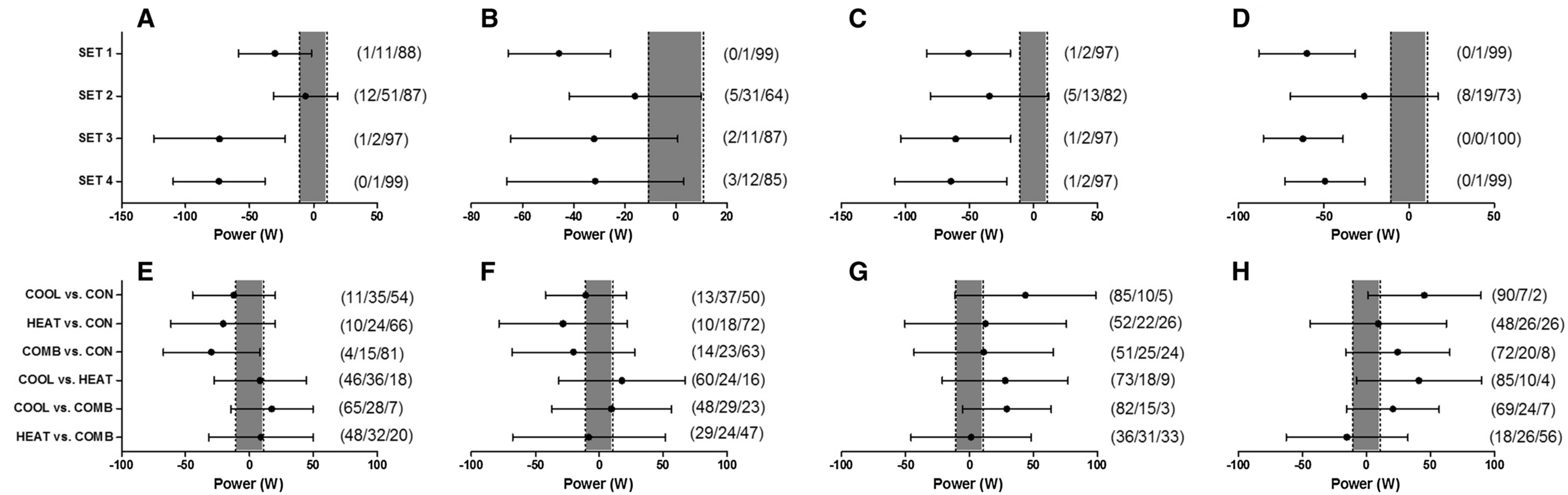

Fig. 2 Changes in peak power output (PPO) during single sprints (SS) within CON (**a**), COOL (**b**), HEAT (**c**) and COMB (**d**), as well as between conditions during SET 1 (**e**), SET 2 (**f**), SET 3 (**g**) and SET 4 (**h**). Changes are presented in raw units (90% confidence intervals) relative to the smallest worthwhile change (i.e., shaded region). Quantitative chances (%) of increase/trivial/decrease are indicated in parentheses and qualitatively interpreted as: > 25–75%, possibly; > 75–95%, likely; > 95–99%, very likely; > 99%, almost certainly

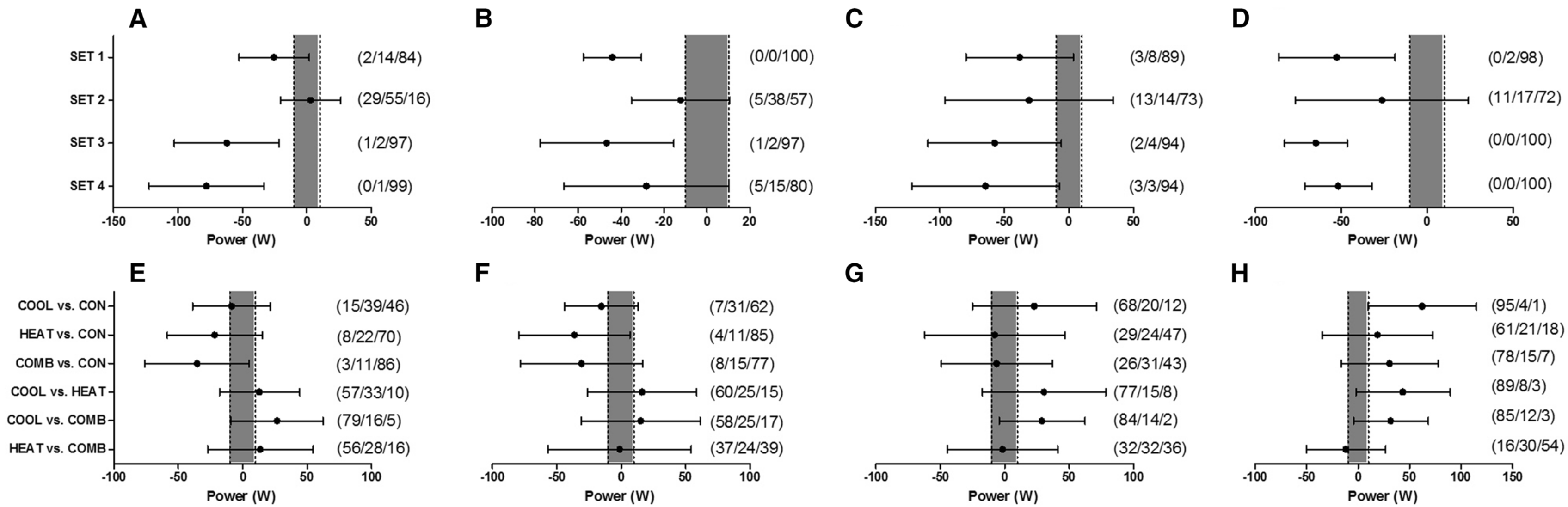

Fig. 3 Changes in mean power output (MPO) during single sprints (SS) within CON (**a**), COOL (**b**), HEAT (**c**) and COMB (**d**), as well as between conditions during SET 1 (**e**), SET 2 (**f**), SET 3 (**g**) and SET 4 (**h**). Changes are presented in raw units (90% confidence intervals) relative to the smallest worthwhile change (i.e., shaded region). Quantitative chances (%) of increase/trivial/decrease are indicated in parentheses and qualitatively interpreted as: > 25–75%, possibly; > 75–95%, likely; > 95–99%, very likely; > 99%, almost certainly

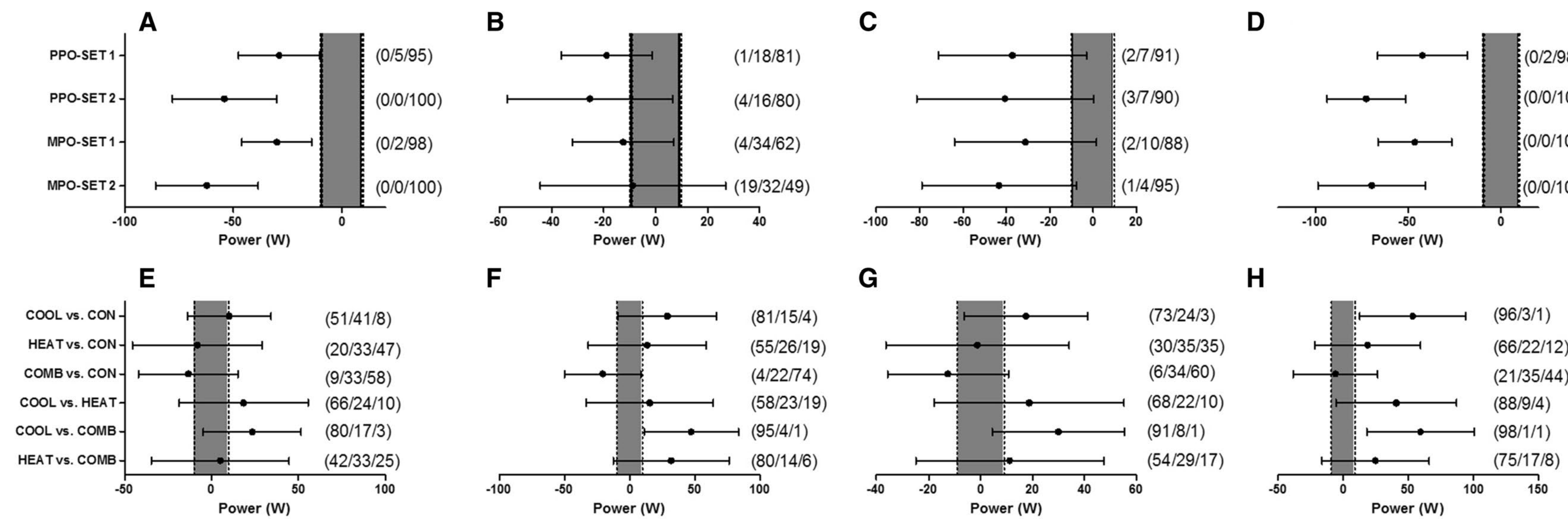

Fig. 4 Changes in peak (PPO) and mean power output (MPO) during repeated sprints (RS) within CON (**a**), COOL (**b**), HEAT (**c**) and COMB (**d**). Between condition changes for PPO during RS for SET 1 (**e**) and SET 2 (**f**) and for MPO for SET 1 (**g**) and SET 2 (**h**). Changes are presented in raw units (90% confidence intervals) relative to the smallest worthwhile change (i.e., shaded region). Quantitative chances (%) of increase/trivial/decrease are indicated in parentheses and qualitatively interpreted as: > 25–75%, possibly; > 75–95%, likely; > 95–99%, very likely; > 99%, almost certainly

experimental condition except COOL (Fig. 4a–d). Between conditions, COOL resulted in a smaller decrement in APO compared with CON and COMB in SET and SET 2 (Fig. 4g, h).

Differences in T_{re} at the end of the first-half were unclear between conditions (CON: 38.6 ± 0.6 °C; COOL: 38.6 ± 0.4 °C; HEAT: 38.6 ± 0.6 °C; COMB: 38.8 ± 0.4 °C, $p = 0.383$). Main effects for time, condition and interaction for changes in T_{re} during half-time were $p < 0.001$, $p = 0.400$ and $p = 0.075$, respectively (Fig. 5a). At the end of the 15 min half-time period, the decrease in T_{re} within COOL and COMB was greater compared with CON and HEAT. Differences in T_{SK} at the end of the first-half were unclear between conditions (CON: 36.5 ± 0.9 °C; COOL: 36.7 ± 0.7 °C; HEAT: 36.6 ± 0.6 °C; COMB: 36.5 ± 0.7 °C, $p = 0.446$), whilst time, condition and interaction effects for changes during half-time were all $p < 0.001$. Specifically, while a decrease in T_{SK} was evident in all experimental conditions during half-time (Fig. 5b), the decrease within COOL was the most pronounced, and was greater compared with CON (− 1.2 ± 0.7 °C), HEAT (− 1.8 ± 0.6 °C) and COMB (− 1.5 ± 0.7 °C). Moreover, the decline in T_{SK} in both HEAT (0.6 ± 0.6 °C) and COMB (0.3 ± 0.7 °C) was smaller compared with CON. Body temperature at the end of the first-half was similar between conditions (CON: 37.7 ± 0.3 °C; COOL: 37.9 ± 0.3 °C; HEAT: 37.8 ± 0.4 °C; COMB: 37.9 ± 0.3 °C, $p = 0.922$). Main effect for time was $p = 0.001$, while condition and interaction effects were $p < 0.001$ for changes in T_B during half-time. Similar to changes in T_{SK}, the decline in T_B was most pronounced in COOL compared with CON (− 0.6 ± 0.2 °C), HEAT (− 0.7 ± 0.2 °C) and COMB (− 0.3 ± 0.2 °C) (Fig. 5c). In addition, the decline in T_B within HEAT was substantially lower compared with CON (− 0.3 ± 0.2 °C) and COMB (− 0.3 ± 0.2 °C). Estimated muscle temperature was similar at the end of the first-half (CON: 38.3 ± 0.3 °C; COOL: 38.3 ± 0.2 °C; HEAT: 38.3 ± 0.3 °C; COMB: 38.4 ± 0.3 °C, $p = 0.211$). Main effects for time, condition and interaction for changes in $T_{es\text{-}Mus}$ were all $p < 0.001$. The decline within HEAT and COMB was substantially attenuated compared with COOL and CON (Fig. 5d). Moreover, the decrease in $T_{es\text{-}Mus}$ was substantially greater in COMB compared with HEAT towards the end of the half-time period (~ 0.2 °C).

Changes in all temperature measurements during the second-half are presented in Fig. 6. Time, condition and interaction effects for changes in T_{re} were $p < 0.001$, $p = 0.796$ and $p = 0.726$, respectively, where changes in T_{re} were similar between conditions upon commencement and throughout the second-half (Fig. 6a). Main effects for time, condition and interaction in T_{SK} (Fig. 6b) during the second-half were $p < 0.001$, $p = 0.013$ and $p < 0.001$, respectively. Specifically, T_{SK} in COOL was lower compared with CON (0.8–0.9 °C),

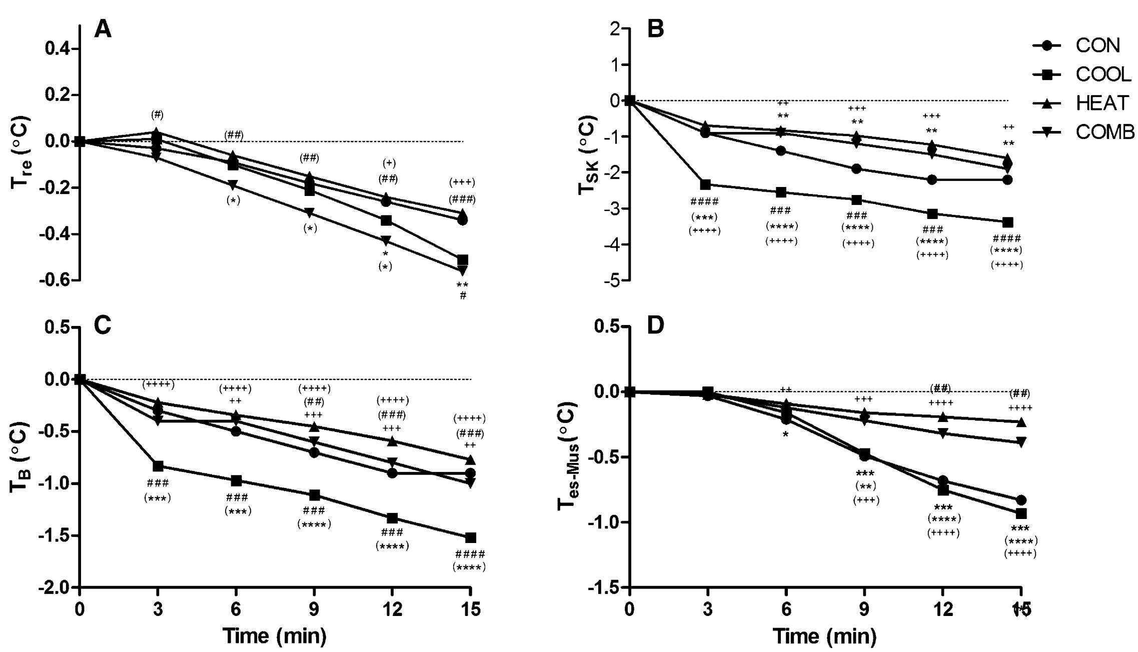

Fig. 5 Changes in rectal temperature (T_{re}, **a**), mean skin temperature (T_{SK}, **b**), mean body temperature (T_B, **c**) and estimated vastus lateralis muscle temperature ($T_{es\text{-}Mus}$, **d**) during half-time interval. Error bars have been omitted to improve visual clarity. Between group differences are denoted by symbols; *CON vs. COMB, #CON vs. COOL, +CON vs. HEAT, (*)COMB vs. COOL, (#)COMB vs. HEAT, (+)COOL vs. HEAT, and number of symbols indicate probability (%) of an increase or decrease (eg., * > 25–75%, possibly; ** > 75–95%, likely; *** > 95–99%, very likely; **** > 99%, almost certainly)

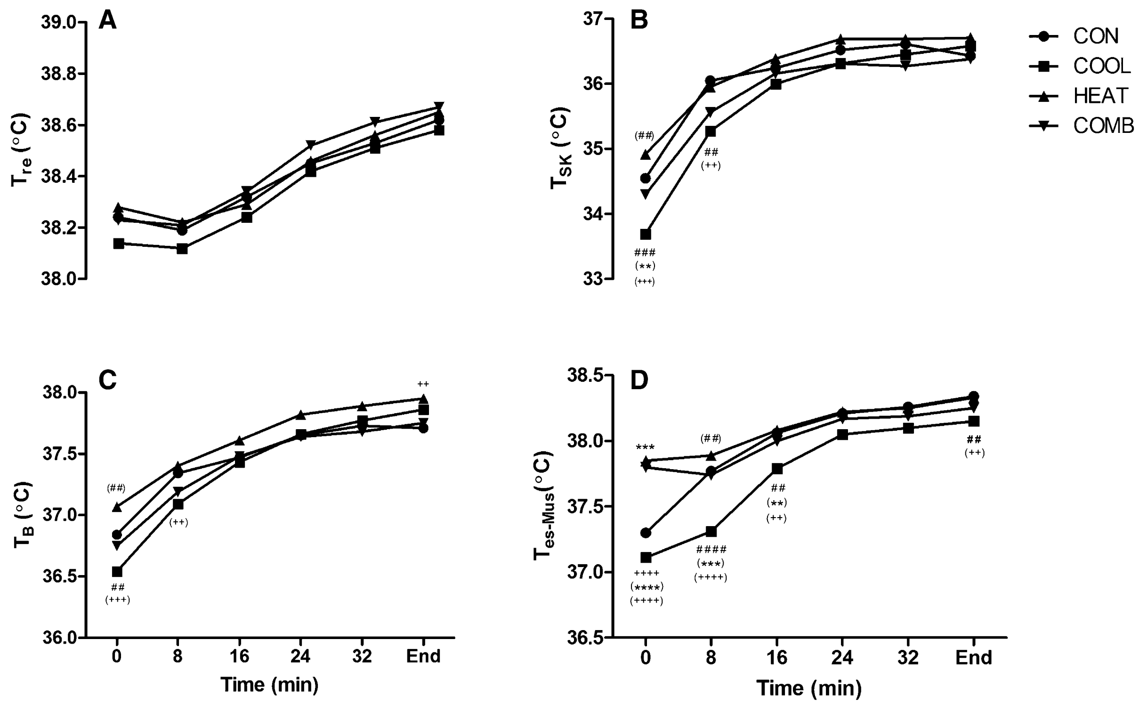

Fig. 6 Changes in core temperature (T_{re}, **a**), mean skin temperature (T_{SK}, **b**), mean body temperature (T_B, **c**) and estimated vastus lateralis muscle temperature ($T_{es\text{-}Mus}$, **d**) during the 2nd half of intermittent cycling protocol. Error bars have been omitted to improve visual clarity. Between group differences are denoted by symbols; *CON vs. COMB, #CON vs. COOL, +CON vs. HEAT, (*)COMB vs. COOL, (#)COMB vs. HEAT, (+)COOL vs. HEAT, and number of symbols indicate probability (%) of an increase or decrease (eg., * > 25–75%, possibly; ** > 75–95%, likely; *** > 95–99%, very likely; **** > 99%, almost certainly)

HEAT (0.7–1.2 °C) and COMB (0.6 °C) during the beginning portions of the second-half (i.e. 0–8 min), after which between-group differences were unclear. Moreover, upon commencement of the second-half, T_{SK} in HEAT was higher compared with COMB (0.6 ± 0.6 °C). Time, condition and interaction effects for changes in T_B (Fig. 6c) during the second-half were $p < 0.001$, $p = 0.092$ and $p < 0.001$, respectively. Changes in T_B during the beginning portions of the second-half were the lowest in COOL compared with CON (0.3 °C) and HEAT (0.3–0.5 °C). In addition, T_B in COMB was lower compared with HEAT (0.3 °C). Time, condition and interaction for changes in $T_{es\text{-}Mus}$ (Fig. 6d) during the second-half were all $p < 0.001$. Estimated muscle temperatures in HEAT (37.9 ± 0.3 °C) and COMB (37.8 ± 0.2 °C) at the start of the second-half were substantially higher compared with CON (37.3 ± 0.4 °C). In addition, $T_{es\text{-}Mus}$ in COOL (37.1 ± 0.4 °C) was lower compared with CON (− 0.3 to − 0.5 °C), HEAT (− 0.3 to − 0.7 °C) and COMB (− 0.2 to − 0.7 °C) at the beginning portions of the second-half. Furthermore, $T_{es\text{-}Mus}$ was substantially lower in COOL (38.1 ± 0.3 °C) compared with CON (38.3 ± 0.3 °C) and HEAT (38.3 ± 0.3 °C) at the end of the second-half.

Changes in HR, RPE and TS are presented in Table 1. Time, condition and interaction effects for changes in HR were $p < 0.001$, $p = 0.573$ and $p = 0.076$, respectively, with a small difference in COOL compared with HEAT at the start of second-half (111 ± 14 vs. 116 ± 14 bpm), following which all between-group differences in HR were unclear. Time, condition and interaction effects for changes in RPE were $p < 0.001$, $p = 0.142$ and $p = 0.109$, respectively. Changes in RPE were similar at the start but were substantially greater in HEAT and CON compared with COOL at 24 min into the second-half.

Time, condition and interaction effects for changes in TS were all $p < 0.001$, respectively. Thermal sensation at the start of second-half in COOL and COMB was lower compared with HEAT and CON. Differences in TS were substantially lower in COOL compared with HEAT and CON, which persisted until 8 min (Table 1). In addition, TS was lower in COMB at the onset of the second-half compared with CON, and also substantially lower than HEAT from the start of the second-half until the 8 min. By 16 min into the second-half, all differences in TS between conditions became unclear. Main effects for time, condition and interaction for changes in USG were $p = 0.044$, $p = 0.329$ and $p = 0.827$, respectively. Differences in pre- (CON: 1.021 ± 0.007; COOL: 1.015 ± 0.010; HEAT: 1.018 ± 0.009; COMB; 1.019 ± 0.006) and post-exercise USG (CON: 1.022 ± 0.006; COOL: 1.018 ± 0.01; HEAT: 1.019 ± 0.009; COMB: 1.021 ± 0.008) were unclear between the groups.

Table 1 Changes in heart rate (HR), ratings of perceived exertion (RPE) and thermal sensation (TS) during intermittent cycling in the heat

	First half-end	Time (min)–second-half				
		Start	8	16	24	End
HR (bpm)						
CON	160 ± 17	116 ± 14	137 ± 15^{D}	163 ± 17^{D}	155 ± 15^{D}	160 ± 15^{D}
COOL	163 ± 11	111 ± 14$^{(*B)}$	137 ± 9^{D}	161 ± 15^{D}	154 ± 14^{D}	163 ± 11^{D}
HEAT	159 ± 14	121 ± 16	142 ± 18^{D}	163 ± 17^{D}	157 ± 15^{D}	159 ± 16^{D}
COMB	164 ± 13	113 ± 21	141 ± 13^{D}	162 ± 16^{D}	159 ± 15^{D}	163 ± 15^{D}
RPE (A.U.)						
CON	17.4 ± 2.2	6.0 ± 0	12.6 ± 1.9$^{D, (*B)}$	16.1 ± 2.3^{D}	16.0 ± 1.6$^{D\ (\#B)}$	17.6 ± 1.7^{D}
COOL	16.8 ± 2.0	6.0 ± 0	12.4 ± 3.0^{D}	14.9 ± 2.7$^{D, (*B)}$	14.9 ± 2.0$^{D, (*B)}$	17.2 ± 2.1^{D}
HEAT	16.9 ± 2.5	6.0 ± 0	13.7 ± 1.9^{D}	16.2 ± 2.1^{D}	16.1 ± 2.0^{D}	17.2 ± 2.1^{D}
COMB	17.0 ± 2.2	6.0 ± 0	12.8 ± 1.7^{D}	15.6 ± 2.4^{D}	15.2 ± 1.6^{D}	17.0 ± 2.2^{D}
TS (A.U.)						
CON	6.7 ± 1.1	5.2 ± 0.8$^{(+C, \#C)}$	5.7 ± 1.0$^{B\ (\#B)}$	6.2 ± 1.0^{D}	6.3 ± 1.0^{D}	6.4 ± 1.1^{C}
COOL	6.2 ± 1.1	3.6 ± 1.4$^{(*C)}$	4.9 ± 1.5$^{(*B)}$	5.7 ± 1.3^{D}	5.9 ± 1.3^{D}	6.2 ± 1.4^{D}
HEAT	6.2 ± 1.1	4.9 ± 0.9$^{(+C)}$	5.9 ± 0.9$^{D\ (+B)}$	6.2 ± 1.1^{D}	6.2 ± 1.1^{D}	6.2 ± 1.1^{D}
COMB	6.3 ± 1.1	3.4 ± 1.3	5.1 ± 1.1^{D}	5.9 ± 1.3^{D}	6.2 ± 1.1^{D}	6.2 ± 1.1^{D}

All within- and between-condition differences were analysed in raw units, with the smallest worthwhile change (0.2 × between-subject SD) determined from first-half. Probability of an increase or decrease associated with within group differences are denoted by A (25–75%, possibly), B (> 75–95%, likely), C (> 95–99%, very likely) and D (> 99%, almost certainly). All between-group differences are indicated in parentheses by symbols specific to experimental condition (i.e. # vs. COOL; * vs. HEAT; + vs. COMB), followed by quantitative chances (A: 25–75%, possibly, B: > 75–95%, likely, C: > 95–99%, very likely and D: > 99%, almost certainly)

Discussion

The present study investigated the effects of combined core cooling and lower body heat maintenance during half-time interval, on a second-half intermittent sprint performance in the heat. It was hypothesised that such a combined strategy could minimise the decline in muscle contractile function following the half-time interval, yet increase the capacity for heat storage, which could benefit prolonged exercise performance. Our findings demonstrate that the use of a blizzard blanket was effective in attenuating the decrease in $T_{\text{es-Mus}}$ during half-time as observed in HEAT and COMB, with minimal influence on T_{re} (Fig. 5a, d). However, the expected improvement in sprinting performance during the initial stages of the second-half was not observed when compared to CON (Figs. 2, 3, 4). In addition, the decline in performance during the latter stages of the second-half was most pronounced within HEAT and COMB (Figs. 2, 3, 4). Conversely, the use of cooling alone resulted in a substantial decrease in body temperatures (i.e. T_{re}, T_{SK}, T_{B}; Figs. 5 and 6), resulting in improved perceptual responses (i.e. RPE and TS; Table 1), in line with the better maintenance of sprint performance, particularly at the latter stages of the exercise protocol.

The use of a heat maintenance garment in HEAT and COMB significantly attenuated the decline in $T_{\text{es-Mus}}$ during half-time (Fig. 5d). This was evident following the end of the 15 min half-time where $T_{\text{es-Mus}}$ in HEAT and COMB was substantially higher when compared with CON and COOL (HEAT: − 0.42 ± 0.24 °C, COMB: − 0.57 ± 0.19 °C, COOL: − 1.20 ± 0.37 °C and CON: − 1.00 ± 0.38 °C). Our findings are supported by previous work demonstrating a slower decline in post-warm-up T_{m} following the use of insulated garments (Faulkner et al. 2012, 2013; Raccuglia et al. 2016). However, comparing the decline in T_{m} with these studies would be inappropriate given the differences in experimental context (i.e. post-warm-up strategy vs. half-time intervention). In this regard, to the authors' knowledge, this is the first study to report T_{m} (albeit estimated) during two halves of intermittent sprint performances following the use of a half-time lower body heat maintenance strategy. Indeed, studies investigating the use of heated garments during half-time have utilised T_{C} as a surrogate measurement of T_{m} with the assumption that the pattern of change will be similar (Beaven et al. 2018; Kilduff et al. 2013; Russell et al. 2018). Although caution is warranted as our T_{m} measures are estimates, it allows for determining the independent changes in T_{m} and T_{C}. Moreover, the estimation error can be considered low, given that the difference between measured and estimated T_{m} during exercise and post-exercise recovery was reported to range between 0.06 and 0.22 °C (Flouris et al. 2015). As such, the findings of this study demonstrate to a certain extent that the use of the blizzard blanket as a half-time strategy was effective in the maintenance of T_{m}

independent of changes in T_{re} (Fig. 5a, d). For instance, it was evident that there was a substantial decrease in T_{re} (COMB: -0.54 ± 0.13 °C vs. CON: -0.34 ± 0.31 °C), and an attenuated decline in $T_{es\text{-}Mus}$ (COMB: -0.39 ± 0.18 °C vs. CON: -0.85 ± 0.25 °C) in COMB at the end of the half-time interval. In addition, decline in $T_{es\text{-}Mus}$ in HEAT following half-time was substantially attenuated when compared with CON (HEAT: -0.42 ± 0.24 °C vs. CON: -1.00 ± 0.38 °C) while T_{re} responses were generally similar (HEAT: 38.3 ± 0.51 °C vs. CON: 38.2 ± 0.43 °C). Taken together, it is likely that the use of a lower body heat maintenance garment in both conditions (HEAT and COMB) did not influence T_{re} responses during the half-time interval.

The mixed-method cooling consisting of ice slurry ingestion, hand cooling and the use of ice vest was effective in reducing T_{re} (Fig. 5a). Due to the limited time available during half-time, such combination of modalities offers the appropriate stimulus to sufficiently reduce T_C, and yet at the same time practical to implement (Duffield et al. 2009). From the results, COMB and COOL resulted in the largest decrease in T_{re} following half-time (Fig. 5a). A decrease of ~0.5 °C in T_{re} was observed after the half-time interval in both of these conditions (COMB and COOL). Comparatively, Duffield et al. (2009) reported a decrease of ~0.3 °C following 20 min of mixed-method precooling. Furthermore, Minett et al. (2012) reported that a longer precooling duration (20 min vs. 10 min) resulted in a greater reduction in T_C ($d = 1.32$). It is likely that the combination of both internal and external cooling methods applied here resulted in a greater cooling effect as compared to the previous studies where only external cooling methods were utilised (i.e. cooling vest, cold towels and ice packs).

Although the decrease in $T_{es\text{-}Mus}$ during half-time was successfully minimised in HEAT, the expected improvement in performance was not evident. Indeed, our results demonstrate that the use of a lower body heat maintenance garment during half-time was detrimental to prolonged intermittent sprint performance in the heat, particularly at the latter portions of the second-half. The current findings are in contrast to previous studies (Kilduff et al. 2013; Russell et al. 2018), which have consistently demonstrated improved sprinting performance following passive heating during half-time, particularly during the initial portion of a 6 × 40 m RS protocol. These discrepant findings are likely explained by differences in exercise duration and environmental conditions. Indeed, in the aforementioned studies, sprints were conducted in thermoneutral environments (~19–20 °C), and the sprinting protocol was substantially shorter. In the current study, a 65–66 min intermittent exercise protocol was utilised to better typify the physical demands associated with team-sport. Moreover, given the increasing prevalence of major tournaments being held in hot environmental conditions (e.g. 2020 Tokyo Olympics and 2022 FIFA World Cup in Qatar), the use of half-time heat maintenance strategies needed further substantiation within such context. Accordingly, the current findings do not advocate the use of heat maintenance garments as a half-time intervention. The observed decrease in performance is likely due to the attainment of an elevated T_{re} (~38.6 °C) and T_B (~37.8 °C), which could have precipitated hyperthermia-induced fatigue, and in turn negated any contractile benefits conferred by maintaining a higher T_m (Drust et al. 2005). Specifically, while elevations in T_m have been shown to improve maximal power out during sprinting (Faulkner et al. 2012; Gray et al. 2006), muscle contractile force and voluntary activation have been shown to progressively decrease with increasing T_C, independent of changes in T_m, in passively heated participants (Thomas et al. 2006).

In the current study, the authors investigated combining cooling and heat maintenance strategies, targeted at minimising thermoregulatory strain whilst retaining muscle contractile benefits, respectively. In this respect, it was initially suggested that the use of passive heating alone might exacerbate the increase in thermal load, leading to an earlier onset of hyperthermia-induced fatigue. However, despite that T_{re} and $T_{es\text{-}Mus}$ were appropriately manipulated in COMB, sprinting performances were not improved compared with HEAT, and instead were substantially decreased compared with CON and COOL (Figs. 2, 3, 4). Our findings are in contrast with recent findings by Beaven et al. (2018), who demonstrated improved RS performance (5 × 40 m) following combined precooling and lower limb passive heating. Specifically, sprint performances following the combination treatment (precooling and passive heating) were improved in sprints 1–3 compared with precooling and control, and better maintained in sprints 4–5 compared with passive heating alone and control. While differences in experimental design, exercise duration and environmental temperatures between the studies may largely account for the disparity in results, the current study demonstrates that relatively high T_m may limit prolonged exercise performance in the heat, despite some alleviations in T_{re} and T_{SK}. The reasons underpinning our findings with COMB are unclear. It is possible that the thermoregulatory, perceptive and CNS-mediated benefits extended by cooling the skin and core may have been negated by the maintenance of higher T_B and $T_{es\text{-}Mus}$. Indeed, high T_{SK} and T_m have been suggested to provide an inhibitory feedback to the central motor command, down-regulating exercise intensity (Kayser 2003; Tucker et al. 2004; Ulmer 1996). Furthermore, high T_{SK} may have mediated for an anticipatory reduction in central recruitment and power output (Tucker et al. 2004).

The COOL intervention seemed to be the most effective in attenuating the decline in sprinting performance during the second-half (Figs. 2, 3, 4). Our finding are in line with the growing consensus (Castle et al. 2006; Duffield et al. 2009; Skein et al. 2012) that prolonged intermittent exercise performance may be maintained and/or improved following prior cooling. However, the majority of studies to date have investigated the effects of half-time cooling in combination with pre-exercise cooling (Aldous et al. 2018; Brade et al. 2014; Minett et al. 2011, 2012), making direct comparisons difficult. We are only aware of two studies that have specifically investigated the effects of half-time cooling per se (Hornery et al. 2005; Maroni et al. 2018) on second-half exercise performance. In both these studies, exercise performances were not enhanced following half-time cooling procedures. As such, further research is needed to elucidate the performance benefits associated with half-time cooling interventions.

The improved exercise performance evident following COOL is likely explained by the lower body temperatures observed at various time-points throughout the second-half (Fig. 5a–c), as well as improved RPE and TS (Table 1). While enhanced heat storage capacity has been traditionally regarded as the primary mechanism underpinning improved exercise performance following precooling (Marino 2002), there is emerging evidence implicating psychophysiological mechanisms as well (Choo et al. 2017; Stevens et al. 2018). For instance, it has been purported that ice ingestion can extend the voluntary drive to exercise by influencing afferent feedback regarding thermal state, independent of changes in body temperatures (Siegel et al. 2011). In addition, changes in T_{SK} have been suggested to provide afferent feedback, which is considered an important regulator of exercise intensity and thermal comfort during self-paced exercise (Flouris and Schlader 2015; Sawka et al. 2012; Schlader et al. 2011; Tatterson et al. 2000). Specifically, Schlader et al. (2011) demonstrated that a lower pre-exercise T_{SK} and TS resulted in higher self-selected intensity (power output) at exercise onset, which consequently led to an overall increase in the amount of work completed. Despite the inherent differences between continuous self-paced and intermittent exercise protocols, it is likely that improved thermal perception, in concert with the reduced thermal strain following COLD modulated for an improved exercise intensity (power output) during the second-half.

Conclusion

In summary, the results of the present study show that lower body passive heating alone or in combination with mixed modality cooling (i.e. ice slushy ingestion, hand cooling and ice vest) were effective half-time strategies to attenuate the decline in $T_{es\text{-}Mus}$. However, lower body heat maintenance even when used concurrently with cooling was detrimental to prolonged intermittent sprint performance in the heat, particularly at the latter stages of the exercise protocol. The combination of upper body cooling modalities utilised in this study led to a substantial decrease in $T_{re,}T_{SK}$, and TS. Although the cooling effects on T_{re} were slightly diminished following the onset of the second-half, changes in T_{SK} and by extension T_B were persistent, resulting in improved TS and RPE during the earlier and latter segments of the second-half, respectively. This likely contributed to better maintenance of exercise performance observed during the latter stages of the second-half.

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