Title:

Physiological and perceptual responses to exercising in restrictive heat loss attire with use of an upper-body sauna suit in temperate and hot conditions.

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Abstract

The aim of this experiment was to quantify physiological and perceptual responses to exercise with and without restrictive heat loss attire in hot and temperate conditions.

Ten moderately-trained individuals (mass; 69.44±7.50 kg, body fat; 19.7±7.6%) cycled for 30-mins (15-mins at 2 $W.kg^{-1}$ then 15-mins at 1 $W.kg^{-1}$) under four experimental conditions; temperate (TEMP, 22°C/45%), hot (HOT, 45°C/20%) and, temperate ($TEMP_{SUIT}$, 22°C/45%) and hot (HOT_{SUIT}, 45°C/20%) whilst wearing an upper-body "sauna suit".

Core temperature changes were higher (P<0.05) in $TEMP_{SUIT}$ (+1.7±0.4$°C.hr^{-1}$), HOT (+1.9±0.5$°C.hr^{-1}$) and HOT_{SUIT} (+2.3±0.5$°C.hr^{-1}$) than TEMP (+1.3±0.3$°C.hr^{-1}$). Skin temperature was higher (P<0.05) in HOT (36.53±0.93°C) and HOT_{SUIT} (37.68±0.68°C) than TEMP (33.50±1.77°C) and $TEMP_{SUIT}$ (33.41±0.70°C). Sweat rate was greater (P<0.05) in $TEMP_{SUIT}$ (0.89±0.24 $L.hr^{-1}$), HOT (1.14±0.48 $L.hr^{-1}$) and HOT_{SUIT} (1.51±0.52 $L.hr^{-1}$) than TEMP (0.56±0.27 $L.hr^{-1}$). Peak heart rate was higher (P<0.05) in $TEMP_{SUIT}$ (155±23 $b.min^{-1}$), HOT (163±18 $b.min^{-1}$) and HOT_{SUIT} (171±18 $b.min^{-1}$) than TEMP (151±20 $b.min^{-1}$). Thermal sensation and perceived exertion were greater (P<0.05) in $TEMP_{SUIT}$ (5.8±0.5 and 14±1), HOT (6.4±0.5 and 15±1) and HOT_{SUIT} (7.1±0.5 and 16±1) than TEMP (5.3±0.5 and 14±1).

Exercising in an upper-body sauna suit within temperate conditions induces a greater physiological strain and evokes larger sweat losses compared to exercising in the same conditions, without restricting heat loss. In hot conditions, wearing a sauna suit increases physiological and perceptual strain further, which may accelerate the stimuli for heat adaptation and improve HA efficiency.

Key words

Sauna suit, heat stress, thermoregulation, physiological strain, heat acclimation, training, restrictive heat loss, exercise.

Introduction

Heat acclimation (HA) is an intervention undertaken for athletic (Racinais et al. 2015; Casadio et al. 2016) and occupational purposes (Sawka et al. 2011; Yamazaki 2013), completed in the days or weeks prior to competition or undertaking physical work in heat stress. HA improves the capacity of an individual to dissipate heat via augmented sweating (Patterson et al. 2004), increases the capacity for heat storage by reducing body temperature (Buono et al. 1998), and reduces the negative thermal sensations (Gibson et al. 2015b). The benefits of HA include enhanced endurance performance (Lorenzo et al. 2010; James et al., 2016), improved thermal comfort (Sunderland et al. 2008; Willmott et al., 2017) and a reduction in the likelihood of heat illness (Yamazaki 2012; Amorim et al. 2015). The HA phenotype is induced across numerous integrated physiological systems, such as cardiovascular (Periard et al. 2016), neuromuscular (Racinais et al. 2017), and at a cellular/molecular level (Horowitz 2014), which occurs following repeated exposures to potentiating stimuli for adaptation (e.g. core temperature ≥38.5°C [Fox et al. 1963], increased skin temperature [Regan et al. 1996] and elevated sweat rates [Buono et al. 2009]).

Whilst notable experimental work has highlighted the benefits of utilising passive HA (e.g. resting in hot-dry or hot-humid conditions) (Armstrong and Kenney 1993; Racinais et al. 2016; Pallubinsky et al. 2017), or by implementing thermal exposures, such as hot water immersion (HWI) (Zurawlew et al. 2015; Ruddock et al. 2016), or sauna post-exercise (Scoon et al. 2007), the most common and potentially most potent HA methods require exercise-heat stress (Racinais et al. 2015). A variety of HA protocols have been published ranging in durations of 4-20 days, utilising prolonged exposures (30-120-mins) typically in hot-dry or hot-humid conditions (~40°C, 40% relative humidity [RH]) (Tyler et al. 2016). Accordingly, two fundamental criteria are required during HA to stress the body, which is achieved by raising and sustaining an elevated core (T_{re}) and skin temperature (T_{skin}), and promoting profuse sweating, which concomitantly provide a multitude of prominent physiological and perceptual adaptations (Sawka et al., 2011).

Most HA interventions are completed within controlled environmental chambers, however, the duration of HA training, allied with logistical and financial issues, may limit the prescription of current laboratory HA protocols (Casadio et al. 2016) and disrupt training quality prior to competition. These are likely reasons for only 15% of athletes undertaking a recognised HA intervention prior to the IAAF World Championships, in spite of hot climates being forecast (Periard et al. 2017). A proposed method for inducing (should access to an environmental chamber not be possible), or enhancing the efficiency (by accelerating the attainment of necessary physiological stimuli for adaptation) of HA is the wearing of clothing/garments which restrict heat loss during exercise (Dawson 1994). Wearing garments that inhibit evaporative heat loss such as vinyl suits, or by overdressing in regular clothing, attenuates the rate of heat dissipation in temperate training environments (Dawson, 1994; Steele et al., 2015; Van der Velde et al., 2016; Stevens et al., 2017). Inhibited heat loss results in a greater rate of heat storage during exercise and ultimately, elevations in physiological strain (Steele et al. 2015). The elevation in T_{re} is a key stimuli for increasing T_{skin} and sweat output, with associated elevations in skin blood flow reducing blood pressure, elevating cardiovascular strain (e.g. heart rate), the initiation of cellular signalling and inducing thermal discomfort (Taylor, 2014). Greater physiological strain theoretically provides the necessary mechanisms to induce heat adaptation and may present an alternative strategy to be undertaken during normal training as opposed to that within simulated hot environments (e.g. within a chamber) or additional sessions (e.g. post-exercise HWI). Furthermore, the use of restrictive heat loss attire during typical HA within environmental chambers may provide an ergogenic benefit without the necessity of increasing exercise intensity, time and, or volume during important training periods (e.g. tapering), although investigation is required.

The primary aims of this experiment were to determine whether the wearing of an upper-body sauna suit during exercise in temperate conditions (22°C, 45% RH) would; 1) increase key potentiating stimuli for heat adaptation in comparison to exercising in regular clothing, and 2) whether these increases in temperate conditions were equivalent to exercise performed in a hot-dry environment replicating typical HA conditions (40°C, 20% RH). This study also aimed to 3) determine whether wearing an upper-body sauna suit in hot-dry conditions would enhance key potentiating stimuli required during heat acclimation. It was hypothesised that wearing a sauna suit in temperate conditions would elicit physiological strain equivalent to exercising in regular clothing in hot conditions, and that wearing the vinyl suit in hot conditions would provide a more rapid attainment of the necessary physiological strain to induce heat adaptation.

Methods

Participants

Ten moderately trained participants (6 males and 4 females; mean ± standard deviation [SD] age: 25 ± 3 years, mass: 69.44 ± 7.50 kg, stature: 175 ± 9 cm, body surface area 1.84 ± 0.13 m^2, and body fat: 19.7 ± 7.6%) volunteered, after providing written informed consent. Participants had not exercised in hot conditions (>25°C) for >3 months, nor were they regular sauna, steam or hot bath users. Each participant abstained from strenuous exercise, caffeine and alcohol 24-hrs prior to each session. Food intake was restricted 2-hrs prior to exercise, normal diets were maintained throughout the study. Participants arrived euhydrated, as indicated by urine osmolality (U_{osm}) <700mOsm·kg^{-1} and specific gravity (U_{sg}) <1.020 (Sawka et al. 2007). All female participants were taking oral contraceptive pills, beginning experimentation on day 2 of the pill phase, which occurred during the early-follicular phase (e.g. 3–5 days after the onset of menstruation) of their self-reported menstrual cycle, as verified by a questionnaire (Mee et al. 2015, 2017). The study was conducted in accordance with the Institution's ethics and governance committee, and Declaration of Helsinki (2013). Exercise was terminated if T_{re} ≥39.7°C (zero incidence).

Experimental design

A randomised, repeated-measures design was adopted, with each participant visiting the laboratory on four occasions, 72-hrs apart to minimise any acclimation effect from repeated heat exposures. During each visit, following instrumentation and 15-mins passive rest in temperate laboratory conditions, participants cycled for 30-mins, replicating the onset of a typical isothermic HA protocol (Gibson et al. 2016), within four conditions; temperate (TEMP: 22°C, 45% RH), temperate whilst wearing an upper-body sauna suit ($TEMP_{SUIT}$: 22°C, 45% RH), hot (HOT: 45°C, 20% RH) and hot whilst wearing an upper-body sauna suit (HOT_{SUIT}: 45°C, 20% RH). In addition to shorts, socks and shoes (plus sports bra for females), only an upper-body suit was worn to mitigate against excessive heat gain, whilst still ensuring that sites for maximal relative sweating and thus evaporation, remained restricted (i.e. back, forearm, axilla, chest, abdomen and buttocks) (Taylor et al. 2013).

Exercise protocol

Each trial was completed inside a controlled environmental chamber, (WatFlow, TISS, Hampshire, UK). Participants cycled (Monark, 620 Ergomedic, Vansbro, Sweden) at a power output prescribed relative to body mass (2 $W.kg^{-1}$ for 15-mins, then 1 $W.kg^{-1}$ for the following 15-mins [Gibson et al. 2016]), as opposed to intensities relative to maximal oxygen uptake ($\dot{V}O_{2max}$), thus removing the requirement to undertake a $\dot{V}O_{2max}$ test. During the $TEMP_{SUIT}$ and HOT_{SUIT} trials, each participant wore a commercially available, upper-body vinyl sauna suit (Everlast, London, UK), to restrict evaporative heat loss throughout the 30-mins of exercise. Fluid ingestion was not permitted during the trials. Physiological and perceptual measures were recorded every 5-mins during the exercise protocol.

Physiological measures

On the first visit, skinfold thickness was calculated using calipers (Harpenden, Burgess Hill, UK) and a four site skin fold calculation (Durnin and Womersley 1974), later body fat (%) was calculated from body density (Siri 1956). Stature and nude body mass (NBM) were measured using a stadiometer (Detecto Scale Company, Missouri, USA) and weighing scales (Adam Equipment Inc., Connecticut, USA [to the nearest 0.01 kg [±0.2%]]), respectively, with these data used to estimate body surface area (BSA) (Du Bois and Du Bois 1916).

Hydration status was measured prior to each experimental session using a Pocket Pal-Osmo meter (U_{osm}: Vitech Scientific Ltd., West Sussex, UK) and light refractometer (U_{sg}: Atago Co., Tokyo, Japan). T_{re} was continuously monitored using a single-use probe (Henleys Medical, Hertfordshire, UK) self-inserted 10 cm past the anal sphincter. T_{skin} was measured using telemetry thermistors (U-Type and Gen II transmitter, Eltek, UK) attached to the right-hand side of the body at the pectoralis major muscle belly (T_{chest}), lateral head of triceps brachii (T_{arm}), rectus femoris muscle belly (T_{thigh}) and lateral head of the gastrocnemius (T_{calf}). Mean T_{skin} (Ramanathan 1964) and T_{re}:T_{skin} gradient were retrospectively calculated (Cuddy et al. 2014). Heart rate (HR) was continuously monitored using a Polar 810i strap (Polar, Electro Oy, Kempele, Finland). Sweat rate was estimated by the difference in towel-dried NBM pre and post-exercise, corrected for time, urine output (zero incidence), but not metabolic or respiration losses, which were assumed negligible and similar between trials (Dion et al. 2013).

Perceptual measures

Ratings of perceived exertion (RPE [Borg 1982]) from 6 (*no exertion*) to 20 (*maximal exertion*), thermal comfort (TC [Zhang et al. 2004]) from 0 (*comfortable*) to 4 (*very uncomfortable*), and thermal sensation scale (TSS [Toner et al. 1986]) from 0 (*unbearably cold*) to 8 (*unbearably hot*), were assessed every 5-mins during exercise.

Statistical analyses

Data are reported as mean ± SD, and were assessed for normality and sphericity prior to further statistical analyses (SPSS, IBM version 22.0). Baseline measures of NBM, U_{osm} and U_{sg} and calculated sweat rate during each trial were analysed using a 1-way ANOVA. Individual sites of peak T_{chest}, T_{arm}, T_{thigh} and T_{calf} were also analsyed using a 1-way ANOVA between the four experimental conditions (TEMP, $TEMP_{SUIT}$, HOT, HOT_{SUIT}) as participants only wore an upper-body sauna suit covering only 60% of BSA. All other dependent variables were analysed using a 2-way repeated-measures ANOVA between the four experimental conditions (TEMP, $TEMP_{SUIT}$, HOT, HOT_{SUIT}) and seven time points (0-mins, 5-mins, 10-mins, 15-mins, 20-mins, 25-mins, 30-mins), with Bonferroni correction applied during post-hoc analysis. Whilst a 3-way ANOVA separating environmental conditions (TEMP and HOT) and clothing (suit and no suit) would theoretically present an additional level of analysis, this would not permit all comparisons (i.e. between HOT and $TEMP_{SUIT}$), thus it was not utilised. This statistical approach also befits the research question whereby each experimental condition may be a strategy in its own right. Statistical significance was accepted as $P<0.05$. Effect sizes were estimated and meaningful differences evaluated for peak data using Cohen's *d*, with interpretation of data as; small = 0.2, moderate = 0.5, and large = 0.8 (Cohen, 1988). *A-priori* interpretation boundaries for meaningful physiological changes (Δ) were; ΔT_{re} >0.20°C, ΔHR >5 $b.min^{-1}$ and Δsweat rate >0.20 $L.h^{-1}$, and >1 in scale scores for perceptual measures (Willmott et al., 2017). Pearson's product moment correlation coefficients were used to identify relationships between trials for peak physiological and perceptual measures.

Results

The physiological and perceptual measures during each trial are displayed within Table 1, whereas the differences between trials and their associated effect size are displayed within Table 2. Prior to commencing testing, no differences ($P>0.05$) were observed between conditions for U_{osm} (F=0.3), U_{sg} (F=0.7) or NBM (F=0.6) (Table 1).

Insert Table 1 near here please

Physiological measures

T_{re} demonstrated a difference between conditions (F=14.5, $P<0.001$) and over time (F=146.5, $P<0.001$). Observation of an interaction effect (F=13.1, $P<0.001$) and post-hoc analyses identified that from 20-mins onwards HOT_{SUIT} was greater than TEMP and $TEMP_{SUIT}$, and from 25-mins onwards HOT_{SUIT} was greater than TEMP, $TEMP_{SUIT}$ and HOT. HOT was also greater than TEMP from 25-mins onwards. No difference was observed between $TEMP_{SUIT}$ and HOT at any time ($P>0.05$).

T_{skin} demonstrated a difference between conditions (F=36.6, $P<0.001$) and over time (F=93.4, $P<0.001$). Observation of an interaction effect (F=11.6, $P<0.001$) and post-hoc analyses identified that from 5-mins onwards HOT and HOT_{SUIT} were greater than TEMP and $TEMP_{SUIT}$. From 15-mins onwards, HOT_{SUIT} was also greater than HOT. Peak T_{chest} (F=41.7, $P<0.001$), T_{arm} (F=7.3, $P<0.001$), T_{thigh} (F=15.3, $P<0.001$) and T_{calf} (F=60.3, $P<0.001$) differed between conditions. Post-hoc analyses identified a higher ($P<0.05$) T_{chest} in; HOT_{SUIT} compared to TEMP, $TEMP_{SUIT}$ and HOT, in HOT compared to TEMP, and, in $TEMP_{SUIT}$ compared to TEMP. T_{arm} was higher in HOT and HOT_{SUIT} compared to TEMP. No differences ($P>0.05$) were observed between $TEMP_{SUIT}$ and HOT for T_{chest} or T_{arm}. T_{thigh} and T_{calf} were higher ($P>0.05$) in HOT and HOT_{SUIT} compared to TEMP and $TEMP_{SUIT}$.

The T_{re}:T_{skin} gradient demonstrated a difference between conditions (F=72.6, $P<0.001$) and over time (F=76.0, $P<0.001$). Observation of an interaction effect (F=13.9, $P<0.001$) and post-hoc analyses observed that from 5-mins onwards HOT and HOT_{SUIT} were greater than TEMP and $TEMP_{SUIT}$. From 25-mins onwards HOT_{SUIT} was also greater than HOT. At 30-mins, HOT and HOT_{SUIT} were no longer different.

HR demonstrated a difference between conditions (F=19.5, $P<0.001$) and over time (F=491.2, $P<0.001$). Observation of an interaction effect (F=11.7, $P<0.001$) and post-hoc analyses identified that from 5-mins onwards HOT_{SUIT} was greater than $TEMP_{SUIT}$ and from 10-mins onwards HOT_{SUIT} was greater than TEMP and $TEMP_{SUIT}$. From 20-mins onwards HOT was greater than $TEMP_{SUIT}$ and at 30-mins HOT_{SUIT} was greater than HOT.

Sweat rate demonstrated a difference between conditions (F=10.3, $P<0.001$). A greater ($P<0.05$) sweat rate was observed within $TEMP_{SUIT}$, HOT and HOT_{SUIT} compared to TEMP.

Insert Table 2 near here please

Insert Figure 1 near here please

Perceptual measures
RPE demonstrated a difference between conditions (F=17.9, $P<0.001$) and over time (F=93.4, $P<0.001$). Observation of an interaction effect (F=11.6, $P<0.001$) and post-hoc analyses identified that from 5-mins onwards HOT_{SUIT} was greater than TEMP. From 15-mins HOT was also greater than TEMP. No difference was observed between TEMP and $TEMP_{SUIT}$, or $TEMP_{SUIT}$ and HOT.

TSS demonstrated a difference between conditions (F=53.9, $P<0.001$) and over time (F=105.0, $P<0.001$). Observation of an interaction effect (F=11.9, $P<0.001$) and post-hoc analyses identified that from 5-mins onwards HOT and HOT_{SUIT} were greater than TEMP and $TEMP_{SUIT}$. $TEMP_{SUIT}$ was greater than TEMP from 10-mins onwards, and from 20-mins HOT_{SUIT} was greater than HOT. At 30-mins, TEMP and $TEMP_{SUIT}$ were not different.

TC demonstrated a difference between conditions (F=10.4, $P<0.001$) and over time (F=43.1, $P<0.001$). Observation of an interaction effect (F=7.0, $P<0.001$) and post-hoc analyses identified that from 20-mins HOT_{SUIT} was greater than TEMP and $TEMP_{SUIT}$ and from 25-mins HOT_{SUIT} was greater than TEMP, $TEMP_{SUIT}$ and HOT.

Insert Figure 2 near here please

Mean and individual data for ΔT_{re}, end T_{skin}, peak HR and sweat rate for each condition are displayed within Figure 3.

Insert Figure 3 near here please

Discussion

Overview
A raised and maintained T_{re}, T_{skin} and an increased sweat rate have been identified as the primary stimuli for inducing heat adaptation (Fox et al. 1963; Sawka et al. 2011). Our data highlights that, when commencing equivalent exercise from a similar fluid balance (U_{osm}, U_{sg} and NBM) and physiological state (T_{re}, T_{skin} and HR), wearing an upper-body vinyl 'sauna' suit can increase the magnitude of change in an individual's T_{re} and resultant sweat rate (Table 1, Figure 1 and 3). The increased T_{re} is greater than that during temperate exercise and is similar to that observed within hot conditions. Furthermore, the increase in physiological strain is enhanced by combining hot conditions and a vinyl suit, purporting a potential for increased efficiency during HA without the requirement to increase exercise intensity nor volume to achieve the same physiological strain.

A primary aim of this experiment was to determine whether wearing an upper-body vinyl suit in temperate conditions would elicit equivalent physiological responses to potentiate heat adaptation as training in a hot environment. Whilst there were no differences (*P*>0.05) between $TEMP_{SUIT}$ and HOT for peak T_{re}, HR or sweat rate (Table 2), it is clear the HOT trial provided a larger physiological strain than temperate exercise without restricted heat loss (TEMP) (Figure 1 and 3). Further, no perceptual differences (*P*>0.05) were observed between $TEMP_{SUIT}$ and HOT for RPE or TC, with the only differences being T_{skin}, T_{re}:T_{skin} gradient and TSS (*P*<0.05 [Table 1 and 2]). The elevated T_{skin} between $TEMP_{SUIT}$ and HOT (~3°C) likely reflected the higher ambient air temperature in the chamber, compared to the air temperature in the microclimate under the suit (Mee et al. 2018), which only covered the upper-body (~60% of the BSA). Whilst much of the body was insulated by the upper-body sauna suit, the legs still represent ~40% of the BSA (Ramanathan, 1964; Cross et al. 2008) with an approximate 1.0 $mg.cm^{-2}.min^{-1}$ cutaneous water loss potential (Taylor et al. 2013), which may have limited the benefit of $TEMP_{SUIT}$. The elevation in TSS between $TEMP_{SUIT}$ and HOT (~0.5 A.U.) is likely a result of the difference in T_{skin} (Gagge et al. 1969).

In a similar experiment, eight trained athletes ran at 50% of their $\dot{V}O_{2max}$ in hot conditions (40°C, 30% RH) in normal clothing for training, and in cool conditions (15°C, 50% RH) whilst wearing excess clothing (Steele et al. 2015). Both approaches increased physiological strain index ([PSI] +5.8 and +4.5, respectively), though mean PSI was higher in hot conditions compared with overdressing in cool conditions (6.0 ± 1.0 *vs.* 5.2 ± 1.1, respectively). Unfortunately, based upon available data it is not possible to determine whether T_{re} or HR were lower or whether one measurement had a greater influence on the calculation of PSI. Nonetheless, these exploratory data are supportive of our HOT *vs.* $TEMP_{SUIT}$ comparison, with the authors suggesting that by adequately overdressing, athletes may be able to mimic heat stress and potentially obtain the benefits of heat adaptation in a cooler environment (Steele et al. 2015). In line with the present experiment, recent data have reported the effects of wearing additional clothing (shorts, top, winter cycle jacket and gloves) *vs.* regular clothing (shorts and top only), with a greater increase in physiological strain when completing an 80-mins standardised cycling training session outdoors in temperate conditions (~17°C, ~82% RH) (Stevens et al. 2017). In spite of differences in training session duration which likely explain the magnitude of difference (ΔT_{re}) in comparison to our data, Stevens et al. (2017) noted a similar pattern of physiological differences to that of our comparisons between TEMP and $TEMP_{SUIT}$ with elevated mean T_{re} (theirs +0.4°C, ours +0.2°C) and sweat rate (both ~+0.3 $L.hr^{-1}$) alongside similar magnitudes of HR increase (theirs +3 $b.min^{-1}$, ours +4 $b.min^{-1}$), albeit without statistical difference in our data (Table 2). These exploratory data point to a potential benefit of "overdressing" and restricting heat loss, to elicit greater potentiating physiological stimuli, which may promote heat adaptation via attenuating evaporative cooling (Figure 3). Consequently, it is proposed that training in an upper-body sauna suit within temperate conditions ($TEMP_{SUIT}$) confers a larger physiological strain compared to training without a sauna suit (TEMP). Furthermore, $TEMP_{SUIT}$ elicits similar increases in T_{re}, HR and sweat rate to that of training without a sauna suit in hot conditions (HOT).

Previous acute HA experiments utilising cycle ergometry in conditions of ~40°C and 50% RH have identified that workloads of a comparable nature to this experiment (e.g. ~1.4-2.0 $W.kg^{-1}$) elicit rates of heat storage, that increase T_{re} by 1.0-1.9$°C.hr^{-1}$ in a range of participants including trained athletes and recreationally active individuals, and both males (Gibson et al. 2015b; Willmott et al. 2016, 2017; James et al. 2016) and females (Mee et al. 2015, 2016).

These data, which are similar to the current experiment (Table 1 and 2, Figure 1 and 3) give confidence that “overdressing” by utilising upper-body vinyl suits, or perhaps additional layers of regular clothing can elicit comparable physiological responses to experiments where heat adaptation has occurred. Additionally, the participants only wore an upper-body sauna suit; both alterations may have lessened the effectiveness of the $TEMP_{SUIT}$ in comparison to the HOT trial. Whilst the influence of restricted heat loss clothing during exercise in occupational contexts have been described (Aoyagi et al. 1995; McLellan and Aoyagi 1996), the use of sauna suits during training for performance has been less robustly investigated. Emerging data has reported the benefit of wearing a sauna suit during a 6-week training programme in temperate conditions (30-min sessions, 5 days per week) (Van der Velde et al. 2016). Physiological adaptations included; reductions in resting HR (-4 $b.min^{-1}$), systolic (-2 mmHg) and diastolic blood pressure (-3 mmHg), and, an improved anaerobic threshold (+5.6% of $\dot{V}O_{2max}$) and $\dot{V}O_{2max}$ (+4.3 $mL.kg^{-1}.min^{-1}$) (Van der Velde et al. 2016). These enhancements appear congruous with the magnitudes of adaptation associated with HA (Tyler et al. 2016), albeit they were achieved over a considerably longer period than most HA protocols and did not include a comparable control group. Nonetheless, it might be proposed that the same dose of HA over more frequent (daily or twice-daily), longer exposures (~90-mins) condensed into a shorter training period (7-14 days) and increasing the surface area of restricted heat loss (i.e. full-body sauna suit) would be effective at inducing the HA phenotype and thus requires further investigation. Likewise, the potential to shorten or complete training sessions across different locations will allow team/groups or individuals to implement heat alleviating strategies (e.g. HA), when previously restricted to attend warm-weather training camps or use heat chambers, due to logistical or monetary limitations.

A further aim of this study was to identify whether wearing an upper-body vinyl suit would enhance key potentiating stimuli in hot-dry conditions replicating a traditional HA session. As evidenced by the significantly greater physiological (Figure 1 and 3) and perceptual (Figure 2) responses to HOT_{SUIT} (Table 2), and proposed by others, wearing additional clothing appears to be a potential viable strategy which may be utilised throughout training to enhance heat tolerance (Dawson 1994), in addition to the previously identified benefit as a priming stimuli for sweat adaptations (Mee et al. 2017). Therefore, restricting heat loss during HA may present a more efficient method for attaining sufficient physiological stimuli, without increasing absolute exercise intensity. Further, although speculative, wearing sauna suits may offer supplementary perceptual, sudomotor and circulatory (e.g. skin blood flow) adaptations, imposed by the benefits of hot-wet conditions (Shvartz et al., 1979; Regan et al., 1996), which are recommended at the latter stages of HA (Periard et al., 2015; Racinais et al., 2015). This may support individuals exercising in either hot-wet or hot-dry conditions (Eichna et al., 1945; Fox et al., 1967), however, despite the benefits of superior sweat loss capacity, an earlier onset of dehydration and cardiovascular strain may occur (González-Alonso et al., 1998), especially if evaporative requirement is inhibited (Gagnon et al., 2013), thus hydration guidelines must be followed (Maughan and Shirreffs, 2008). It is also acknowledged that a possible time-lag using rectal thermometry may have reduced the differences between the ΔT_{re} across conditions, as opposed to using a more responsive index of core temperature (e.g. oesophageal [Mündel et al., 2016]).

Practical application and future direction

Our data indicate that clothing which restricts sweat evaporation may be worn during exercise to enhance heat adaptation stimuli, however further work is required to elucidate the full potential of this method in both acute and chronic interventions using intensities and durations of exercise consistent with existing heat acclimation protocols. This may demonstrate its efficacy across exercise modalities (e.g. running/walking, rowing and cycling), both indoors and outdoors for athletic or occupational populations (e.g. firefighters and military), and for those individuals for whom heat tolerance is compromised (e.g. elderly or clinical populations), but access to heat training facilities is limited. Additional research is required to determine whether repeated restriction of evaporation via excessive/specific clothing can induce the HA phenotype to the same extent as a traditional chamber based protocol. Given the problems with accessing chamber facilities for large cohorts (e.g. team-sports, occupational or military personnel), the opportunity to overdress and train in temperate conditions to induce heat adaptation prior to competing in a warmer climate is appealing, although, we highlight the need for monitoring body temperature and hydration status, whilst also calculating fluid loss and individualising rehydration strategies for individuals adopting this technique.

Refinements to the exercise protocol (i.e. increased exercise intensity) and increasing the area of restricted heat loss (i.e. full-body sauna suit) may provide equivalent responses to exercising in hot conditions. Restricting whole-body water loss using a full-body sauna suit, the subsequent evaporation from limbs undergoing mechanical work and elevated self-generated air flow (Deren et al. 2014) may facilitate faster increases in T_{re}, helping to expedite HA. A further practical advancement would be to determine whether wearing restrictive clothing expedites HA when exercising at higher intensities, and therefore greater heat production, than those implemented in the present study is undertaken. Finally, sauna suits may assist in storing the heat generated from exercise, helping to maintain a higher body temperature. If these garments can expedite the time to achieving an elevated body temperature, this may reduce the amount of physical work that must be completed in each training session to achieve recommended guidelines for the maintenance of an elevated T_{re} (i.e. >38.5°C [Taylor, 2014; Gibson et al. 2015]). Previously, another ‘passive’ technique of HWI post-exercise, has been shown to be effective method of raising and maintaining T_{re}, to elicit heat adaptation (Zurawlew et al. 2015). Therefore, for those undertaking HA, overdressing will help to quickly raise body temperature and we highlight the potential to follow physical exertion with HWI to minimise the exercise requirement of HA, although further research is required to support this.

Conclusion

Exercising within temperate conditions whilst wearing an upper-body sauna suit induces a greater physiological strain (i.e. core temperature) and evokes a larger sweat loss in comparison to exercising without a sauna suit in the same conditions. In hot conditions, wearing a sauna suit further enhances physiological and perceptual strain. Wearing a full-body sauna suit during repeated training in temperate conditions may be a viable alternative to HA undertaken in environmental chambers, when a greater exercise intensity is used, with further research warranted. The use of a sauna suit during exercise in a hot environment may accelerate the attainment of important potentiating stimuli for heat adaptation and reduce the physical work, making HA more efficient.

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Conflicts of interest

The authors confirm there are no conflicts of interest.

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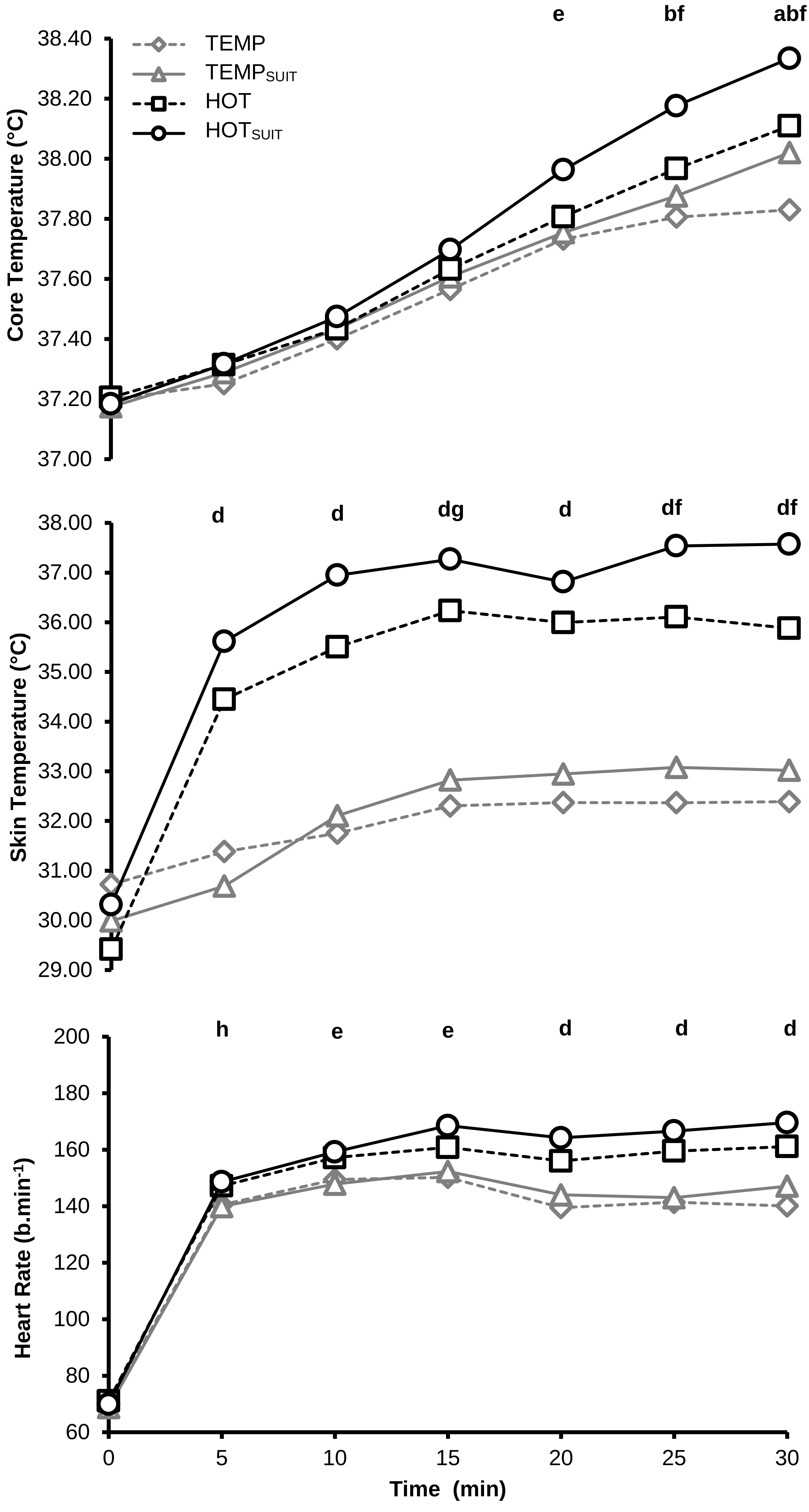
Figure legends

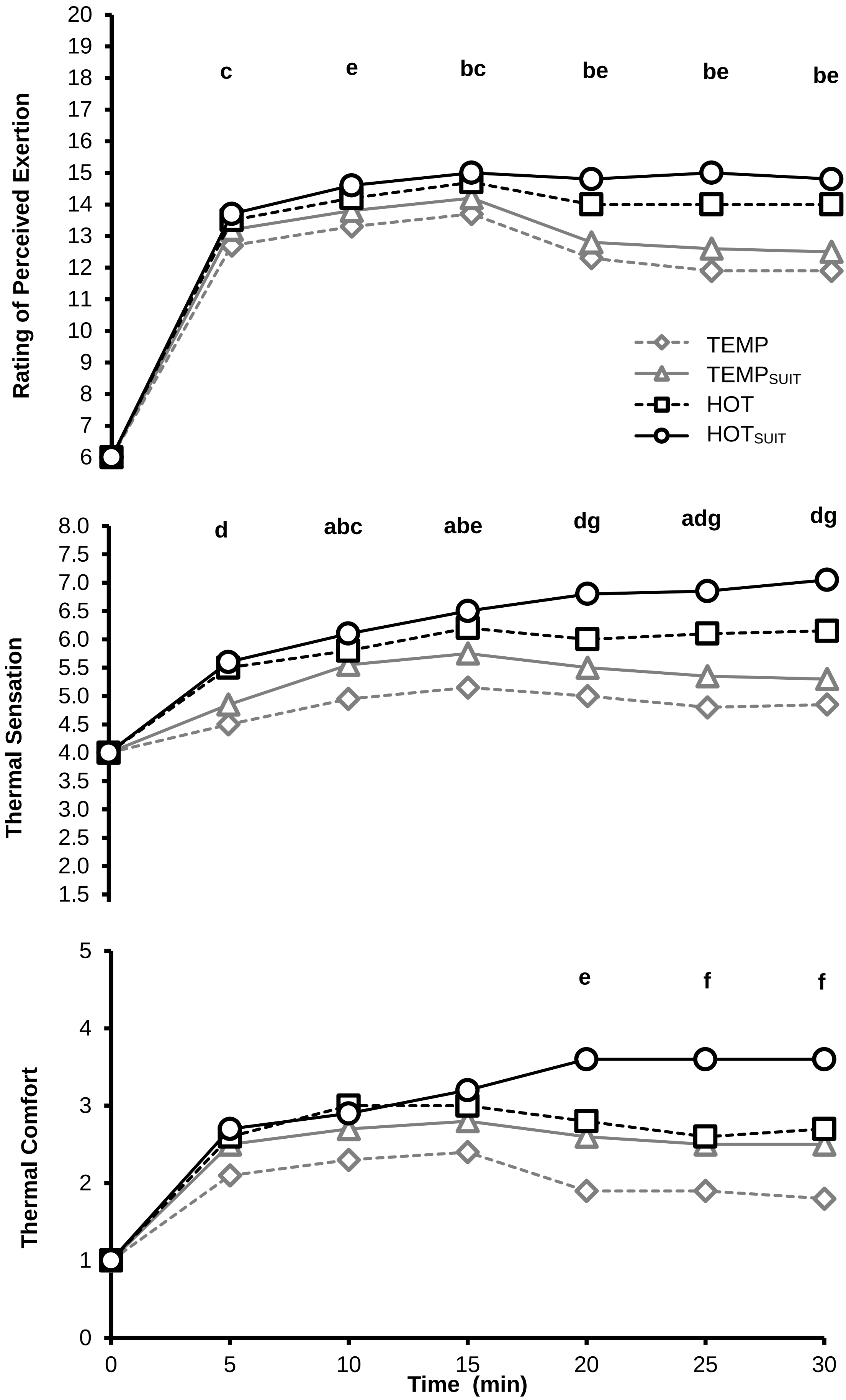
Figure 1. Mean physiological measurements, core temperature (Top), skin temperature (Middle) and heart rate (Bottom) during 30-mins of exercise in TEMP, $TEMP_{SUIT}$, HOT and HOT_{SUIT} conditions. SD has been removed for clarity. Letters indicate statistical difference ($P<0.05$) whereby; a: TEMP *vs.* $TEMP_{SUIT}$, b: TEMP *vs.* HOT, c: TEMP *vs.* HOT_{SUIT}, d: TEMP, $TEMP_{SUIT}$ *vs.* HOT, HOT_{SUIT}, e: TEMP, $TEMP_{SUIT}$ *vs.* HOT_{SUIT}, f: TEMP, $TEMP_{SUIT}$, HOT *vs.* HOT_{SUIT}, g: $TEMP_{SUIT}$ *vs.* HOT_{SUIT}, h: HOT *vs.* HOT_{SUIT}.

Figure 2. Mean perceptual measurements, rating of perceived exertion (Top), thermal sensation (Middle) and thermal comfort (Bottom) during 30-mins of exercise in TEMP, $TEMP_{SUIT}$, HOT and HOT_{SUIT} conditions. SD has been removed for clarity. Letters indicate statistical difference ($P<0.05$) whereby; a: TEMP *vs.* $TEMP_{SUIT}$, b: TEMP *vs.* HOT, c: TEMP *vs.* HOT_{SUIT}, d: TEMP, $TEMP_{SUIT}$ *vs.* HOT, HOT_{SUIT}, e: TEMP, $TEMP_{SUIT}$ *vs.* HOT_{SUIT}, f: TEMP, $TEMP_{SUIT}$, HOT *vs.* HOT_{SUIT}, g: HOT *vs.* HOT_{SUIT}.

Figure 3. Mean ± SD (black marker and line) and individual responses (grey marker and lines) to TEMP, $TEMP_{SUIT}$, HOT and HOT_{SUIT} conditions at the end of exercise for Δ core temperature (1), end skin temperature (2), peak heart rate (3) and sweat rate (4). Letters indicate statistical difference ($P<0.05$) whereby; a: *vs.* TEMP, b: *vs.* $TEMP_{SUIT}$, c: *vs.* HOT, d: *vs.* HOT_{SUIT}.



e
bf
abf
TEMP
TEMPSUIT
HOT
HOTSUIT
Core Temperature (°C)
38.40
38.20
38.00
37.80
37.60
37.40
37.20
37.00
d
d
dg
d
df
df
Skin Temperature (°C)
38.00
37.00
36.00
35.00
34.00
33.00
32.00
31.00
30.00
29.00
h
e
e
d
d
d
Heart Rate (b.min-1)
200
180
160
140
120
100
80
60
0
5
10
15
20
25
30
Time (min)


Rating of Perceived Exertion
c
e
bc
be
be
be
TEMP
TEMP SUIT
HOT
HOT SUIT
Thermal Sensation
d
abc
abe
dg
adg
dg
Thermal Comfort
e
f
f
Time (min)

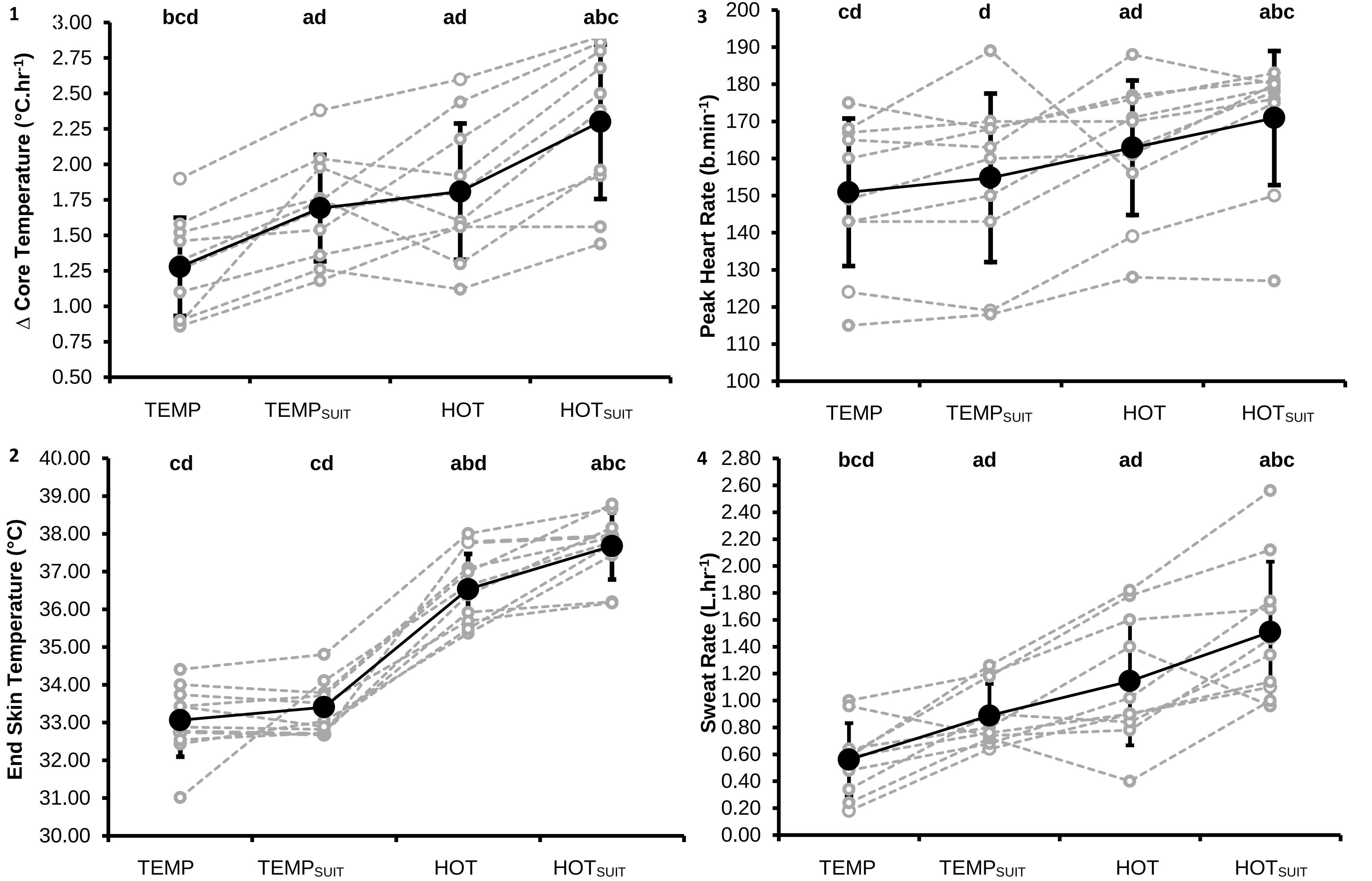

1
Δ Core Temperature (°C.hr-1)
bcd
ad
ad
abc
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
TEMP
TEMPSUIT
HOT
HOTSUIT
3
Peak Heart Rate (b.min-1)
cd
d
ad
abc
200
190
180
170
160
150
140
130
120
110
100
TEMP
TEMPSUIT
HOT
HOTSUIT
2
End Skin Temperature (°C)
cd
cd
abd
abc
40.00
39.00
38.00
37.00
36.00
35.00
34.00
33.00
32.00
31.00
30.00
TEMP
TEMPSUIT
HOT
HOTSUIT
4
Sweat Rate (L.hr-1)
bcd
ad
ad
abc
2.80
2.60
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
TEMP
TEMPSUIT
HOT
HOTSUIT

Table 1. Mean ± SD physiological and perceptual measures during each trial.

	TEMP	$TEMP_{SUIT}$	HOT	HOT_{SUIT}
		Rest measures		
T_{re} (°C)	37.20 ± 0.36	37.17 ± 0.35	37.21 ± 0.42	37.18 ± 0.41
T_{skin} (°C)	30.72 ± 1.44	29.99 ± 0.54	29.42 ± 0.90	30.32 ± 0.82
HR (b.min^{-1})	70 ± 9	69 ± 12	71 ± 16	70 ± 11
NBM (kg)	69.45 ± 7.47	69.61 ± 7.50	69.28 ± 7.70	69.43 ± 7.40
U_{osm} (mOsm·kg^{-1})	350 ± 178	365 ± 197	371 ± 215	354 ± 197
U_{sg}	1.011 ± 0.002	1.014 ± 0.005	1.012 ± 0.003	1.010 ± 0.004
		Exercise measures		
Peak T_{re} (°C)	37.84 ± 0.34^{bcd}	38.02 ± 0.32^{ad}	38.11 ± 0.31^{ad}	38.33 ± 0.32^{abc}
ΔT_{re} (°C.hr^{-1})	1.3 ± 0.3^{bcd}	1.7 ± 0.4^{ad}	1.9 ± 0.5^{ad}	2.3 ± 0.5^{abc}
Peak T_{skin} (°C)	33.06 ± 0.97^{cd}	33.41 ± 0.70^{cd}	36.53 ± 0.93^{abd}	37.68 ± 0.68^{abc}
Mean T_{re}:T_{sk} (°C)	5.3 ± 1.9^{cd}	5.5 ± 0.5^{cd}	2.8 ± 1.1^{ab}	1.7 ± 0.8^{ab}
Peak HR (b.min^{-1})	151 ± 20^{cd}	155 ± 23^{d}	163 ± 18^{ad}	171 ± 18^{abc}
Sweat rate (L.hr^{-1})	0.56 ± 0.27^{bcd}	0.89 ± 0.24^{ad}	1.14 ± 0.48^{ad}	1.51 ± 0.52^{abc}
Peak RPE	14 ± 1^{cd}	14 ± 1^{d}	15 ± 1^{a}	16 ± 1^{ab}
Peak TSS	5.3 ± 0.5^{cd}	5.8 ± 0.5^{cd}	6.4 ± 0.5^{abd}	7.1 ± 0.5^{abc}
Peak TC	1 ± 1	2 ± 1	2 ± 1	3 ± 1^{abc}

Note; [a] difference *vs.* TEMP (P<0.05), [b] difference *vs.* $TEMP_{SUIT}$ (P<0.05), [c] difference *vs.* HOT (P<0.05), [d] difference *vs.* HOT_{SUIT} (P<0.05)

Table 2. Mean ± SD differences between trials (effect size and correlation coefficient).

	TEMP *vs.* $TEMP_{SUIT}$	TEMP *vs.* HOT	TEMP *vs.* HOT_{SUIT}	$TEMP_{SUIT}$ *vs.* HOT	$TEMP_{SUIT}$ *vs.* HOT_{SUIT}	HOT *vs.* HOT_{SUIT}
Peak T_{re} (°C)	0.18 ± 0.11* (*d* = 0.5, *r* = 0.95)	0.27 ± 0.13*† (*d* = 0.8, *r* = 0.93)	0.50 ± 0.09*† (*d* = 1.5, *r* = 0.97)	0.09 ± 0.19 (*d* = 0.3, *r* = 0.84)	0.31 ± 0.14*† (*d* = 1.0, *r* = 0.92)	0.23 ± 0.11*† (*d* = 0.7, *r* = 0.95)
ΔT_{re} (°C.hr^{-1})	0.41 ± 0.27*† (*d* = 0.4, *r* = 0.75)	0.53 ± 0.36*† (*d* = 1.5, *r* = 0.69)	1.02 ± 0.39*† (*d* = 2.5, *r* = 0.73)	0.12 ± 0.39 (*d* = 0.4, *r* = 0.63)	0.61 ± 0.36*† (*d* = 1.3, *r* = 0.77)	0.49 ± 0.25*† (*d* = 0.8, *r* = 0.90)
Peak T_{skin} (°C)	0.31 ± 1.06 (*d* = 0.4, *r* = 0.26)	3.44 ± 1.22 (*d* = 3.7, *r* = 0.22)	4.58 ± 1.25* (*d* = 5.6, *r* = 0.12)	3.13± 0.84 (*d* = 3.8, *r* = 0.53)	4.27 ± 0.90* (*d* = 6.2, *r* = 0.40)	1.14 ± 0.78* (*d* = 1.4, *r* = 0.66)
Mean T_{re}:T_{sk} (°C)	0.14 ± 0.99 (*d* = 0.2, *r* = 0.81)	2.80 ± 1.11 (*d* = 1.7, *r* = 0.61)	3.92 ± 1.41* (*d* = 2.7, *r* = 0.20)	2.66 ± 0.84* (*d* = 3.4, *r* = 0.68)	3.77 ± 0.86* (*d* = 5.8, *r* = 0.18)	1.11 ± 0.82 (*d* = 1.2, *r* = 0.68)
Peak HR (b.min^{-1})	4 ± 8 (*d* = 0.2, *r* = 0.94)	12 ± 12† (*d* = 0.6, *r* = 0.83)	20 ± 11*† (*d* = 1.1, *r* = 0.84)	8 ± 17† (*d* = 0.4, *r* = 0.71)	16 ± 14*† (*d* = 0.8, *r* = 0.80)	8 ± 9*† (*d* = 0.4, *r* = 0.90)
Sweat rate (L.hr^{-1})	0.33 ± 0.27*† (*d* = 1.2, *r* = 0.46)	0.58 ± 0.43*† (*d* = 1.3, *r* = 0.47)	0.95 ± 0.51*† (*d* = 2.3, *r* = 0.32)	0.26 ± 0.31† (*d* = 0.6, *r* = 0.86)	0.62 ± 0.37*† (*d* = 1.7, *r* = 0.80)	0.37 ± 0.37*† (*d* = 0.8, *r* = 0.76)
Peak RPE	1 ± 1† (*d* = 0.0, *r* = 0.84)	1 ± 1† (*d* = 0.0, *r* = 0.57)	2 ± 1*† (*d* = 2.0, *r* = 0.80)	1 ± 2† (*d* = 1.0, *r* = 0.15)	1 ± 1*† (*d* = 2.0, *r* = 0.53)	1 ± 1† (*d* = 1.0, *r* = 0.75)
Peak TSS	0.5 ± 0.5 (*d* = 1.0, *r* = 0.61)	1.1 ± 0.8† (*d* = 2.2, *r* = 0.13)	1.8 ± 0.7*† (*d* = 3.6, *r* = 0.04)	0.6 ± 0.5* (*d* = 1.2, *r* = 0.55)	1.3 ± 0.5*† (*d* = 2.6, *r* = 0.54)	1.3 ± 0.5*† (*d* = 1.4, *r* = 0.54)
Peak TC	1 ± 1† (*d* = 1.0, *r* = 0.54)	1 ± 1† (*d* = 1.0, *r* = 0.68)	1 ± 1† (*d* = 2.0, *r* = 0.68)	0 ± 1 (*d* = 0.0, *r* = 0.73)	0 ± 1 (*d* = 1.0, *r* = 0.73)	0 ± 1 (*d* = 1.0, *r* = 0.73)

Note; * significant difference between trials (*P*<0.05), † difference above the *a-priori* pre-defined limits.