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The effects of single versus twice daily short term heat acclimation on heat strain and 3000 m running performance in hot, humid conditions

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ABSTRACT

Endurance performances are impaired under conditions of elevated heat stress. Short term heat acclimation (STHA) over 4–6 days can evoke rapid adaptation, which mitigate decrements in performance and alleviate heat strain. This study investigated the efficacy of twice daily heat acclimation (TDHA) compared to single session per day heat acclimation (SDHA) and normothermic training, at inducing heat acclimation phenotype and its impact upon running performance in hot, humid conditions.

Twenty one, moderately trained males were matched and assigned to three groups; SDHA (mean ± SD) (peak oxygen consumption [$\dot{V}O_{2peak}$] 45.8 ± 6.1 mL kg^{-1} min^{-1}, body mass 81.3 ± 16.0 kg, stature 182 ± 3 cm), TDHA (46.1 ± 7.0 mL kg^{-1} min^{-1}, 80.1 ± 11.9 kg, 178 ± 4 cm) or control (CON) (47.1 ± 3.5 mL kg^{-1} min^{-1}, 78.6 ± 16.7 kg, 178 ± 4 cm). Interventions consisted of 45 min cycling at 50% $\dot{V}O_{2peak}$, once daily for 4d (SDHA) and twice daily for 2d (TDHA), in 35 °C, 60% relative humidity (RH), and once daily for 4 days (CON) in 21 °C, 40% RH. Participants completed a pre- and post-intervention 5 km treadmill run trial in 30 °C, 60% RH, where the first 2 km were fixed at 40% $\dot{V}O_{2peak}$ and the final 3 km was self-paced.

No statistically significant interaction effects occurred within- or between-groups over the 2–4 days intervention. While within-group differences were found in physiological and perceptual measures during the fixed intensity trial post-intervention, they did not statistically differ between-groups. Similarly, TDHA (−36 ± 34 s [+3.5%]) and SDHA (−26 ± 28 s [+2.8%]) groups improved 3 km performances (p=0.35), but did not differ from CON (−6 ± 44 s [+0.6%]).

This is the first study to investigate the effects of HA twice daily and compare it with traditional single session per day STHA. These STHA protocols may have the ability to induce partial adaptive responses to heat stress and possibly enhance performance in environmentally challenging conditions, however, future development is warranted to optimise the administration to provide a potent stimuli for heat adaptation in athletic and military personnel within a rapid regime.

1. Introduction

Endurance performances across a spectrum of distances are impaired by heat stress (McCann and Williams, 1997; Guy et al., 2015). While exercising or physically active within the heat, systemic metabolic heat production ($\dot{H}_{prod}$) is typically balanced by heat dissipation though enlarged skin blood flow. This process consequently increases skin temperature and augments sweating, which ultimately facilitates evaporation (Poirier et al., 2015). Reductions in self-paced exercise or fixed intensity military tasks, are a result of physiological strain and, or behavioural thermoregulation during heat stress (Sawka et al., 2011; Racinais et al., 2015). To compete or serve optimally under heat stress, heat acclimation or acclimatisation is typically recommended (Racinais et al., 2015), as repeated heat strain confer physiological and metabolic adaptations, in addition to reducing perceptual feelings, which alleviate physiological strain and enhance physical performance (Sawka et al., 2011; Taylor, 2014; Racinais et al., 2015). To induce such adaptations, repeated daily exercise is performed in hot environmental conditions, which may be simulated (i.e. heat acclimation [HA]) or naturally occurring (i.e. heat acclimatisation). Long-term HA (LTHA) consists of 60–120 min of exercise at moderate intensities (~50% relative to maximal oxygen uptake [$\dot{V}O_{2max}$]) over 10 to 14 days, within target environmental conditions (Armstrong and Maresh, 1991). However, despite total phenotypic adaptations occurring within 14–21 days during LTHA, ≤5 daily exposures during short term HA (STHA) facilitates

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practically significant thermoregulatory and cardiovascular (~75%) adaptations (Pandolf, 1998), over a more applicable duration for athletes and military personnel. Previous STHA studies (Cotter et al., 1997; Patterson et al., 2004; Sunderland et al., 2008; Garrett et al., 2009, 2011; Costa et al., 2014; Mee et al., 2015; Gibson et al., 2015) have reported physiological and athletic performance improvements within hot conditions.

During training, prior to competition or in the lead up to military deployment, STHA may appear more feasible for inclusion in established schedules due to lesser disruption and costs, particularly when tapering (Gibson et al., 2015) and will avoid unnecessary reductions in the quality of training or heat-related illnesses. Rapid examples of STHA prior to hockey (Sunderland et al., 2008), cricket (Petersen et al., 2010) and cycling (Brade et al., 2013) performance, have reported partial adaptations over 4–5 consecutive (Petersen et al., 2010; Brade et al., 2013) and 10 nonconsecutive days (Sunderland et al., 2008), within hot environmental conditions. These convenient methods of HA consisted of short (30–45 min), high intensity or sport specific training within 30–35 °C, and are similar to Houmard et al. (1990) recommendations of short-duration (30–35 min), moderate intensity (75% $\dot{V}O_{2max}$) exercise in the heat to induce adaptation. Although only partial HA adaptions were reported in physiological and perceptual measures, improvements in exercise performance were observed (+5% (Brade et al., 2013) and +33% (Sunderland et al., 2008)). Therefore, these prompt STHA methods may be more appealing and practical when applied to the competing athlete or military personnel.

Contrary to pre-planned, self-paced exercise performances, which have definitive start and end times, with readily available fluids and reside in safe, sporting surroundings, such as the Olympics, military personnel face an array of extreme situations. The increased risk of heat-related illnesses may arise from requirements to carry and wear heavy protective clothing, sleep deprivation, dehydration and the uncertainty surrounding time before deployment and prolonged durations to perform optimally in hazardous, combat and adverse environmental circumstances (Sawka et al., 2011). Therefore, due to practical constraints such as deployment times, prompt STHA should be applied to military soldiers, if they are required to heat acclimate to target conditions within a matter of days. Likewise, athletes may prefer rapid STHA to reduce the negative impact upon their quality of training during a tapering phase. It has been demonstrated that during once versus twice daily acclimatisation, no between-group difference exists in core temperature (T_{re}) or body mass change, while investigating the risk of heat injury in American football players over a two week training period (Herzog et al., 2009).

Consequently, the plausibility of further reducing the duration of STHA interventions by performing twice daily heat acclimation, warrants investigation. The aim of this study was to investigate the physiological and perceptual adaptions, and 3 km running performance in hot, humid conditions, after four days of single session HA, two days of twice daily HA and four days of single session normothermic training. It was hypothesised that both HA protocols would induce similar adaptations, as opposed to no changes after temperate training. It was further hypothesised there would be no statistically significant difference in adaptation and running performance between HA protocols.

2. Methods

2.1. Participants

Twenty one moderately trained (performance level 2) (De Pauw et al., 2013) males volunteered and provided written consent after being informed of the purpose and associated risks of the experiment. The study was approved by the Institutional Research Ethics and Governance Committee and conducted in accordance to the Declaration of Helsinki of 1975, as revised in 2008. Participants were matched for physiological parameters (Table 1) and assigned to three groups; single session per day heat acclimation (SDHA), twice daily heat acclimation (TDHA) or control (CON).

Table 1
Mean ± SD physiological characteristics and prescribed running and cycling intensities.

	TDHA	SDHA	CON	*p*
Age (years)	25 ± 1	23 ± 1	27 ± 3	0.12
Stature (cm)	178 ± 4	182 ± 3	178 ± 4	0.21
Body mass (kg)	80.1 ± 11.9	81.3 ± 16.0	78.6 ± 16.7	0.47
BSA (m^2)	1.98 ± 0.13	2.09 ± 0.16	1.96 ± 0.19	0.31
Running $\dot{V}O_{2peak}$ (mL kg^{-1} min^{-1})	46.1 ± 7.0	45.8 ± 6.1	47.1 ± 3.5	0.90
Cycling $\dot{V}O_{2peak}$ (L min^{-1})	3.9 ± 0.4	3.9 ± 0.5	3.5 ± 0.6	0.33

TDHA = twice daily heat acclimation group, SDHA = single session per day heat acclimation group and CON = control group, BSA = body surface area, $\dot{V}O_{2peak}$ = peak oxygen uptake.

2.2. Experimental design

On the completion of a running and cycling peak oxygen uptake ($\dot{V}O_{2peak}$) test separated by 48 h, and a running 5 km preloaded time trial (5 kmTT), participants were either assigned to; four consecutive days of HA (SDHA), or four consecutive days of temperate training (CON) or two consecutive days of twice daily HA (TDHA). Participants then completed a post-training 5 kmTT 48 h following completion of the intervention. Participants wore minimal clothing, including shorts, t-shirt and sports shoes, which remained constant throughout each trial.

2.3. Pre-experimental protocol and equipment

Participants avoided alcohol, caffeine and large food intake prior to each visit, and arrived in a euhydrated state (indicated by urine osmolality [U_{osm}] < 700 mOsm kg^{-1} and specific gravity [U_{sg}] < 1.020) (Sawka et al., 2007). Stature was measured and nude body mass (NBM) assessed using physician scales (Detecto Scale Company, USA) to determine body surface area (BSA) (DuBois and DuBois, 1916). Fresh mid-flow urine samples were requested to determine fluid balance indices using a hand-held light refractometer (Atago Co., Tokyo, Japan) and Pocket Pal-Osmo (Vitech Scientific, Ltd). T_{re} was continually recorded on logging monitors (YSI, 4600 series, Hampshire, UK), using a single use probe (449 H, Henleys Medical, Hertfordshire, UK), inserted 10 cm past the anal sphincter. This method of measuring core temperature is accurate (± 0.13 °C) and prevents the likelihood of serious heat related-illnesses (Sawka et al., 2011). HR monitors were affixed to the chest (Accurex+, Polar Electro, Oy, Kempele, Finland) and monitored continuously during all exercise. Participants were familiarised to perceptual scales, including ratings of perceived exertion (RPE), from 6 (no exertion) to 20 (maximal exertion) (Borg, 1982) and thermal sensation (TSS), from 0 (unbearably cold) to 8 (unbearably hot) (Toner et al., 1986). Participants were aware they could stop exercising at any time and were removed from the heat if T_{re} reached ≥ 39.7 °C (zero incidences). Non-urine fluid loss (NUFL) was estimated post-exercise using weighing scales and the difference between pre- and post-exercise towel-dried NBM, corrected for urine output and fluid consumption (zero incidences), but not for respiratory or metabolic losses which were assumed similar and negligible between tests. Fingertip capillary blood samples were collected on arrival to HA and CON session 1 and