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Isothermic and fixed intensity heat acclimation methods induce similar heat adaptation following short and long-term timescales

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ABSTRACT

Heat acclimation requires the interaction between hot environments and exercise to elicit thermoregulatory adaptations. Optimal synergism between these parameters is unknown. Common practise involves utilising a fixed workload model where exercise prescription is controlled and core temperature is uncontrolled, or an isothermic model where core temperature is controlled and work rate is manipulated to control core temperature.

Following a baseline heat stress test; 24 males performed a between groups experimental design performing short term heat acclimation (STHA; five 90 min sessions) and long term heat acclimation (LTHA; STHA plus further five 90 min sessions) utilising either fixed intensity (50% $\dot{V}O_{2peak}$), continuous isothermic (target rectal temperature 38.5 °C for STHA and LTHA), or progressive isothermic heat acclimation (target rectal temperature 38.5 °C for STHA, and 39.0 °C for LTHA). Identical heat stress tests followed STHA and LTHA to determine the magnitude of adaptation.

All methods induced equal adaptation from baseline however isothermic methods induced adaptation and reduced exercise durations (STHA = −66% and LTHA = −72%) and mean session intensity (STHA = −13% $\dot{V}O_{2peak}$ and LTHA = −9% $\dot{V}O_{2peak}$) in comparison to fixed ($p < 0.05$). STHA decreased exercising heart rate (−10 b min^{-1}), core (−0.2 °C) and skin temperature (−0.51 °C), with sweat losses increasing (+0.36 L h^{-1}) ($p < 0.05$). No difference between heat acclimation methods, and no further benefit of LTHA was observed ($p > 0.05$). Only thermal sensation improved from baseline to STHA (−0.2), and then between STHA and LTHA (−0.5) ($p < 0.05$). Both the continuous and progressive isothermic methods elicited exercise duration, mean session intensity, and mean T_{rec} analogous to more efficient administration for maximising adaptation.

Short term isothermic methods are therefore optimal for individuals aiming to achieve heat adaptation most economically, i.e. when integrating heat acclimation into a pre-competition taper. Fixed methods may be optimal for military and occupational applications due to lower exercise intensity and simplified administration.

1. Introduction

Repeated exposure to stressful hot environments initiates the heat-adapted phenotype. The heat-adapted phenotype is acquired most effectively when hot and humid environmental conditions and physical work (intensity, duration and frequency) interact to stress thermoregulatory and cardiovascular systems (Sawka et al., 2011); this process is known as heat acclimation (Garrett et al., 2011). Primary adaptations induced by heat acclimation include decreased core temperature (Armstrong and Maresh, 1991; Buono et al., 1998; Garrett et al., 2011) and reduced heat storage (Aoyagi et al., 1997) facilitated by increased sudomotor function (Chinevere et al., 2008; Lorenzo and Minson, 2010; Machado-Moreira et al., 2006; Martinez et al., 2012), increased skin blood flow (Lorenzo and Minson, 2010), and cardiovascular adjustments eliciting greater maintenance of stroke volume and reduced heart rate at a

Abbreviations: FIXED, fixed intensity heat acclimation experimental group; HR, heart rate; HST, heat Stress Test; ISO_{CONT}, continuous isothermic heat acclimation experimental group; ISO_{PROG}, progressive isothermic heat acclimation experimental group; LTHA, long term heat acclimation; STHA, short term heat acclimation; T_{rec}, rectal temperature; T_{sk}, skin temperature; $\dot{V}O_{2peak}$, peak oxygen uptake

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given workload (Frank et al., 2001). These adaptations contribute to a decreased thermal and perceptual strain (Castle et al., 2011), ultimately facilitating increased exercise performance in hot and cool environments (Lorenzo et al., 2010). Heat acclimation is often categorised into short term (STHA) and long term (LTHA) induction periods. LTHA, the traditional time scale, generally comprises ≥ 10 daily heat exposures (Garrett et al., 2011), potentiating the most complete phenotypic adaptation. STHA utilises ≤ 5 daily exposures, facilitating rapid, but, incomplete adaptation ($\sim$75% compared to LTHA (Pandolf, 1979)). Notwithstanding, STHA still remains an effective tool used by practitioners for augmenting adaptation before exposure to hot environments, improving tolerance to exercise or work (Garrett et al., 2012, 2009).

Increased core temperature is a fundamental requirement for inducing heat acclimation (Regan et al., 1996; Taylor and Cotter, 2006). Isothermic heat acclimation (also known as controlled hyperthermia) is imposed based upon endogenous (internal) criteria (Castle et al., 2012; Garrett et al., 2014, 2012, 2009; Hom et al., 2012; Machado-Moreira et al., 2006; Magalhães et al., 2010a, 2010b; Patterson et al., 2014, 2004), and might provide sustained targeting and attainment of specific and individualised internal temperatures through a combination of active and passive heat acclimation (Fox et al., 1963). The balance between work and rest to target and maintain specific core temperatures ensures a consistency, or a progression of endogenous heat strain to induce adaptation, albeit requiring alterations in administration throughout each session. Implementation of fixed intensity heat acclimation methods is in comparison relatively simple, with participants maintaining a fixed workload throughout each active acclimation session (Amorim et al., 2011; Castle et al., 2011; Cheung and McLellan, 1998; Houmard et al., 1990; Kresfelder et al., 2006; Lorenzo and Minson, 2010; Lorenzo et al., 2010; Marshall et al., 2007; Nielsen et al., 1997, 1993; Sandström et al., 2008; Watkins et al., 2008; Yamada et al., 2007). Fixed methods derive exercise workloads from a pre acclimation baseline, and the exogenous (external) environment are consistent day-on-day. Though this method may provide sufficient heat strain during the initial sessions of heat acclimation regimens, fixed methods may not achieve the desired, nor optimally potentiating stimuli – increased core temperature, as the thermal strain relative to the start of acclimation diminishes with ensuing adaptation (Taylor and Cotter, 2006; Taylor, 2014). During both STHA and LTHA, relative workload and the thermal strain of heat acclimation are likely to reduce during fixed intensity as on-going adaptation is seen. Isothermic heat acclimation, where endogenous thermal stimulus is consistently targeted throughout, may positively sustain the rate of adaptation, or advance adaptation should a progressive increase in core temperature be implemented (Taylor and Cotter, 2006; Taylor, 2014). Progressive isothermic methods have only previously been implemented using models where the environmental conditions or workload for acclimation are increased (Burk et al., 2012; Chen et al., 2013; Daanen et al., 2011), this presumably to offset the aforementioned ongoing adaptation. These progressive methods are not certain to increase core temperature in the manner that a progressive increase in the isothermic target temperature would. Varied administration of heat acclimation methods has likely produced different phenotypic adaptive responses. The mode of exercise, relative exercise intensity and climatic conditions may modulate different degrees of adaptation (Taylor and Cotter, 2006). Should the anticipated core temperature changes be observed between methods it is likely that fixed heat acclimation methods are analogous to a reduction in the potentiating stimuli for adaptation and consequently the rate of adaptation would decrease from STHA to LTHA. The isothermic continuous method should theoretically sustain potentiating stimuli and consequently sustain the rate of adaptation from STHA to LTHA. Finally a progressive isothermic method could theoretically be used to increase potentiating stimuli and may increase the rate of adaptation from STHA to LTHA.

The aim of the present study was to determine whether any differences in heat adaptation occurred between an established exogenous controlled, fixed intensity heat acclimation method, an endogenous controlled, isothermic heat acclimation method, and a stepwise progressive endogenous isothermic heat acclimation method, after STHA and LTHA periods. No direct comparison has been made of the observed adaptation and administration differences between isothermic and fixed heat acclimation methods across STHA and LTHA timescales; additionally evidence is limited in support of a stepwise progression in thermal strain to increase the rate of adaptation from STHA to LTHA. We hypothesised that the rate of phenotypic adaptation would be greater in isothermic heat acclimation methods in comparison to fixed methods due to sustained strain. It was additionally hypothesised that a greater rate of adaptation would be induced by utilising a progressive model. It was also hypothesised that implementation of isothermic heat acclimation would require reduced exercise durations and lower average sessional exercise intensities, in spite of initially higher exercise intensities, which would favour athletes in the pre-competition taper.

2. Methods

2.1. Participants

Twenty-four healthy males were assigned into fixed intensity (FIXED), or isothermic heat acclimation (ISO) groups, ISO was then subdivided into continuous isothermic heat acclimation (ISO_{CONT}), or progressive isothermic heat acclimation (ISO_{PROG}) groups; participants were matched for peak oxygen uptake ($\dot{V}_{O_{2peak}}$) and anthropometric characteristics. Data are presented in Table 1. Confounding variables of smoking, caffeine, glutamine, alcohol, generic supplementation, prior thermal, hypoxic and hyperbaric exposures were all controlled in line with previous work in the field (Gibson et al., 2014; Taylor et al., 2011). Following institutional ethics approval and full description of experimental procedures, all participants completed medical questionnaires and provided written informed consent following the principles outlined by the declaration of Helsinki of 1975, as revised in 2013. The experimental design for the study is presented in Fig. 1 with full explanation of the heat acclimation methods contained within the "Heat Acclimation Methods" Section 2.4 which follows.

2.2. Preliminary testing

Participants consumed 500 mL of water 2 h before all preliminary and experimental exercise sessions (Sawka et al., 2007). A urine osmometer (Alago Vitech Scientific, Pocket PAL-OSMO, UK) was used to ensure consistent hydration prior to each experimental session (Garrett et al., 2014). Participants were deemed euhydrated and subsequently able to commence further preliminary, and experimental procedures if urine osmolality was < 700 mOsm kg^{-1} H_2O (Sawka et al., 2007). Prior to the initial $\dot{V}_{O_{2peak}}$ experimental trial, height (cm) using a fixed stadiometer (Detecto Physicians Scales; Cranlea & Co., Birmingham, UK), and body density, using calipers (Harpenden, Burgess Hill, UK) and a four site skin fold calculation (Durnin and Womersley, 1974) were determined, later body fat (%) was calculated from body density (Siri, 1956) and body surface area (Du Bois and Du Bois, 1916). Nude body mass (NBM) was recorded to 0.01 kg from digital scales (ADAM GFK 150, USA), relative metabolic heat production (MHP;