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The reliability of a heat acclimation state test prescribed from metabolic heat production intensities

A.G.B. Willmott [a,b,*], M. Hayes [a,b], J. Dekerle [a,b], N.S. Maxwell [a,b]

[a] Centre of Sport and Exercise Science and Medicine (SESAME), Environmental Extremes Laboratory, University of Brighton, Welkin House, Denton Road, Eastbourne BN20 7SN, UK
[b] School of Sport and Service Management, University of Brighton, Welkin House, Denton Road, Eastbourne BN20 7SN, UK

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ABSTRACT

Acclimation state indicates an individual's phenotypic response to a thermally stressful environment, where changes in heat dissipation capacity are determined during a heat acclimation state test (HAST). Variations in thermoregulatory and sudomotor function are reported while exercising at intensities relative to maximal oxygen uptake. This inter-individual variation is not true when intensity is prescribed to elicit a fixed rate of metabolic heat production ($\dot{H}_{prod}$). This study investigated the reliability of peak T_{re} and two composite measures (sweat gain and sweat setpoint) derived from indices of thermosensitivity during a HAST prescribed from $\dot{H}_{prod}$ intensities.

Fourteen participants (mean ± SD; age 23 ± 3 years, stature 174 ± 7 cm, body mass 75.0 ± 9.4 kg, body surface area 1.9 ± 0.1 m^2, peak oxygen consumption [$\dot{V}O_{2peak}$] 3.49 ± 0.53 L min^{-1}) completed a lactate threshold-$\dot{V}O_{2peak}$ test and two duplicate $\dot{H}_{prod}$ HASTs on a cycle ergometer. The HAST consisted of three, 30-min periods of exercise at fixed $\dot{H}_{prod}$ intensities relative to body mass (3, 4.5 and 6 W kg^{-1}), within hot dry conditions (44.7 ± 1.8 °C and 18.1 ± 4.7% relative humidity).

Peak T_{re} (38.20 ± 0.36 *vs.* 38.16 ± 0.42 °C, p=0.54), sweat setpoint (36.76 ± 0.34 and 36.79 ± 0.38 °C, p=0.68) and sweat gain (0.37 ± 0.14 and 0.40 ± 0.18 g s^{-1} °C^{-1}, p=0.40) did not differ between HASTs. Typical error of measurement (TEM), coefficient variation (CV) and intra-class coefficient of correlation (ICC) were 0.19 °C, 0.5% and 0.80 for peak T_{re}, 0.21 °C, 0.6% and 0.65 for sweat setpoint and 0.09 g s^{-1} °C^{-1}, 28% and 0.68 for sweat gain, respectively.

The use of fixed $\dot{H}_{prod}$ intensities relative to body mass is a reliable method for measuring T_{re} and ascertaining sweat setpoint during a HAST, whereas, sweat gain displays greater variability. A $\dot{H}_{prod}$ HAST appears sufficiently reliable for quantifying heat acclimation state, where TEM in peak T_{re} and sweat setpoint are small enough to identify physiologically meaningful improvements post-intervention.

1. Introduction

An individual's primary phenotypic response to a thermally stressful environment is indicated by acclimation state (Havenith and van Middendorp, 1990). Acclimation state changes are determined during an incremental, sub-maximal heat acclimation state test (HAST). HASTs are predominantly used to pre-screen individuals to determine changes in heat dissipation capacity under fixed heat stress and evaluate the effectiveness of heat alleviating strategies, such as heat acclimation protocols. Previously, HASTs (Havenith and van Middendorp, 1986, 1990), have identified two composite measures of sweat setpoint and sweat gain, derived from indices of thermosensitivity including, sudomotor (sweat rate [$\dot{m}_{sw}$]) function and thermoregulatory (rectal temperature [T_{re}]) responses to exercise. Fig. 1 demonstrates the linear $\dot{m}_{sw} - T_{re}$ relationship for slope to provide a measure of sweat gain (an assessment of sudomotor sensitivity), and the x-intercept represents the point of sweating above baseline, known as the sweat setpoint (Havenith and van Middendorp, 1990). When comparing between-individuals, a greater magnitude in sweat gain and a lower sweat setpoint may permit effective regulation in body temperature within thermally challenging environments. Superior

Abbreviations: BSA, Body surface area; ΔT_{re}, Change in rectal temperature; CV, Coefficient variation; HR, Heart rate; HAST, Heat acclimation state tests; ICC, Intra-class correlation coefficient; LOA, Limits of agreement; $\dot{V}O_{2max}$, Maximal oxygen uptake; $\dot{H}_{prod}$, Metabolic heat production; NBM, Nude body mass; $\dot{V}O_{2peak}$, Peak oxygen consumption; RPE$_{peak}$, Peak ratings of perceived exertion; TSS$_{peak}$, Peak thermal sensation; RPE, Ratings of perceived exertion; T_{re}, Rectal temperature; RH, Relative humidity; RER, Respiratory exchange ratios; SD, Standard deviation; SE, Standard error; $\dot{m}_{sw}$, Sweat rate; TSS, Thermal sensation; TEM, Typical error of measurement; U_{osm}, Urine osmolality; U_{sg}, Urine specific gravity

* Corresponding author at: School of Sport and Service Management, University of Brighton, Welkin House, Denton Road, Eastbourne BN20 7SN, UK.
E-mail address: A.Willmott@brighton.ac.uk (A.G.B. Willmott).

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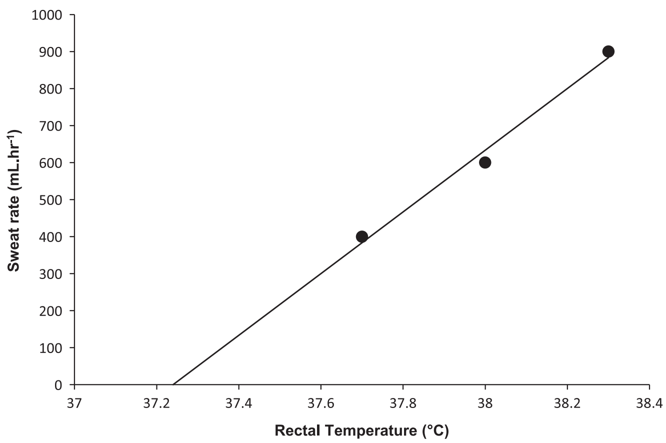

Fig. 1. An individual participant's rectal temperature and sweat rate responses during each 30 min block of exercise (represented by black circles) within a heat acclimation state test (HAST) to determine sweat gain (slope) and sweat setpoint (*x*-intercept).

sweat gains and reductions in sweat setpoint after an intervention may indicate a greater change in heat acclimation state, demonstrating improved adaptive responses in thermoregulation and sudomotor function at rest and during exercise under thermal stress. Therefore, the improved body temperature regulation would reduce physiological strain and improve aerobic performance (Sawka et al., 2011).

Individuals with larger aerobic capacities are thought to be partially heat acclimated by exhibiting lower resting and exercising heart rate and core temperatures, and superior sudomotor capacities within hot-dry conditions (Havenith and van Middendorp, 1986; Pandolf, 1998). However, these trained individuals exercise at greater intensity compared to untrained individuals, when exercising at similar percentages of maximal oxygen uptake (% $\dot{V}O_{2max}$), thus generating greater metabolic heat due to larger absolute oxygen uptake (Gagnon et al., 2008; Mora-Rodriguez et al., 2010). Consequently, Jay et al. (2011) demonstrated how large variations in $\dot{V}O_{2peak}$ between-groups matched for body mass and body surface area (BSA) may induce greater changes in T_{re} (ΔT_{re}) during relative intensity exercise. Conversely, improving exercise intensity prescriptions between-independent groups by using fixed rates of metabolic heat production ($\dot{H}_{prod}$) provided similar thermoregulatory responses between trained and untrained individuals (Jay et al., 2011). Previous HASTs have prescribed exercise intensities relative to $\dot{V}O_{2max}$, therefore, researchers might have observed greater T_{re} in individuals with a larger aerobic capacity (Jay et al., 2011), indicating a lower acclimation state, yet superior sweat gains, indicative of high acclimation state. Consequently, prescribing intensity of exercise using $\dot{H}_{prod}$ per unit mass (W kg^{-1}) may reduce systematic bias in ΔT_{re} between-independent groups of varying biophysical characteristics or fitness levels (Jay et al., 2011; Cramer and Jay, 2014). Thus, previous studies may be confounded by methodological limitations, including exercising at different $\dot{H}_{prod}$ as well as failure to control for body mass and BSA, which in turn generated type 1 errors. If previous HASTs were performed between-independent groups, pre to post-intervention (*i.e.* heat acclimation), where alterations in body mass or training status may occur, the changes within T_{re} and local sweat rates may have been misinterpreted and at risk of being considered practically meaningful, instead of being attributed to the intervention itself and not a difference in exercise intensity.

A new HAST must prescribe $\dot{H}_{prod}$ intensities, which elicit reliable changes in core temperature and thermosensitivity, while minimising measurement error within biological variations and instrument noise (Atkinson and Nevill, 1998). A reliable test would also promote greater confidence in thermosensitive adaptations within- and between-groups, after acute and chronic heat acclimation protocols. Previous studies report coefficient variation (CV%) for sudomotor (11% local; Hayden et al., 2004 and 4.7% whole-body sweat rates; Brokenshire et al., 2009), T_{re} (0.3%; Hayden, et al. 2004, 0.6%; Brokenshire et al., 2009 and 0.34%; Mee et al., 2015), and heart rate (3.9%; Hayden, et al. 2004, 3%; Brokenshire et al., 2009 and 1%; Mee et al., 2015) variables during running and cycling heat stress tests, respectively. However, it is difficult to make comparisons between studies of different magnitudes of heat stress, duration, mode and intensity of exercise.

While acknowledging the pioneering work of Havenith and van Middendorp (1986, 1990), recent methodologies by Jay et al. (2011) and Cramer and Jay (2014), have included the prescription of $\dot{H}_{prod}$ (W kg^{-1}) exercise intensities. This may enable accurate and reliable measures of core temperature and thermosensitivity between individuals to determine heat acclimation state, evaluate pre to post-intervention efficacy between-independent groups and further support the proposal that $\dot{H}_{prod}$ may be an optimal method to prescribe heat acclimation (Gibson et al., 2015). However, the reliability of T_{re}, sweat gain and sweat setpoint is unknown while exercising at variable $\dot{H}_{prod}$ exercise intensities within a HAST, but is required for confident interpretations to be made regarding heat acclimation state. The aim of this study was to examine the reliability of a new HAST which prescribes $\dot{H}_{prod}$ intensities relative to body mass. It was hypothesised there would be agreement and no significant difference in (1) the T_{re} or composite measures of sweat gain and sweat setpoint, and (2) physiological and perceptual measures between both $\dot{H}_{prod}$ HASTs.

2. Methods

2.1. Participants

Fourteen active, moderately trained ($\dot{V}O_{2peak} > 45$ ml kg^{-1} min^{-1}) male participants (mean ± standard deviation [SD]; age 23 ± 3 years, stature 174 ± 7 cm, nude body mass [NBM] 75.0 ± 9.4 kg, BSA 1.9 ± 0.1 m^2 and peak oxygen consumption [$\dot{V}O_{2peak}$] 3.49 ± 0.53 L min^{-1}) volunteered and provided written informed consent for the study. The study was approved by the Institution Research Ethics and Governance Committee and conducted in accordance with the Declaration of Helsinki of 1975, as revised in 2008. Participants had not been exposed to hot conditions (> 25 °C) in the 3 months prior to the investigation. Participants abstained from caffeine, alcohol and prolonged strenuous activity for 24 h prior to testing. They also refrained from food 2 h before exercise and arrived in a euhydrated state indicated by a urine osmolality < 700 mOsm kg^{-1} and specific gravity < 1.020 (Sawka et al., 2007).

2.2. Experimental design

After completing an incremental cycling lactate threshold (LT) to $\dot{V}O_{2peak}$ test, participants completed two $\dot{H}_{prod}$ HASTs, separated by 48 h.

2.3. Measurements and equipment

All tests were completed on a cycle ergometer (Monark 620 Ergomedic, Varberg, Sweden). During each visit, participants produced fresh, mid-flow urine samples to determine hydration indices of urine osmolality (U_{osm}) and specific gravity (U_{sg}), assessed using a Pocket Pal-Osmo (Vitech Scientific, Ltd.) and hand-held refractometer (Atago Co., Tokyo, Japan), respectively. Stature and