The effect of heat acclimation on thermal strain during Explosives Ordnance Disposal (EOD) related activity in moderate and hot conditions.

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INTRODUCTION

Uncompensable heat stress (UHS) occurs when the rate of evaporation required from the body’s surface to maintain thermal equilibrium exceeds the evaporative capacity of the environment (Cheung et al., 2000). The resultant thermal strain is associated with reduced physical and cognitive performance and comfort as well as deterioration of job specific tasks (Taylor and Orlansky, 1993). UHS can occur when wearing a range of protective equipment and is determined by, amongst other factors, body surface coverage, characteristics of the garment (thermal insulation and evaporative resistance), metabolic rate and ambient conditions (Hanson, 1999). The rate of onset of thermal strain can be reduced by increasing the capacity for heat storage (e.g. pre-cooling; Marino, 2002 and increasing fitness; Selkirk and McLellan, 2001) or by reducing the rate of heat storage (e.g. cooling systems; Thake and Price, 2007 and altering work to rest ratios; McLellan et al., 1993). Heat acclimation is a further method commonly used to reduce thermal strain and its use has been investigated in various modes of personal protective equipment (PPE; for review see Cheung et al., 2000). However the modes PPE that have been examined weigh substantially less than an explosives ordnance disposal (EOD) suit and usually fully encapsulate the wearer, unlike the partial coverage of the EOD suit. Furthermore the effect of acclimation is usually only investigated at hot ambient temperatures. Therefore the aim of this study was to evaluate the impact of acclimation on physiological and perceptual strain during activities representative of EOD operations, with and without wearing an EOD suit, in moderate (20°) compared to hot (40°C) conditions.

METHODS

With local ethical committee approval six non heat acclimated participants (5 male and 1 female; age 22±3 yrs; body mass 79.5±12.1 kg; stature 176.2±5.3 cm) were recruited. Four experimental visits took place prior to 6 acclimation sessions (PRE) and were repeated thereafter (POST) to enable a pre to post acclimation comparison to be made between each condition. Acclimation consisted of six one hour treadmill walks (4 km-h⁻¹ whilst wearing a 37 kg large EOD suit (Ergotec 4010, NP Aerospace, UK) with the duel integral fans turned off in 22±1°C; 47±5% relative humidity (RH). These six sessions were completed over 9 days in a 2 day on 1 day off pattern. Pre and post acclimation trials were conducted over an eight day period and consisted of temperate (20°C) and hot (40°C) conditions whilst wearing the same EOD suit with the fan system turned on (delivering ≈200 and 100 L-min⁻¹ of ambient air to the wearers back and head
respectively) and, on a separate occasion, when only wearing a cotton trousers and T-shirt (No suit condition; NoS). To reduce the risk of participant fatigue the trial order was fixed for clothing ensemble with participants conducting NoS trials on the first and third visits and EOD trials on the second and fourth visits. Ambient temperature was applied using a cross-over type design.

Within each experimental trial participants undertook a modified 66 min activity sequence, composed of 4 × 16 min 30 sec cycles, representative of EOD operations (Thake and Price, 2007) within a 3 m × 5 m enclosed area. In brief each cycle consisted of 3 min treadmill walking (4 km·hr⁻¹); 2 min manual activity (moving 1.25 kg weights between two shelves 27 cm and 64 cm above the floor whilst kneeling); 2 min crawling and searching activity (forward and back along a 2.40 m ladder with 11 equally spaced rungs interspersed with ‘searching’ by moving the head twice left and right at each end of the ladder); 3 min unloaded arm ergometry (60 rev·min⁻¹); 5 min seated rest. Manual activity and crawling and searching activity work rates were controlled by asking participants to move on the beat of a metronome (30 beat·min⁻¹; Seiko DM-20, Japan). Each physical activity was separated by a 30 sec transfer period.

Heart rate (HR; Polar Vantage, Finland), rectal temperature (Tᵣ), mean skin temperature (Tₖ; Grant Instruments, Cambridge, UK) and respiratory gas analysis (Cosmed K4b², HaB Direct, UK) were monitored continuously and recorded in the last 30 sec of each component of the activity cycle. Sweat rate was estimated from pre to post trial changes in nude body mass on each visit. Heat storage was calculated according to Havenith et al., (1995). Physiological strain index (PhSI) was calculated from normalised increases in HR and Tᵣ that are described, with equal weighting, on a 0 (no strain) to 10 very high strain) scale (Tikuisis et al., 2002). Rating of perceived exertion (RPE; 6-20 scale), thermal sensation (TS) and thermal comfort (TC; 9 point 0-8 scale) were sought during the arm ergometry stage of the protocol. A perceptual based strain index (PeSI) was calculated from normalised increases in RPE and TS that are described, with equal weighting, on a 0 (no strain) to 10 very high strain) scale (Tikuisis et al., 2002).

Data were analysed using a general linear model analysis of variance (ANOVA) that incorporated main effects for condition (20°C NoS; 20°C EOD; 40°C NoS; 40°C EOD), acclimation (pre to post), time and condition × acclimation interaction. Where appropriate significant main effects were investigated using Tukey post hoc tests.

RESULTS

Acclimation increased tolerance time from 53:48±11.59 to 60:10±09:34 (min:sec) in 40°C EOD trials (two participants completed four activity cycles in PRE trials in comparison to four doing so in POST trials). Whereas both PRE and POST 20°C EOD, 20°C and 40°C NoS trials where completed by all six participants.

EOD trials

Acclimation (change from PRE to POST measurements) reduced Tᵣ, heat storage, HR, oxygen consumption (˙Vō₂), PhSI, RPE, TS and PeSI and improved TC when the EOD suit was worn, with the magnitude of change being greater in the 20°C compared to the 40°C EOD trials (see Table 1 for changes and levels of significance). Tₖ was only reduced in the 20°C EOD (36.6±0.5
to 36.1±0.1°C vs. 37.9±0.6 to 38.1±0.5°C in 40°C EOD). Sweat rate did not change PRE to POST acclimation in either EOD condition (20°C EOD 0.7±0.3 to 0.6±0.2 L·hr⁻¹ vs. 40°C EOD 1.0±0.3 to 1.2±0.5 L·hr⁻¹). Reductions in absolute values for Tₑ and HR across the 20°C (Tₑ 37.9±0.4 to 37.5±0.2°C; HR 120±16 to 92±15 bt·min⁻¹ at cycle 4) compared to 40°C (Tₑ 38.5±0.3 to 38.2±0.3°C; HR 151±16 to 141±15 bt·min⁻¹ at cycle 4) EOD trials are reflected by the difference in the PhSI between conditions PRE to POST acclimation (Figure 1). In 20°C EOD PhSI remains relatively constant POST compared to a steady rate of increase over the four activity cycles in PRE, indicating that acclimation may have shifted participants from experiencing UHS to being able to maintain thermal balance, a situation of compensable heat stress. PhSI was reduced POST compared to PRE acclimation in the 40°C EOD trial, however PhSI did continue to rise after acclimation indicating a situation of UHS, albeit lower than at an equivalent stage of the protocol PRE acclimation.

Table 1: PRE to POST acclimation changes in selected variables (±SD) during arm ergometry (except Tₑ and Tₖₜ and heat storage taken at rest) in the fourth activity cycle within each condition. n=6 except n=2 for 40 EOD (participants completing both Pre and Post trials). Arrows indicate reduction ↓, increase ↑ and no change ↔. Main effect for condition *P<0.001; PRE to POST acclimation within each condition #P<0.05, δP<0.01, φP<0.001.

<table>
<thead>
<tr>
<th>Variable</th>
<th>20 No Suit</th>
<th>20 EOD</th>
<th>40 No Suit</th>
<th>40 EOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectal Temp. (°C)*</td>
<td>↓0.26±0.23</td>
<td>↓0.59±0.41</td>
<td>↔0.01±0.22</td>
<td>↓0.08±0.14</td>
</tr>
<tr>
<td>Mean Skin Temp. (°C)*</td>
<td>↓0.61±0.8</td>
<td>↓0.42±0.45</td>
<td>(0.01±0.12)</td>
<td>(0.22±0.00)</td>
</tr>
<tr>
<td>Heat Storage (J·g⁻¹)*</td>
<td>(0.06±0.91)</td>
<td>↓1.20±0.96</td>
<td>↓0.27±1.29</td>
<td>↓0.33±0.19</td>
</tr>
<tr>
<td>HR (bt·min⁻¹)*</td>
<td>↓12±7</td>
<td>↓29±33</td>
<td>↓9±10</td>
<td>↓6±2</td>
</tr>
<tr>
<td>̇VO₂ (L·min⁻¹)*</td>
<td>↓0.08±0.1</td>
<td>↓0.29±0.63</td>
<td>↓0.26±0.22</td>
<td>↓0.06±0.60</td>
</tr>
<tr>
<td>PhSI*</td>
<td>↓0.6±0.6</td>
<td>↓2.9±0.4</td>
<td>(0.0±0.5)</td>
<td>↓1.3±1.2</td>
</tr>
<tr>
<td>RPE Overall*</td>
<td>↓1.3±2.2</td>
<td>↓3.5±2.4</td>
<td>(1.5±3.6)</td>
<td>↓3.5±2.1</td>
</tr>
<tr>
<td>Thermal Sensation*</td>
<td>↓0.7±0.8</td>
<td>↓2.0±0.9</td>
<td>↓0.7±0.8</td>
<td>↓1.0±0.0</td>
</tr>
<tr>
<td>Thermal Comfort*</td>
<td>↑0.7±0.8</td>
<td>↑2.1±1.0</td>
<td>↑1.0±1.3</td>
<td>↑1.0±0.0</td>
</tr>
<tr>
<td>PeSI*</td>
<td>↓0.9±1.1</td>
<td>↓2.6±1.2</td>
<td>↓1.0±1.8</td>
<td>↓1.9±0.8</td>
</tr>
</tbody>
</table>

The benefit of acclimation was more evident after 33 min (2 activity cycles) were the PRE compared to POST acclimation PhSI responses diverge in both 20°C and 40°C EOD conditions (Figure 1). Concurrently PeSI was reduced POST acclimation in both 20°C and 40°C EOD trials due to the reduction in RPE and TS. The largest PRE and POST acclimation difference in PeSI was evident in the final activity cycle of the 20°C EOD trial. PeSI values were in excess of PhSI values both PRE and POST acclimation.
Figure 1: PhSI (during last 30 sec of each activity) and PeSI (during arm ergometry) PRE and POST acclimation (±SD) in 20°C and 40°C whilst wearing an EOD suit. PRE to POST difference $P \leq 0.001$.

No suit trials

Acclimation also reduced HR, $\dot{V}O_2$, RPE, TS and PeSI and improved TC in 20°C and 40°C NoS trials (see Table 1 for changes and levels of significance). In addition $T_c$, $T_{sk}$ and PhSI were lower POST acclimation at 20°C but not at 40°C. However a small reduction in PeSI was evident at 40°C post acclimation and could be related to the reduction in heat storage also observed in this condition. No difference in sweat rate was observed PRE to POST acclimation.

To summarise, acclimation resulted in reductions of physiological and/or perceptual strain indexes across all trials. Although benefits were evident whilst wearing the EOD suit in 40°C the largest improvement in both physiological and perceptual strain was evident when wearing the EOD suit in 20°C.

CONCLUSIONS

Six one hour treadmill walks (4 km·hr$^{-1}$) conducted at room temperature ($\approx$20°C, 45% RH) when wearing the EOD suit with the integral fans turned off induced positive physiological and perceptual adaptations evident when conducting EOD related activities whilst wearing the suit
with the integral fan system turned on in both temperate (20°C) and hot (40°C) conditions. In accord the PhSI and PeSI were able to differentiate between EOD related activity conducted at 20°C and 40°C, as well as detect PRE compared to POST acclimation differences under the same conditions. PeSI values tended to be higher than PhSI in the same condition and may be partly explained by the achievable core temperature prior to fatigue being less than 39.5°C, as used in the PhSI formulae, in this non endurance trained population (Selkirk and McLellan, 2001). The improvement in both physiological and perceptual responses was not as pronounced in 40°C compared to 20°C in the EOD suit. A key factor being that the ambient air temperature, that being vented through the EOD suit via the fan system, was in excess of skin temperature in the hotter condition, therefore contributing to heat storage and a situation of UHS. Whereas the known physiological adaptations due to acclimation (Cheung et al., 2000) were able to improve thermal balance in the cooler (20°C) ambient condition whilst wearing the EOD suit with the fan system turned on, giving rise to a post acclimation compensable heat stress situation. It is however likely that habituation to working in the EOD suit also impacted on movement economy, as partly evidenced by reduced POST acclimation $\dot{V}O_2$. Thus habituation to wearing an EOD suit is a confounding variable in evaluating the effect of acclimation per se in improving thermal tolerance in this hitherto naive participant group. These data indicate that acclimation may yet prove to be a useful countermeasure against thermoregulatory strain in some UHS situations, particularly when ambient temperature is lower than skin surface temperature.

REFERENCES


