Journal of Thermal Biology 46 (2014) 65–71

Contents lists available at ScienceDirect

Journal of Thermal Biology

journal homepage: www.elsevier.com/locate/jtherbio

Firefighter feedback during active cooling: A useful tool for heat stress management?

Robbie J. Savage [a,*], Cara Lord [b], Brianna L. Larsen [b], Teagan L. Knight [c], Peter D. Langridge [c], Brad Aisbett [b]

[a] Human Performance Science, 1/109 Park St, South Yarra, 3141 Victoria, Australia
[b] Centre for Physical Activity & Nutrition Research, Deakin University, 221 Burwood Highway, Burwood, Victoria 3125, Australia
[c] Country Fire Authority, 8 Lakeside Dr, Burwood East, 3151 Victoria, Australia

ARTICLE INFO

Article history:
Received 21 August 2014
Received in revised form
10 October 2014
Accepted 10 October 2014
Available online 22 October 2014

Keywords:
Core temperature
Thermal sensation
Heat stress management
Firefighting

ABSTRACT

Monitoring an individual's thermic state in the workplace requires reliable feedback of their core temperature. However, core temperature measurement technology is expensive, invasive and often impractical in operational environments, warranting investigation of surrogate measures which could be used to predict core temperature. This study examines an alternative measure of an individual's thermic state, thermal sensation, which presents a more manageable and practical solution for Australian firefighters operating on the fireground. Across three environmental conditions (cold, warm, hot & humid), 49 Australian volunteer firefighters performed a 20-min fire suppression activity, immediately followed by 20 min of active cooling using hand and forearm immersion techniques. Core temperature (T_c) and thermal sensation (TS) were measured across the rehabilitation period at five minute intervals. Despite the decline in T_c and TS throughout the rehabilitation period, there was little similarity in the magnitude or rate of decline between each measure in any of the ambient conditions. Moderate to strong correlations existed between T_c and TS in the cool (0.41, $p<0.05$) and hot & humid (0.57, $p<0.05$) conditions, however this was resultant in strong correlation during the earlier stages of rehabilitation (first five minutes), which were not evident in the latter stages. Linear regression revealed TS to be a poor predictor of T_c in all conditions (SEE = 0.45–0.54 °C) with a strong trend for TS to over-predict T_c (77–80% of the time). There is minimal evidence to suggest that ratings of thermal sensation, which represent a psychophysical assessment of an individual's thermal comfort, are an accurate reflection of the response of an individual's core temperature. Ratings of thermal sensation can be highly variable amongst individuals, likely moderated by local skin temperature. In account of these findings, fire managers require a more reliable source of information to guide decisions of heat stress management.

1. Introduction

Physically demanding suppression activities and extreme thermal environments can place Australian firefighters at a high risk of heat stress (Aisbett and Nichols, 2007; Walker, 2014). Active cooling on the fireground reduces the time taken for hyperthermic firefighters to return to levels of normothermia (Giesbrecht et al., 2007). In recent years research has supported the use of hand and forearm immersion (HFI) techniques as an effective cooling strategy following strenuous physical activity in firefighting and other field environments (Barr et al., 2009; Giesbrecht et al., 2007; Khomenok et al., 2008; Selkirk et al., 2004; De Groot et al., 2013). With any water immersion strategy, heat dissipates from the warm blood via convection and conduction, through peripheral vasodilation of blood vessels (Chen et al., 2011; Giesbrecht et al., 2007). The hand region is particularly efficient in these mechanisms as it contains a greater proportion of arteriovenous anastomoses relative to the rest of the body, encouraging greater local vasodilation and thus heat dissipation (Wang et al., 2007). Adding the forearms to water augments this effect by increasing total skin surface area exposure (Giesbrecht et al., 2007).

Although physical signs and symptoms coincide with hyperthermia, the accurate assessment of this condition requires evaluation of core temperature measurements (Rav-Acha et al.,

* Corresponding author.
E-mail addresses: robbie@hpscience.com.au (R.J. Savage), clor@deakin.edu.au (C. Lord), bllars@deakin.edu.au (B.L. Larsen), t.knight@cfa.vic.gov.au (T.L. Knight), p.langridge@cfa.vic.gov.au (P.D. Langridge), brad.aisbett@deakin.edu.au (B. Aisbett).

http://dx.doi.org/10.1016/j.jtherbio.2014.10.003
0306-4565/

2003). Elevation of core temperature causes dysfunction of the central nervous system and cellular destruction (Glazer, 2005), leading to the signs and symptoms presented during heat illness. Although core temperature varies with anatomical location (oesophagus, stomach, and rectum) (Byrne and Lim, 2007), it represents the most accurate gauge of homoeostasis and remains the criterion measurement for normothermia and hyperthermia. Normothermic individuals typically display core temperatures between 36.5 and 37.2 °C, with the onset of hyperthermia observed at core temperatures exceeding 37.5 °C (Taylor et al., 2008). For intermittent firefighting duties in which strenuous work is interspersed with periods of rest (Horn et al., 2013), core temperature can provide accurate feedback on the thermal state of firefighters, guiding decisions on the safe return to tasks following rest. However, core temperature monitoring technology (core sensor pills/rectal thermometers) is costly, requires additional equipment and is often not feasible for use in operational environments (remote locations, extreme temperatures, unpredictable work demands).

An alternative assessment of an individual's thermal condition may be offered via subjective feedback, where levels of thermal strain are indicated on a numerical scale. Ratings of self-perception have been proven as a useful and reliable feedback mechanism in occupational settings (Capodaglio, 2002; Young et al., 1987) through the use of perceptual cues to estimate the intensity of physical strain (Borg, 1978). Thermal sensation, which reflects the response of the body's thermoreceptors to a thermal stimulus (Zhang, 2003), is often used as a measure of perceived strain and tolerance in working or rehabilitative settings (Carter et al., 2007; Chou et al., 2008; Mundel et al., 2006; Selkirk et al., 2004). Thermal sensation is responsible for the initiation of behavioural thermoregulation, and has been found to respond via equal contribution of fluctuations in core temperature and skin temperature (Frank et al., 1999). The relationship between core temperature and thermal sensation suggests subjective responses may be predictive of an individual's thermal condition.

Studies to date have assessed changes in thermal sensation in line with physiological markers, particularly skin temperature, in response to varying external thermal conditions (Arens et al., 2006a; Chen et al., 2011; Wang et al., 2007; Yao et al., 2008). Empirically, the relationship between thermal sensation and skin temperature was tested by Chen et al. (2011), who illustrated the large correspondence between the measures when participants underwent air-conditioned heating or cool ($r=0.49$, $p<0.01$). However, despite the interplay between skin temperature and thermal sensation, skin temperature cannot be used as a surrogate measure of core temperature. Studies illustrating changes in skin and core temperature highlight the disparity between the respective measures, when tracked over time both during and post-work recovery (Frank et al., 1999; Giesbrecht et al., 2007; González-Alonso et al., 1999; Huizenga et al., 2004). There is also a large variance in temperature measurements between skin sites across the body (González-Alonso et al., 1999; Huizenga et al., 2004). Consequently the strong correspondence between thermal sensation and skin temperature bears little relevance to any equivalent correspondence between thermal sensation and core temperature. Since core temperature remains the benchmark measurement for the onset of hyperthermia, proxy measures need direct comparison with core temperature for assessment of their suitability.

To the author's knowledge, research has yet to identify whether thermal sensation provides an accurate representation of the behaviour of core temperature during active cooling. If this feedback from firefighters is reliable, it could mitigate the need for less practical measures of core temperature, to make informed decisions in the context of heat stress management. This study investigated the relationship between thermal sensation and core temperature measurements during active cooling using HFI across a range of ambient conditions common to Australian firefighters, to comment on the utility of subjective feedback by firefighters on the fireground.

2. Methods

2.1. Subjects and environmental conditions

This study was conducted during three separate trials in differing Australian climates; cool, warm, hot & humid. Such conditions represent the diversity of climates in which Australian firefighter operate (Sullivan et al., 2012). The external environment is an important consideration in the context of testing as ambient conditions have been shown to influence both the self-perception of temperature (Strigo et al., 2000) and the effectiveness of HFI (Carter et al., 2007). The descriptive characteristics of each condition are presented in Table 1. Ambient temperature and humidity were measured using a portable measurement device (Kestrel 3500 (Michigan, USA) for cold and warm conditions, Braun weather station (London, England) for hot & humid conditions).

In total, 49 subjects participated in this study, with a separate cohort of subjects tested in each condition. In the cool and warm conditions, subjects represented Australian volunteer firefighters whereas in the hot & humid condition, subjects were full time Australian salaried firefighters. All subjects signed written and informed consent using ethical approval from Deakin University.

2.2. Experimental design

To compare objective and subjective thermal responses, participants performed a series of simulated firefighting activities followed by a period of active cooling. Across all environmental conditions, subjects first conducted a 20-min firefighting simulation followed by 20 min of active cooling. The firefighting simulation comprised a series of suppression tasks, dummy drags, advancing a charged hose and stair climbing, performed continuously at a self-selected pace. These simulations were operationally relevant, were incorporated in training exercises and supervised by experienced personnel. All simulations were performed in full structural personal protective clothing (PPC) and self-contained breathing apparatus (SCBA) (total external mass=20–27 kg, dependent upon uniform brand, cylinder type and cylinder volume).

Immediately following task simulations, subjects proceeded to a rehabilitation area where they removed their PPC and excess SCBA and sat in a chair whilst submerging their hands and forearms in water. The immersion occurred in two containers of water (volume=20 L) built into the arms of custom designed deck chairs.

Table 1
Subject characteristics (mean ± SD) and climate for three testing conditions.

	Cool	Warm	Hot & humid
Temperature (°C)[a]	10–12	21.5–22	33.3–36.9
Humidity (%)[a]	60–63	42–46	33–61
Participant numbers	17 (males)	19 (males)	12 (10 males, 2 females)
Mass (kg)	85.7 ± 19.41	91.6 ± 15.2	83.4 ± 7.64
Height (m)	1.79 ± 0.07	1.78 ± 0.07	1.78 ± 0.04
Age (yr)	27.3 ± 11.12	49.9 ± 10.6[†]	30.7 ± 10.1
BMI	26.3 ± 5.19	29.0 ± 4.76	26.4+2.36

[a] Environmental conditions for rehabilitation area.
[†] Significantly different from other conditions.