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Practical pre-cooling methods for occupational heat exposure

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ABSTRACT

This study aimed to identify a pre-cooling method to reduce the physiological and perceptual strain, and the inflammatory response, experienced by individuals who wear personal protective equipment. Eleven males (age 20 ± 2 years, weight 75.8 ± 9.3 kg, height 177.1 ± 5.0 cm) completed 15min pre-cooling (phase change vest [PCV], forearm cooling [ARM], ice slurry consumption [ICE], or a no cooling control [CON]) and 45min intermittent walk (4 km h^{-1}, 1% gradient) in 49.5 ± 0.6 °C and 15.4 ± 1.0% RH, whilst wearing firefighter ensemble. ICE reduced rectal temperature (T_{re}) before heat exposure compared to CON (ΔT_{re}: 0.24 ± 0.09 °C, $p < 0.001$, $d = 0.38$) and during exercise compared to CON, ARM, and PCV ($p = 0.026$, $\eta_p^2 = 0.145$). Thermal sensation was reduced in ICE and ARM vs. CON ($p = 0.018$, $\eta_p^2 = 0.150$). Interleukin-6 was not affected by pre-cooling ($p = 0.648$, $\eta_p^2 = 0.032$). It is recommended that those wearing protective equipment consume 500 ml of ice slurry 15min prior to work to reduce physiological and perceptual strain.

1. Introduction

An occupational risk of heat strain exists for numerous job roles, such as firefighting, explosive ordnance disposal, and policing. Heat strain can lead to heat related illnesses, such as heat exhaustion and heat stroke (Barwood et al., 2009; Lipman et al., 2013). The acute symptoms of these illnesses, such as dizziness, syncope, and an altered mental state, are dangerous within an emergency response situation (Binkley et al., 2002). Heat strain can also lead to reductions in productivity, as seen with reduced work times recorded with increased heat strain whilst wearing firefighter equipment (Selkirk and McLellan, 2004).

Heat strain can be generated by an increase in environmental temperature and endogenous heat from physical activity, leading to increases in heart rate and core temperature as the body tries to dissipate heat (Cheung et al., 2000). The addition of personal protective equipment (PPE), which is worn by many emergency responders, exacerbates an individual's heat storage, as it impairs heat dissipation via evaporation, and therefore can cause uncompensable heat strain (Cheung et al., 2000; Stewart et al., 2011; Blacker et al., 2013). This is a consequence of PPE often being heavy and impermeable. PPE combined with physical activity and/or high environmental temperatures can therefore lead to high levels of physiological and perceptual strain (Eglin et al., 2004; Petruzzello et al., 2009; Stewart et al., 2011).

Heat exposure and exercise can also result in an inflammatory response, with inflammatory cytokines such as Interleukin-6 (IL-6) having been recorded to increase post live fire exposure (Walker et al., 2015; Watt et al., 2016). Resting IL-6 levels in healthy men range from 0.02 to 10.01 pg mL^{-1} with median values of 1.46 pg mL^{-1} (Ridker et al., 2000). However, frequent exposure to fire scenarios may result in a raised resting level of IL-6 (17.0 ± 5.7 pg mL^{-1}) (Watt et al., 2016). Elevated levels of IL-6 may lead to the development of atherosclerosis (Woods et al., 2000; Lindmark et al., 2001). Consequently, raised resting IL-6 levels increase the risk of suffering from a cardiovascular event, with resting levels of greater than 2.28 pg mL^{-1} increasing the relative risk by 2.3 times compared to levels below 1.04 pg mL^{-1} (Ridker et al., 2000). In 2014 56% of U.S. firefighter deaths were due to cardiac-related events, making it the leading cause of death amongst firefighters, although contributory factors were not considered in the study (Fahy et al., 2015). It is therefore desirable to reduce the inflammatory response that is experienced. There is currently limited information regarding the role of effective pre-cooling methods on the ability to reduce the inflammatory response.

Pre-cooling is a frequently researched and applied method used by athletes to decrease physiological and perceptual strain in hot environments (Tyler et al., 2013). Pre-cooling aims to reduce core temperature and subsequently increase the body's heat sink (Ross et al., 2013). There is currently little research into the use of pre-cooling for occupations, possibly due to the logistical difficulties of implementing the methods suggested because of facilities and time constraints (Ross et al., 2013). The assessment of practical pre-cooling methods that can be easily applied by occupations is needed. Currently, forearm cooling or phase change vests (PCV) are used by some individuals before entering a fire, leaving the PCV on throughout the exposure.

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Forearm and hand immersion pre-cooling has only previously been used in combination with other methods (iced towels, iced vest, or feet cooling) (James et al., 2015; Tokizawa et al., 2015). Hand and forearm cooling in 9–18 °C water for 20–30min, combined with these other methods, may elicit a 0.2 °C reduction in core temperature immediately after pre-cooling, which may result in a 0.3–0.4 °C reduction in change in core temperature post exercise (Minett et al., 2012; James et al., 2015; Tokizawa et al., 2015). However, the application of a mixed method is unfeasible as it immobilises individuals and requires a large freezing storage capacity. Forearm and hand cooling alone could be beneficial, as there is a large potential for heat transfer, due to the high surface area-to mass ratio, and the arteriovenous anastomoses (AVA) in the hands, together with superficial veins up to the elbow, which form a specialised heat exchange organ allowing for large variations in local blood flow (Vanggaard et al., 2012). The reduction of skin temperature noted with forearm cooling may also reduce thermal sensation from "hot" to "warm" (Minett et al., 2012; James et al., 2015). However, cold water immersion prior to heat exposure may result in vasoconstriction and reduced blood flow, consequently minimising heat transfer (Walløe, 2015). As a method currently reported to be used within the Fire Service, it is important to establish if it is beneficial.

PCV may also be an effective cooling intervention, as it acts as a thermal storage medium, absorbing energy when the phase change material's state is altered from a solid to a liquid (Reinertsen et al., 2008). The vest is lined with numerous inserts of this phase change material. PCV have been demonstrated to reduce end core temperature by ~0.2 °C, trunk temperature by 8 °C, and improve thermal sensation from "hot" to "warm" (Reinertsen et al., 2008; House et al., 2013), although there is minimal research into their use, especially in uncompensable environments.

Alternatively, ice slurries have been suggested as a practical method of reducing thermoregulatory strain in an occupational setting, due to the minimal preparation time and ease of use (Brearley, 2012). Mechanistically, the slurry creates a large heat storing capacity due to the additional energy required to melt the ice (334 kJ kg^{-1}) (Siegel et al., 2010). Slurry consumption has therefore been noted to elicit average core temperature reductions of 0.32–0.66 °C prior to exercise as well as increased time to exhaustion and decreased heart rates at the end of an exercise period (Siegel et al., 2010, 2012; Yeo et al., 2012; James et al., 2015). However, 7–7.5 g.$kgBM^{-1}$ slurry is currently recommended (Brearley, 2012; Siegel et al., 2012), making preparation complex on a large scale for multiple individuals at a time. Whether a standard single bolus, which would be more practical in an applied setting, can also effectively reduce thermoregulatory strain remains unknown.

This study therefore aimed to investigate the effect of forearm immersion, phase change vests and ice slurry consumption on the physiological and perceptual strain and inflammatory response generated whilst performing a simulated occupational heat exposure. Practicality of the pre-cooling methods has been considered, with only a 15min application time and ice slurry dosage maintained as a single bolus size for all participants, to ensure ease of use.

It was hypothesised that (1) PCV, forearm cooling (ARM) and ice slurry consumption (ICE) would result in reduced physiological and perceptual strain compared to a control trial (CON), (2) ICE would generate the greatest reductions in strain compared to CON, and (3) PCV, ARM and ICE would result in a reduced inflammatory response, recorded as an attenuated rise in IL-6, compared to CON.

2. Method

2.1. Participants

Twelve physically active, > 3 times a week, non-heat acclimated males were recruited from University of Brighton. Participants gave informed written consent and completed a medical questionnaire before beginning the study, which was approved by the University of Brighton ethics committee and conformed to the current Declaration of Helsinki guidelines (2013). One participant dropped out in the CON trial due to nausea at 33min, and consequently was removed from data analysis. The remaining 11 participants (age 20 ± 2 years, weight 75.8 ± 9.3 kg, height 177.1 ± 5.0 cm) completed all trials.

Participants were requested to avoid caffeine and exhaustive exercise 12 h before each session, and alcohol 24 h before. Participant adherence was checked with a questionnaire completed before each session.

2.2. Experimental design

Participants were required to complete four testing sessions: CON, PCV, ARM, ICE. Sessions began between 8:00am and 9:00am, to control for circadian rhythms, and were performed in a randomised order.

Upon arrival to the laboratory hydration levels were measured via a urine sample. Participants were required to be in a euhydrated state for testing to begin, as confirmed by a urine colour (U_{col}) of ≤3, osmolarity (U_{osm}) of < 700mOsm.kgH_2O^{-1} (Pocket Pal-Osmo, Vitech Scientific, Ltd), and urine specific gravity (U_{spg}) of < 1.020 (hand refractometer, Atago Co., Tokyo, Japan) (Sawka et al., 2007).

Each session then consisted of a 10min rest period and a 15min pre-cooling period in ambient temperatures (24.7 ± 1.2 °C, 38.5 ± 8.0% relative humidity (RH)) whilst wearing a wicking base layer (Odlo), trousers (Ballyclare Special Products Ltd.) and boots (9005 GA, Jolly Scarpe, USA).

During PCV cooling the vest (Dräger Comfort Vest CVP 5220, Drägerwerk AG & Co. Germany) was worn over the wicking base layer and fastened as tight as comfortably possible. The PCV contained 20 individual phase change material elements that were integrated into the lining of the vest. The product information for the vest states that the elements are designed to liquefy at a skin temperature of 27.78 °C. During the ARM trial the sleeves of the base layer were rolled up and both arms placed elbow deep in cold tap water (15.8 ± 1.1 °C). For ICE pre-cooling participants consumed 500 ml of ice slurry (-1 °C) consisting of two thirds shaved ice produced using a snow cone maker (JM Posner, Watford, Tesco Stores Ltd, Cheshunt, UK) and one third diluted drinking cordial (Robinsons Orange, 0.6 g per 100 ml carbohydrate content). During CON, PCV and ARM trials participants were given 500 ml of the same diluted cordial made with tap water (22 °C) to control for any hydration effect (Pryor et al., 2015).

After cooling, participants dressed in the remainder of the protective clothing: jacket (Ballyclare Special Products Ltd.), fire hood (MSA Gallet, Bellshill, UK), helmet (F1SF, MSA Gallet, Bellshill, UK), and gloves (Firemaster 3, Southcombe Brothers Ltd, Somerset, UK). They also donned a rucksack weighted at 9.52 kg to replicate a self-contained breathing apparatus, making the total weight of the ensemble 17 kg. Participants then completed a simulated fire exposure, involving 45min of intermittent exercise, alternating between 5min walking (4 km h^{-1} and 1% gradient) and 5min standing rest, on a treadmill (Woodway GmbH, PPS 55 Sport-1, Weil am Rhein, Germany), in 49.6 ± 0.8 °C and 15.4 ± 1.2% RH (see Fig. 1 for schematic). This protocol was selected to elicit T_{re} and HR responses similar to that experienced by Fire Service Instructors during a live house fire wear (Watt et al., 2016; Watkins and Richardson, 2017).

2.3. Physiological measures

Nude body mass was recorded before and after each testing session (Adam GFK 150 Body Scales, Connecticut, USA). A Henley single use rectal temperature probe (449H, Henleys Medical, Hertfordshire, UK) was passed 10 cm past the anal sphincter, and displayed on logging monitors (YSI, 4600 series, YSI, Hampshire, UK) to measure rectal temperature (T_{re}). Contact skin thermistors were attached to the mid-belly of the pectoralis major, biceps brachii, rectus femoris, and gastrocnemius, and recorded via a 1000 series Squirrel Data Logger (Grant