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Heat strain evaluation of overt and covert body armour in a hot and humid environment

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A B S T R A C T

The aim of this study was to elucidate the thermophysiological effects of wearing lightweight non-military overt and covert personal body armour (PBA) in a hot and humid environment. Eight healthy males walked on a treadmill for 120 min at 22% of their heart rate reserve in a climate chamber simulating 31 °C (60%RH) wearing either no armour (control), overt or covert PBA in addition to a security guard uniform, in a randomised controlled crossover design. No significant difference between conditions at the end of each trial was observed in core temperature, heart rate or skin temperature ($P > 0.05$). Covert PBA produced a significantly greater amount of body mass change ($-1.81 \pm 0.44\%$) compared to control ($-1.07 \pm 0.38\%$, $P = 0.009$) and overt conditions ($-1.27 \pm 0.44\%$, $P = 0.025$). Although a greater change in body mass was observed after the covert PBA trial; based on the physiological outcome measures recorded, the heat strain encountered while wearing lightweight, non-military overt or covert PBA was negligible compared to no PBA.

Practitioner summary: The wearing of bullet proof vests or body armour is a requirement of personnel engaged in a wide range of occupations including police, security, customs and even journalists in theatres of war. This randomised controlled crossover study is the first to examine the thermophysiological effects of wearing lightweight non-military overt and covert personal body armour (PBA) in a hot and humid environment. We conclude that the heat strain encountered while wearing both overt and covert lightweight, non-military PBA was negligible compared to no PBA.

1. Introduction

The wearing of bullet proof vests or body armour is a requirement of personnel engaged in a wide range of occupations including military, police, security, customs and even journalists in theatres of war. The primary purpose of the body armour is to protect the wearer from ballistic trauma; however an unintended consequence of wearing body armour in hot and humid environments is an increased risk of heat strain (Caldwell et al., 2011; Cheung et al., 2000; Havenith et al., 1999; Sawka et al., 2011; Taylor et al., 2008). Depending on its thickness and fit, PBA can form a barrier between the wearer's skin and the environment, impairing the amount of sweat that can be evaporated due to the impermeable nature of the material (relative to normal or work clothing) (Craig and Moffitt, 1974; Havenith, 1999). Sweat can also become trapped or absorbed into the clothing layer, further impairing and decreasing the amount of heat transfer (Craig and Moffitt, 1974). PBA can also inhibit sweat loss by establishing a microclimate that sweat has to travel across and subsequently inhibits the evaporative capacity of the human body to transfer heat to the environment (Candas and Hoeft, 1995; Nunneley, 1989; Nunneley et al., 1978).

The combination of these factors may cause an imbalance between heat production and heat dissipation (Holmér, 1995) eventually leading to increased heart rate and core temperature and consequently an increase in heat strain and perceived exertion. Increasing levels of heat stress are associated with dehydration, heat cramps, heat exhaustion, heat stroke and ultimately death if left untreated (Armstrong, 2007; Taylor et al., 2008). Prolonged heat stress coupled with exercise, even if at low intensity, can pose a challenge to the regulation of temperature and oxygen delivery to the working muscles, brain and heart (Gonzalez-Alonso, 2012) and ultimately reduce human performance. Changes in physiologic function have been reported in a military setting (Cheuvront et al., 2008; Majumdar et al., 1997) but inconsistencies exist as to whether lightweight non-military body armour can be detrimental to performance (Caldwell et al., 2011, 2012).

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Cash in transit security guards, otherwise known as armoured vehicle officers (AVOs), are one such example of personnel required to wear lightweight PBA in hot–humid environments (Stewart and Hunt, 2011). AVOs wear PBA in operational activities which can be conducted in hot conditions depending on their geographical location. Although the armour is effective in reducing the risk of mortality its influence on thermal balance needs to be considered. To date, there is a paucity of research examining the thermophysiological effects of wearing this type of non-military lightweight PBA. To our knowledge only two studies (Lehmacher et al., 2007; Stewart and Hunt, 2011) have examined the effects of wearing lightweight body armour on security guards in the field, and a controlled, laboratory based study is warranted. Therefore the current study sought to elucidate the thermophysiological effects of wearing lightweight non-military overt and covert personal body armour (PBA) in a hot and humid environment.

2. Methods

2.1. Participants

A convenience sample of eight, healthy, physically active males was recruited to participate in the experiment. Demographic data is displayed in Table 1. The study was approved by Human Research Ethics Committee of the Queensland University of Technology and participants were informed of the requirements of the study prior to signing a consent form.

2.2. Protocol and study design

The participants attended the laboratory on four separate occasions. The first session involved the collection of anthropometric data and a maximal incremental treadmill test to determine maximal aerobic capacity ($\dot{V}O_{2max}$) and heart rate (HR_{max}). The remaining three sessions involved the participants completing 120 min of treadmill walking that differed only in the PBA that was worn by the participants:

(1) Control: tactical utility pants (Frontline, Australia), short sleeve shirt with collar (Under Armour, Curtis Bay, MD, USA) and utility belt. Participants wore underwear and shoes of their own choice.
(2) Overt: as per control conditions plus the addition of overt PBA (worn over the top of the shirt) weighing 2.977 kg (Craig International Ballistics, South Port, QLD, Australia).
(3) Covert: as per control condition plus the addition of an under armour t-shirt (Under Armour, Curtis Bay, MD, USA) and covert PBA (worn beneath the shirt) weighing 2.571 kg (Point Blank Body Armour, Pompano Beach, FL, USA).

Maximal aerobic capacity was determined from an incremental exercise test, as previously described (Stewart et al., 2014). Maximal and resting heart rates (Polar Team[2], Kempele, Finland) were also recorded during this session and utilised in the determination of the trial workloads. During the remaining three trials participants walked on a treadmill (Stairmaster Club track 2100-LC, Nautilus, Louisville, USA) at a workload that elicited a heart rate, within the first 5 min of the 120 min trial, of 22% heart rate reserve. This workload averaged 4.5 (range 4–5) km h^{-1} and 1.6 (range 1–2) % grade and was selected because the previous field study conducted on armoured vehicle officers found 22% of HRR was the average work intensity from a standard 8 h shift (Stewart and Hunt, 2011). The order of testing (overt, covert, control) was randomised using a random number generator in a controlled crossover design. In addition, all trials were performed at the same time of the day and separated by a minimum of seven days. Participants were requested to abstain from alcohol, tobacco, caffeine and strenuous exercise, and consume an additional 15 ml of water per kg of body mass in the 24 h preceding each trial.

Upon arrival, for the three PBA trials, participants were asked to collect a mid-stream urine sample that was assessed for specific gravity (USG) (PAL 10s, ATAGO, Tokyo, Japan). Participants' with a USG value less than 1.020 were classified as euhydrated (Armstrong, 2005; Hunt et al., 2012) and those with higher values were provided with an additional 500 ml of water to be consumed prior to the commencement of walking. Nude body mass was measured, to the nearest 50 gm (Tanita BWB-600, Wedderburn, Australia) and corrected for fluid consumption, both pre and post-trials to determine sweat losses.

During the 120 min of walking, intestinal core temperature (CorTemp, HQ Inc., Palmetto, FL, USA) (Byrne and Lim, 2007; Hunt and Stewart, 2008), heart rate (Polar Team[2], Kempele, Finland) and mean skin temperature (eTemperature, OnSolution, Baulkham Hills, Australia), calculated from the neck, scapula, hand and shin (ISO 9886, 2004b; Smith et al., 2010), were monitored continuously and recorded at 15 min intervals. Additionally, subjects were asked every 15 min to rate their perceived exertion (Borg, 1962), thermal comfort (Gagge et al., 1969) and thermal sensation (Gagge et al., 1969). At the 30, 60, and 90 min periods the subjects were given 500 ml of water to drink for a total fluid consumption of 1.5 l (Caldwell et al., 2011). The drinking water was provided at the same temperature as the climate chamber (31 °C) to minimise any cooling effect of the consumption.

2.2.1. Experimental conditions

All subjects completed the three PBA trials in a climate chamber (4 × 3 × 2.5 m; length, width, height) at an ambient temperature of 31 °C, 60% relative humidity, 4.7 km/h simulated wind speed and with a radiant heat load (two radiant heaters positioned 0.8–1.8 m from the participant), that produced an average wet bulb globe temperature of 29 ± 1.3 °C. The climatic conditions represented the upper limit for acclimatized individuals undertaking continuous activity at a low metabolic rate in an occupational setting (ISO 7933, 2004a). Subjects were assumed to be acclimatized given the subtropical location within Australia that they resided and that data collection occurred during the summer months. The average temperatures of the geographical location during the testing period were approximately 28.3 °C and 69% relative humidity (Meteorology, 2013).

2.3. Statistical analysis

The experiment was based on a repeated measures experimental design with subjects acting as their own controls, participating in all trials and wearing each of the PBA ensembles. Between-trial differences were measured using two-way

Table 1
Subjects' anthropometric and physiological characteristics. Values are mean ± SD and range.

Age (yrs)	Mass (kg)	Height (m)	$\dot{V}O_{2max}$ (ml kg^{-1} min^{-1})	Heart rate max (bpm)	Σ 6 Skin folds (mm)
26 ± 5.9 (20–39)	76 ± 6.3 (71–87)	1.7 ± 0.6 (1.7–1.9)	55.5 ± 7.9 (42–66)	191 ± 7.4 (185–201)	59.9 ± 21.8 (38.5–104.6)