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Emily R Watkins, Alan J Richardson

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Fire Service Instructor's Undergarment Choice to Reduce Interleukin-6 and Minimise Physiological and Perceptual Strain

Emily R Watkins BSc^{*1}, Alan J Richardson BSc PhD²

Centre for Sport and Exercise Science and Medicine (SESAME), Environmental Extremes Laboratory, University of Brighton, Welkin Laboratories, Denton Road, Eastbourne, BN20 7SR, UK

E.R.Watkins@brighton.ac.uk

A.J.Richardson@brighton.ac.uk

*Corresponding author.

Abstract

Fire Service Instructors frequently experience high levels of physiological and perceptual strain during live fire exposures. Instructors are also at risk of cardiovascular illnesses, with cardiac death being the greatest cause of fire fighter death. Current practice for UK instructors is to select undergarment type based on personal preference, between a boiler suit (BOILER) and a wicking base layer (WBL). Research suggests that shorts and t-shirt (SHORTS) may also be a beneficial alternative undergarment choice. The UK South East Fire Service requested an investigation to identify if undergarment selection can lessen the strain experienced by instructors, and reduce the acute inflammatory response to fire exposures. Eight males completed three 45 min sessions in a heat chamber ($49.5 \pm 1.4^{\circ}\text{C}$ and $16.9 \pm 4.3\%$ RH) whilst performing intermittent walking. At the end of heat exposure change in heart rate was not effected by garment type ($p=0.061$, $\eta_p^2=0.373$). Change in rectal temperature was different between garments ($p=0.009$, $\eta_p^2=0.271$), with trends suggesting

¹ 01273643754.

² 01273643723.

that BOILER resulted in a greater change ($1.03 \pm 0.60^{\circ}\text{C}$) than SHORTS ($0.76 \pm 0.37^{\circ}\text{C}$, $p=0.589$, $d=0.21$) and WBL ($0.72 \pm 0.33^{\circ}\text{C}$, $p=0.545$, $d=0.25$). Interleukin-6 post exposure was greater for BOILER ($6.96 \pm 0.28 \text{ pg.mL}^{-1}$) than both SHORTS ($6.59 \pm 0.30 \text{ pg.mL}^{-1}$, $p=0.043$, $d=0.42$) and WBL ($6.45 \pm 0.43 \text{ pg.mL}^{-1}$, $p=0.031$, $d=0.51$). Overall, undergarment type had little impact on physiological or perceptual strain. However, wearing WBL or SHORTS may reduce the inflammatory response, and consequently decrease the risk of cardiovascular events.

Abbreviations

BOILER, Boiler Suit; PSI, Physiological strain index; SCBA, Self-contained breathing apparatus; SHORTS, shorts and t-shirt; WBL, wicking base layer

Keywords

Fire service; Heat exposure; Clothing; Occupational health

1 Introduction

Fire service instructors teach firefighters to handle fire and emergency situations. Instructors are exposed to a variety of fire situations, with each fire exposure known as a “wear” (Eglin et al. 2004). Wears conducted in fire houses have been documented to last 40 ± 24 min (Eglin & Tipton 2005). During this time instructors wear encapsulating protective clothing and a self-contained breathing apparatus (SCBA) with a combined weight of 16.9 - 27.4kg (Barr et

al. 2010). Within the fire house reported temperatures range from 67-190°C (Eglin et al. 2004; Eglin 2007), however ambient temperatures measured from instructors' shoulders outside their protective clothing range from $55 \pm 14^{\circ}\text{C}$ and $48 \pm 12^{\circ}\text{C}$, and at the hip are $42 \pm 12^{\circ}\text{C}$ (Eglin et al. 2004). The variation in temperatures is common within the fire house, with maximum temperatures noted at ceiling height and instructors staying low and sheltering where possible (Eglin 2007; Barr et al. 2010). During a wear instructors experience high levels of both physiological and perceptual strain (Barr et al. 2010; Petruzzello et al. 2009; Cheung et al. 2010; Smith et al. 1997), putting them at risk of suffering an exertional heat illness (Cheung et al. 2000). Furthermore, instructors are at an increased risk of cardiovascular events, with cardiac death the main cause of firefighter death in any given year (Fahy et al. 2015). Whilst firefighters are required to wear standardised protective clothing during exposures, the undergarment worn beneath is chosen based on personal preference. Consequently, the UK South East Fire Service requested an investigation to discover if undergarment selection may reduce the risk of cardiovascular illness, and lessen the strain experienced by instructors during a wear.

Physiological strain that develops during a wear is a consequence of body heat storage, which increases as the body is no longer able to maintain a balance between heat loss and heat production (Havenith 1999). The heat exchange equation represents the balance needed to maintain body temperature:

$$\pm S = M - (\pm W) - E \pm K \pm C \pm R \left(\frac{W}{m^2} \right)$$

where: S is heat storage, M is metabolism, W is positive or negative work, E is evaporation, K is conduction, C is convection and R is radiation (Gavin 2003).

When wearing protective clothing instructors' work load increases, resulting in an increase in heat production and requirement for heat loss (Rossi 2003; Dreger et al. 2006; Holmér et al. 2006). However, the clothing also reduces evaporative heat loss capacity and therefore when combined with high temperatures, an uncompensable heat stress situation occurs, resulting in heat storage (Havenith 1999; Cheung, McLellan, and Tenaglia 2000).

In uncompensable situations the attainment of a heat balance is not possible unless exercise is terminated or the rate of metabolic heat production is reduced. Thermal sensation (TS) is responsible for the initiation of behavioural thermoregulation (Savage et al 2014), with changes in thermal perception linked to voluntary alterations in exercise work rate, via the stimulation of peripheral thermosensors caused by elevated skin temperature (Flouris & Schlader 2015). Consequently, increased TS can result in reduced exercise intensities (Schlader et al. 2011). Instructors could therefore self-regulate exercise intensity depending on TS during training sessions, although this would not be possible during an emergency situation where maximal effort is required.

In addition, TS can alter the perception of exertion in hot environments (Schlader et al. 2010). Perception of exertion is formed from the combination of both central origins, such as the cardiovascular and respiratory systems, and peripheral origins, such as muscles and skin. An increased rate of rise in perceived exertion can reduce the duration of exercise before behavioural cessation (Crewe et al 2008). Previous studies suggest that TS and rating of perceived exertion (RPE) are elevated during a wear to 6 ± 1 , representing a sensation of "hot" and 14 ± 3 , representing an exertion of between "somewhat hard" and "hard" (Watt et al. 2016), indicating perceptual strain.

High levels of strain may cause instructors to experience increased levels of fatigue (Selkirk & McLellan 2004; Nybo 2008), and also put them at risk of suffering an exertional heat

illness (Cheung et al. 2000). Exertional heat illness occurs when core temperature is elevated (usually $>40^{\circ}\text{C}$) by positive heat storage, and can be associated with organ system failure (Binkley et al. 2002). Signs of exertional heat illness include tachycardia, hyperventilation, altered mental status, vomiting, and coma (Coris et al. 2004). These symptoms within a live fire scenario can be dangerous and life threatening.

Exposure to high temperatures may also have serious cardiovascular health implications, with recent reports noting that cardiac death accounts for 56% of firefighter deaths in America in the last five years, and is the main cause of fatalities in firefighters in any given year (Fahy et al. 2015). The combination of cardiovascular, thermal and psychological stresses which are routinely experienced may trigger cardiac events. Fire suppression activities increase the risk of suffering from a cardiac event by 10-100 times compared to non-firefighting duties (Kales et al. 2007). This risk is further exacerbated by underlying health issues, such as obesity and hypertension (Kales 2007, Kales 2009, Geibe et al 2008). The high incidence of myocardial infarction makes cardiac strain experienced by firefighters a major concern (Cheung et al. 2010; Yang et al. 2013).

Sudden cardiac events can be caused by atherosclerosis, with plaque disruption, thrombotic formations and superficial erosion of the fibrotic plaque being the origin (Smith et al. 2011). Increased resting levels of Interleukin-6 (IL-6), an anti and pro inflammatory cytokine, may be a predictor of cardiovascular illnesses (Rauchhaus et al. 2000; Ridker et al. 2000; Spoto et al. 2014). Elevated levels of IL-6 can increase platelet production and reactivity, in addition to affecting endothelial function and increasing the release of fibrinogen and C-reactive protein (Lindmark et al. 2001). The median basal IL-6 in healthy men is 1.46 pg.mL^{-1} , however it can range from $0.015\text{-}10.01 \text{ pg.mL}^{-1}$ (Ridker et al. 2000). Instructors have previously exhibited increased resting baseline IL-6 ($17.0 \pm 5.7 \text{ pg.mL}^{-1}$) suggesting that they may be at an increased risk of a cardiac event (Watt et al. 2016). Consequently, reducing the

acute IL-6 response to fire exposures may lead to a reduction in resting levels and therefore a decreased risk.

It is important that the strain experienced by instructors is minimised, to reduce the risk of cardiac illness, fatigue and exertional heat illness. Current fire service practice enables instructors to wear either a boiler suit (80% polyester, 20% cotton) (BOILER) or a whole body wicking base layer (70% polyester and 30% polyamide) (WBL) beneath their protective clothing. Previous research has also suggested that shorts and t-shirt (100% cotton) (SHORTS) may be an alternative undergarment option offering a reduction in physiological strain (McLellan & Selkirk 2004), although they are currently not used by UK instructors. The approximate clo values for the undergarment options vary slightly from 0.52 clo for BOILER, to 0.18 clo for WBL, and 0.16 clo for SHORTS (Olesen 1985). Garment choice could alter the inflammatory response, and physiological and perceptual strain experienced by instructors. However, there is little research into which type of undergarment causes the least thermoregulatory impairment, and no research into the effect undergarments may have on inflammation.

Research suggests that wearing a wicking t-shirt lowers thermal sensation and torso temperature in hot environments, compared to a cotton t-shirt, whilst core temperature and ratings of perceived exertion (RPE) may be unaffected by garment type (Roberts et al. 2007). Investigations using protective clothing suggest that tight fitting t-shirts designed to wick away sweat are of no benefit compared to a cotton alternative, with similar core temperatures and heart rates recorded, due the protective clothing acting as a barrier to heat dissipation (Fogarty & Sinclair 2009; Van Den Heuvel et al. 2010; Smith et al. 2014). These studies altered just upper body wicking garments to assess the impact of garment material. No previous study has investigated the use of full body wicking garments in hot environments

under protective clothing, during tasks similar to those completed by instructors; it is therefore unclear if they are a suitable undergarment choice for fire service instructors.

Wearing SHORTS instead of long sleeved tops and trousers has been suggested to decrease the incidence of medical leave caused by heat exhaustion, and does not compromise protection (Prezant et al. 2000) Wearing shorts beneath protective clothing instead of trousers has also been reported to increase time to exhaustion (73.3 ± 3.4 min vs. 65.8 ± 3.9 min, respectively), and reduce maximal heart rates (113 ± 3 b.min⁻¹ vs 120 ± 3 b.min⁻¹ respectively) when walking at a low intensity. Overall, shorts may decrease heat stress by 10-15% when compared to trousers (McLellan & Selkirk 2004). Shorts and t-shirts may therefore be an alternative undergarment option for fire service instructors, however their impact on inflammatory responses is currently unknown.

The aim of the study was therefore to identify which of the three undergarment types (BOILER, WBL, or SHORTS) is most beneficial for fire service instructors to wear, based on the inflammatory response and physiological and perceptual strain generated. It was hypothesised that BOILER would generate a greater IL-6 response than the other undergarments. It was also hypothesised that the BOILER condition would result in a greater level of strain than the SHORTS and WBL conditions. This would be demonstrated through a greater change in core temperature and heart rate, alongside a higher rating of thermal sensation and exertion.

2 Method

2.1 Participants

Eight male students were recruited from the University of Brighton (age, 21 ± 2 yrs; weight, 75.7 ± 7.1 kg; height, 1.77 ± 0.05 m). All individuals were required to be physically active, >3 times a week, to replicate the average physical activity frequency of firefighters (Elliot et

al. 2007; Baur et al. 2012). Participants also had not suffered from heat illness in the last six months, and had not been involved in heat acclimation training or had >3 consecutive days of heat exposure >25°C in the previous month (Périard et al. 2015). Participants gave informed written consent and completed medical questionnaires before taking part. The study was approved by the University of Brighton Ethics Committee and conducted in accordance with the Declaration of Helsinki (revised 2008).

Participants were required to consume a similar diet and not to consume caffeine 12h (Graham 2001) before each testing session. They were also requested to avoid alcohol (Shirreffs & Maughan 2006) and exhaustive exercise within the 24h preceding each session (Stewart et al. 2014).

2.2 Experimental Design

The study used a randomised cross-over design to test the three undergarment types.

Randomisation was conducted using a Latin squares design.

Upon arriving at the laboratories, participants provided a urine sample to check that they were in a hydrated state: urine colour (U_{col}) ≤ 3 , osmolality (U_{osm}) $< 700 \text{ mOsm.kgH}_2\text{O}^{-1}$ (Pocket Pal-Osmo, Vitech Scientific, Ltd), and urine specific gravity (U_{spg}) < 1.020 (hand refractometer, Atago Co., Tokyo, Japan) (Sawka et al. 2007). If participants were not euhydrated 500 mL of additional fluid was consumed and a further urine sample requested 30 min afterwards.

Each session then involved a 10 min rest period in ambient temperature ($23.5 \pm 1.4^\circ\text{C}$, $35.3 \pm 2.3\%$ RH) dressed in an undergarment and fire instructor ensemble: jacket (Ballyclare Special Products Ltd.), trousers (Ballyclare Special Products Ltd.), boots (9005 GA, Jolly Scarpe, USA), fire hood (MSA Gallet, Bellshill, UK), helmet (F1SF, MSA Gallet, Bellshill, UK), and gloves (Firemaster 3, Southcombe Brothers Ltd, Somerset, UK). Participants wore their own

cotton shorts and t-shirt, boiler suits supplied by the fire service, or wicking base layer garments from Odlo (Hünenberg, Switzerland). After rest, participants put on a rucksack weighted at 9.52kg to replicate a SCBA, making the entire ensemble (not including undergarments) weigh 17kg. Participants then completed 45 min of intermittent exercise, alternating between 5 min walking ($4\text{km}\cdot\text{h}^{-1}$ and 1% gradient) and 5 min rest, on a treadmill (Woodway GmbH, PPS 55 Sport-1, Weil am Rhein, Germany), in $49.5 \pm 1.4^{\circ}\text{C}$ and $16.9 \pm 4.3\%$ RH, this is demonstrated in a schematic in Figure 1 with measurement time points also highlighted. To replicate instructors' rest periods, participants remained standing whilst resting, but were allowed to lean on the treadmill. All testing was conducted in the morning to control for circadian rhythms (Drust et al. 2005).

2.3 Physiological Measures

Nude body mass and total garment mass was recorded before and after each testing session (Adam GFK 150 Body Scales, Connecticut, USA, accurate to 0.01kg). T_{re} was measured using a Henley single use rectal temperature probe (449H, Henleys Medical, Hertfordshire, UK) inserted 10cm past the anal sphincter, and displayed on logging monitors (YSI, 4600 series, YSI, Hampshire, UK). Skin temperature was measured via contact skin thermistors placed at four locations: chest, triceps, quadriceps and calf (Ramanathan, 1964), and recorded via a 1000 series Squirrel Data Logger (Grant Instruments, Cambridgeshire, UK). HR was recorded using a Polar FT1 heart rate monitor (Polar electro, Kempele, Finland). All temperature and HR measures were recorded at the end of the resting period, and every 5 min throughout heat exposure.

2.4 Gas Analysis

Expired gas collection occurred via Douglas bags after rest and at the beginning and end of the first and last exercise block. Coefficient of variation for Douglas bag collection was $4.1 \pm 1.3\%$ for volume of oxygen uptake ($\dot{V}\text{O}_2$).

2.5 Interleukin- 6

Venous blood (5mL) was collected from the ante-cubital fossa prior to dressing in the protective ensemble and after nude body mass measurements were taken following heat exposure. Whole blood was centrifuged at 5000rpm for 10 min, plasma was then removed, placed into aliquots and stored at -86°C. An ELISA kit (Sigma-Aldrich, UK) was then used to analyse the plasma samples for IL-6.

2.6 Perceptual Measures

Perceptual strain was assessed via RPE, on a scale of 6-20 (Borg 1982), and the TS scale, a scale from 0 “unbearably cold” to 8 “unbearably hot” (Young et al. 1987). Measures were recorded at the end of the rest period, and every 5 min throughout heat exposure.

2.7 Derivative Calculations

Mean skin temperature (T_{skin}) was determined using measurements taken from the four skin sites (Ramanathan 1964) :

$$T_{skin} (^{\circ}C) = 0.3(T_{chest} + T_{upper arm}) + 0.2(T_{upper leg} + T_{lower leg})$$

Change in T_{re} and HR were also established:

$$\Delta T_{re} = T_{ret} - T_{re0}$$

$$\Delta HR = HR_t - HR_0$$

where T_{ret} and HR_t are measurements recorded every 5 min, and T_{re0} and HR_0 were baseline measures taken at the end of the 10 min resting period.

PSI was calculated as per the equation (Moran et al. 1998):

$$PSI = 5(T_{ret} - T_{re0}) \cdot (39.5 - T_{re0})^{-1} + 5(HR_t - HR_0) \cdot (180 - HR_0)^{-1}$$

where $T_{re}t$ and HR_t were simultaneous measurements taken every 5 min during the exposure, and T_{re0} and HR_0 represent baseline states.

Metabolic energy expenditure ($\dot{M}$) was calculated for each of the 5 time points where gas was collected. $\dot{M}$ was calculated using the equation below (Jay et al. 2011):

$$\dot{M}(\text{Watts}) = \dot{V}O_2 \frac{\left(\frac{RER-0.7}{0.3} e_c\right) + \left(\frac{1-RER}{0.3} e_f\right)}{60} \times 1000$$

where e_c is the caloric equivalent per litre of oxygen for the oxidation of carbohydrates (21.13kJ) and e_f is the caloric equivalent per litre of oxygen for the oxidation of fat (19.62kJ)

Metabolic heat production ($\dot{H}_{prod}$) was calculated by the difference between $\dot{M}$ and the external work rate (W) and is expressed relative to body mass in $W.kg^{-1}$ (Cramer & Jay 2014).

$$\dot{H}_{prod} (W.kg^{-1}) = (\dot{M} - W) / \text{Body Mass}$$

Sweat rate and change in garment mass were calculated at the end of heat exposure.

$$\text{Sweat rate (L.h}^{-1}\text{)} = \text{Body Mass pre} - \text{Body Mass post} / \text{Time (minutes)} \times 60$$

Nude body mass was recorded before dressing in protective clothing prior to the rest period and after exiting the chamber and towel drying.

2.8 Statistical Analysis

A power analysis (G*Power 3.1.9) was conducted to assess the adequacy of sample size based on ΔT_{re} and HR responses. A minimum sample of 6 was indicated to achieve an effect size of 0.60, an α of 0.05, and a power of 0.80.

Data were analysed using IBM SPSS Statistics 20. Data were tested for normality and sphericity via skewness and kurtosis, and the Mauchly test. When the assumption of

sphericity was violated, significance and degrees of freedom were adjusted using the Greenhouse-Geisser method. Two way repeated measures ANOVAs were conducted on all dependant variables to establish if there was a significant main effect for time and garment type, and a significant interaction between time and garment. Bonferroni corrected one way ANOVAs were used to establish where significant interactions occurred. Data is reported as the mean $\pm$ SD, and significance was set at $p \leq 0.05$. Effect sizes for main effects and interactions are reported as partial eta squared (η_p^2), with differences between two undergarment types evaluated via Cohen's d (Lakens 2013). Cohen's d effect size was categorised as small (0.2), medium (0.5) or large (0.8) (Cohen 1988).

3 Results

All trials were successfully completed by seven participants, with one participant choosing to withdraw early, at 36 min, in their SHORTS trial due to nausea and dizziness. All participants met the hydration requirements before each session (see Table 1). Blood was collected from six participants, due to blood collection difficulties occurring with the remaining two participants.

3.1 Physiological Strain

T_{re} at the end of heat exposure was $37.93 \pm 0.56^\circ\text{C}$ in the BOILER trial, $37.83 \pm 0.49^\circ\text{C}$ for SHORTS, and $37.63 \pm 0.30^\circ\text{C}$ for WBL. Change in T_{re} (ΔT_{re}) was analysed instead of T_{re} to control for any variation in resting T_{re} values. ΔT_{re} increased in all trials during heat exposure ($p < 0.001$, $\eta_p^2 = 0.865$). This increase was different between the garment types ($p = 0.009$, $\eta_p^2 = 0.271$) with BOILER being $0.26 \pm 0.48^\circ\text{C}$ greater than SHORTS ($p = 0.589$, $d = 0.21$) and $0.31 \pm 0.54^\circ\text{C}$ greater than WBL ($p = 0.545$, $d = 0.25$) in the last 5 min.

HR at the end of the protocol was $140 \pm 14 \text{ b.min}^{-1}$ for BOILER, compared to $138 \pm 10 \text{ b.min}^{-1}$ for SHORTS and $131 \pm 12 \text{ b.min}^{-1}$ for WBL. Change in HR (ΔHR) increased throughout the heat exposure in all trials ($p < 0.001$, $\eta_p^2 = 0.949$) with the increase being different between the garment types ($p = 0.049$, $\eta_p^2 = 0.323$). Differences were present at 40 min ($p = 0.030$, $\eta_p^2 = 0.444$), with BOILER resulting in a greater ΔHR than SHORTS ($p = 0.070$, $d = 2.21$) and WBL ($p = 0.797$, $d = 1.15$). At the end of the 45 min heat exposure there was a trend towards differences between garments ($p = 0.061$, $\eta_p^2 = 0.373$) with BOILER generating a ΔHR of $65 \pm 10 \text{ b.min}^{-1}$ compared to SHORTS ($57 \pm 8 \text{ b.min}^{-1}$, $p = 0.218$, $d = 1.66$) and WBL ($55 \pm 7 \text{ b.min}^{-1}$, $p = 0.284$, $d = 2.10$).

PSI rose during the exercise protocol ($p < 0.001$, $\eta_p^2 = 0.957$), with garment type resulting in increases of different magnitudes ($p = 0.040$, $\eta_p^2 = 0.346$). PSI scores at 45 min were different between the undergarments ($p = 0.033$, $\eta_p^2 = 0.433$), with trends suggesting that PSI was greatest in the BOILER condition, followed by SHORTS (BOILER vs. SHORTS, $p = 0.253$, $d = 0.34$) and WBL (BOILER vs. WBL, $p = 0.168$, $d = 0.61$). Mean $\pm$ SD for PSI, ΔT_{re} and ΔHR for all time points can be seen in Figure 2.

T_{skin} increased during the heat exposure ($p < 0.001$, $\eta_p^2 = 0.983$), however these changes were irrespective of undergarment type ($p = 0.684$, $\eta_p^2 = 0.081$) (Figure 3).

3.2 Gas Analysis

$\dot{H}_{\text{prod}}$ increased during the heat exposure ($p < 0.001$, $\eta_p^2 = 0.958$), however these changes were not altered by undergarment type ($p = 0.147$, $\eta_p^2 = 0.252$) (Figure 3). $\dot{H}_{\text{prod}}$ at 40 min was $4.57 \pm 0.88 \text{ W.kg}^{-1}$ during the BOILER trial, $3.40 \pm 0.49 \text{ W.kg}^{-1}$ for SHORTS, and $4.03 \pm 1.14 \text{ W.kg}^{-1}$ for WBL.

$\dot{V}O_2$ increased following the periods of exercise ($p<0.001$, $\eta_p^2=0.966$), with trends suggesting a difference between undergarment types ($p=0.082$, $\eta_p^2=0.240$). Relative $\dot{V}O_2$ for BOILER at 40 min was $16.58 \pm 2.19 \text{ mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$, compared to $14.17 \pm 1.50 \text{ mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$ for SHORTS and $14.52 \pm 3.73 \text{ mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$ for WBL. Undergarment type also had no effect on ventilation rate at any point during the heat exposure ($\dot{V}_e$) ($p=0.285$, $\eta_p^2=0.189$), with BOILER resulting in a $\dot{V}_e$ at 40 min of $38.93 \pm 19.49 \text{ L}\cdot\text{min}^{-1}$, compared to $28.12 \pm 10.56 \text{ L}\cdot\text{min}^{-1}$ for SHORTS and $27.58 \pm 10.07 \text{ L}\cdot\text{min}^{-1}$ for WBL.

3.3 Interleukin-6

Before the heat exposure participants had similar IL-6 levels ($p=0.09$, $\eta_p^2=0.382$). After the exposure the BOILER condition resulted in IL-6 levels that were greater than both SHORTS ($p=0.043$, $d=0.42$) and WBL ($p=0.031$, $d=0.51$). SHORTS and WBL were not different, ($p=0.247$, $d=0.16$). Participants' demonstrated similar trends, with all individuals' IL-6 levels being greatest post heat exposure in the BOILER condition, followed by SHORTS and WBL (Figure 4).

3.4 Perceptual Strain

Over the period of the heat exposure TS increased ($p<0.001$, $\eta_p^2=0.958$), with a trend to suggest that the increase was different between undergarment types ($p=0.063$, $\eta_p^2=0.214$). At the end of exposure there was a trend towards BOILER producing a higher TS than SHORTS ($p=0.140$, $d=0.36$) or WBL ($p=0.67$, $d=0.55$). Overall, four participants had reported the highest TS scoring of eight in BOILER, compared to two participants in SHORTS, and one participant in WBL. RPE was not affected by the garment that was worn at any time point ($p=0.586$, $\eta_p^2=0.142$).

4 Discussion

The aim of this study was to investigate the inflammatory response and physiological and perceptual strain experienced by fire service instructors, when wearing different types of undergarments. A 45 min, intermittent exercise, heat exposure protocol was designed to replicate instructors' tasks during a live house fire wear, in a controllable laboratory environment, so levels of strain could be assessed. BOILER produced the greatest IL-6 response, however there were no statistically significant differences in PSI, ΔT_{re} and ΔHR at the end of heat exposure between the garment types. Perceptually, TS and RPE were unaltered by garment types, however small alterations in TS may be meaningful to instructors. Overall undergarment type had little impact on physiological and perceptual strain, however a reduction in inflammatory responses noted in the SHORTS and WBL condition may reduce the risk of instructors' experiencing a cardiovascular event, in comparison to wearing BOILER.

4.1 Physiological Strain

At the end of the heat exposure protocol, trends suggest that BOILER produced the greatest PSI. Decreased PSI is caused by reductions in HR and T_{re} . Average ΔT_{re} was $0.26 \pm 0.48^{\circ}\text{C}$ lower in SHORTS and $0.31 \pm 0.54^{\circ}\text{C}$ lower in WBL compared to BOILER, whilst ΔHR was lower by $8 \text{ b}\cdot\text{min}^{-1}$ for SHORTS and $10 \text{ b}\cdot\text{min}^{-1}$ for WBL compared to BOILER, however these changes were only indicated by trends and were not statistically significant. The reduction in ΔHR is in accordance with the trend towards a lower $\dot{V}O_2$ in the SHORTS and WBL conditions.

These findings support previous research which noted small decreases in HR of $6 \text{ b}\cdot\text{min}^{-1}$ when wearing shorts instead of long trousers underneath protective clothing, after walking at $4.5 \text{ km}\cdot\text{h}^{-1}$, in 35°C , 50% RH (McLellan & Selkirk 2004). The authors also recorded a significant reduction in T_{re} when wearing shorts compared to trousers from 30 min onwards.

The use of continuous exercise instead of intermittent, as used in this study, may explain why significance was present.

Alternatively, WBL have previously been observed to have no effect on T_{re} , with a 47 min intermittent exercise protocol eliciting similar core temperatures whilst wearing either a cotton t-shirt or a wicking top (Roberts et al. 2007). A comparison between WBL and a cotton t-shirt underneath combat uniform also found no differences in core temperature or HR following 40 min of intermittent running (Fogarty & Sinclair 2009). Consequently, WBL may elicit a similar response to that noted by McLellan & Selkirk (2004) when wearing shorts, in that garment types may only cause small reductions in the physiological strain experienced during low intensity exercise.

As exercise intensity increases heat production rises, and consequently the evaporative heat loss individuals require to maintain a thermal steady state is higher (Brotherhood 2008). Small changes in the maximal evaporative capacity of the environment, due to the clothing items' permeability and thickness, have little impact on the ratio between the required evaporation and maximal evaporative capacity, when the required evaporative heat loss is high (Pascoe et al. 1994; McLellan & Selkirk 2004). Consequently, individuals may be unable to maintain a thermal steady state during high intensity exercise ($\geq 4.8 \text{ km.h}^{-1}$ and 5% elevation), regardless of the garment type worn (McLellan & Selkirk 2004). In contrast, when performing low intensity exercise ($\leq 4.5 \text{ km.h}^{-1}$ and 0% elevation) the rate of heat production increase is lower than during high intensity exercise,, therefore resulting in a greater opportunity for clothing changes to effect heat loss (Holmér et al. 2006; McLellan & Selkirk 2004). The addition of protective clothing to low intensity exercise increases heat production, however in this wear protocol it did not increase to the extent of high intensity exercise, as seen by the lower T_{re} response reported in this study.

An additional study using firefighter protective clothing also found no benefit in wearing a WBL during walking, however exercise was conducted in a thermoneutral environment (21.1°C, 58.6% RH) (Smith et al. 2014) instead of a hot environment (49.5°C and 16.9 RH) designed to replicate the temperatures recorded from instructors during a wear (42-55°C) (Eglin et al. 2004). However, the any differences in physiological strain between undergarments exhibited in this investigation were only indicated by trends, and therefore may have little overall impact on the strain experienced by instructors in the field. Consequently, it can be postulated that undergarment selection will have no effect on risk of exertional heat illness.

4.2 Inflammation

Elevated IL-6 from monocytes, endothelial cells, and contracting muscles during exercise may suggest greater inflammation, possibly caused by muscle damage (Bluethmann et al. 1994; Fischer 2006). IL-6 functions as a cytokine that causes an acute-phase reaction to inflammation (Bluethmann et al. 1994; Petersen & Pedersen 2005). The BOILER condition generated the greatest IL-6 levels, indicating an increased inflammatory response when compared to both SHORTS and WBL. Furthermore, all participants displayed similar trends, suggesting that WBL may cause a reduced inflammatory response compared to the other conditions. Previous studies have noted increases in IL-6 due to heat exposure or exercise (Scharhag et al. 2005; Welc et al. 2012). Firefighters have also demonstrated increases in IL-6 following 40 min of simulated fire and rescue tasks in the heat (Walker et al. 2015). Exercising for longer durations of time have also been noted to cause greater increases in IL-6 than reported in this study, with IL-6 after a 4h cycle increasing from $1.0 \pm 0.5 \text{ pg.mL}^{-1}$ to $9.6 \pm 5.6 \text{ pg.mL}^{-1}$ (Scharhag et al. 2005). Therefore, it can be suggested that if a wear lasts longer than 45 min, instructors' IL-6 levels may increase further. Overall, IL-6 increased

following the fire service instructor specific protocol used in this study, which is in line with previous research on changes in IL-6 during physiologically stressing physical activity and high temperatures.

Frequently experiencing elevated levels of IL-6 following exercise can cause an increase in basal IL-6 (Robson-Ansley et al. 2007). As a predictor of cardiovascular illnesses, a reduction in the levels of IL-6 that instructors experience may reduce their risk of suffering from the disease (Ridker et al. 2000). It can therefore be suggested that the BOILER undergarment is the least favourable option for instructors, as it evokes the greatest IL-6 response, indicating the most severe inflammatory response, and possibly the greatest risk of a cardiovascular illness.

4.3 Perceptual Strain

Perceived thermal sensation and exertion forms part of the neuro-anatomical model that produces an overall subjective sensation of homeostasis, which may be linked to motivation and planning of physical actions (Craig 2002; Cheung 2010). Consequently, decreasing perceived exertion and TS may enable instructors to better plan and conduct tasks, and also increase their level of motivation. During this study, no differences in RPE were noted between garment types. This supports previous findings of research investigating the use of WBL and SHORTS (Roberts et al. 2007; Fogarty & Sinclair 2009; Van Den Heuvel et al. 2010; Smith et al. 2014; McLellan & Selkirk 2004).

In contrast, TS was greater by 0.5 in BOILER when compared to SHORTS (small effect, $d=0.36$), and greater by 1.0 in BOILER compared to WBL (moderate effect, $d=0.55$). This trend was close to significance ($p=0.063$, $\eta_p^2=0.214$). Furthermore, four participants reported a feeling of “unbearably hot” during the BOILER condition, compared to just one participant during the WBL trial. A higher TS during the BOILER condition may be linked to an

increase in fatigue, when compared to wearing SHORTS and WBL undergarments (Schlader et al. 2011). Subsequently, instructors may experience a small anticipatory reduction of muscle activation, resulting in a decrease in work intensity during a wear, to ensure the safe completion of the task (Abbiss et al. 2010).

It is difficult to compare the findings of this investigation to that of other research, due to the different types of thermal scales used (McLellan & Selkirk 2004; Roberts et al. 2007; Van Den Heuvel et al. 2010). However, no study investigating the effect of undergarments with protective clothing has found any difference in thermal sensation between clothing items (McLellan & Selkirk 2004; Fogarty & Sinclair 2009; Van Den Heuvel et al. 2010; Smith et al. 2014). This may be due to the differences in the protocol and temperatures used. Although not statistically significant, the small reduction in TS when wearing WBL represents a moderate effect in comparison to the BOILER condition (Cohen 1988). This may be meaningful to fire service instructors, as it could help to motivate individuals and reduce the level of fatigue that they experience, especially when instructors must complete multiple wears a week. When taken together with RPE, undergarments had little effect on perceptual strain, however in relation to practical application, a possible small reduction in TS may be beneficial to instructors.

The differences in inflammation and small changes in strain noted between undergarment types may be caused by the different types of materials that the undergarments are made of. BOILER was the heaviest and thickest undergarment, weighing 0.5kg more than both SHORTS and WBL at the beginning of the session. Heavier garments result in increased metabolic rate, with a 2.7% increase per kg of clothing weight having previously been suggested (Dorman & Havenith 2009), consequently increasing the physiological strain an individual experiences. During this investigation an average increase of 19.8% and 16.1% in $\dot{H}_{\text{prod}}$ was exhibited when wearing BOILER compared to SHORTS and WBL, respectively,

however $\dot{H}_{\text{prod}}$ was subject to large individual variation. This is a greater rise than that noted by Dorman & Havenith (2009), however other factors are likely to have influenced this increase in addition to the weight of the garments, for instance the material type, the air layers created, and the material thickness. The greater the garment thickness the slower the rate of perspiration and moisture vapour transfer to the garment surface (Roberts et al. 2007). Thicker garments also add insulation, which increases the resistance to heat loss. In comparison, thinner garments result in less resistance to heat transfer, and tight fitting undergarments, such as the WBL, reduce the level of insulation, due to the smaller air layers between the skin and garment (Havenith 1999; Havenith 2002). In addition, tight clothing reduces garment movement, and therefore decreases the sensation of wet skin, increasing comfort levels (Havenith 2002). Garments made of fabric with high wicking capabilities also aid thermoregulation and comfort, as moisture is moved from the body to the outer layer of the garment and dispersed across the fabrics surface area (Roberts et al. 2007; Havenith 2001; Kar et al. 2007). However, wearing protective clothing prevents sweat from evaporating off of the clothing surface, and whilst the movement of sweat away from the skin may improve individuals' thermal perception, this may be the reason why little difference in physiological strain was noted.

The strain generated during the simulated wear protocol test used in this study offers a good replication of instructors strain levels. Previous research assessing the strain of walking whilst wearing protective clothing reported a PSI of 6.7 (Stewart et al. 2014). This is higher than the moderate PSI noted for the BOILER condition, as would be expected with the use of explosive ordnance disposal (EOD) clothing, which has additional insulation and weight (13kg) compared to firefighter clothing. During a fire service instructor specific investigation, PSI was 4.7 ± 0.7 after a ~45 min live fire exercise in which instructors wore either BOILER or WBL (Watt et al 2016). This is similar to the PSI noted in this study, as PSI recorded for

BOILER and WBL fall either side of 4.7 ± 0.7 . Furthermore, end T_{re} exhibited in this study ($37.89 \pm 0.56^{\circ}\text{C}$ for BOILER) is also consistent with T_{re} recorded post wear ($38.06 \pm 0.34^{\circ}\text{C}$ and $38.08 \pm 0.26^{\circ}\text{C}$) by Watt et al (2016). Consequently, the findings of this study can be used to recommend undergarments for fire service instructors during live fire situations.

4.4 Limitations

During the protocol participants carried a rucksack to simulate the weight of a SCBA, however they did not breathe through a SCBA. Directly using a SCBA can significantly reduce $\dot{V}O_2$ by increasing breathing resistance and limiting $\dot{V}_e$ (Eves et al. 2005). Testing was completed in a heat chamber rather than during a live fire scenario, to enable temperature and activity to be controlled. Temperature exposure during live fires varies depending upon proximity to the heat source. Future research should consider studying the effects of undergarment types during a live fire house wear, whilst using a SCBA.

5 Conclusion

Following a heat exposure protocol designed to simulated fire service instructors responses to a wear, undergarment choice had little impact on both physiological and perceptual strain. However, inflammatory response was higher during the BOILER trial than both SHORTS and WBL. Due to instructors frequent exposure to live fire situations, this may reduce their risk of cardiovascular illness. Fire service instructors regularly exposed to heat should therefore wear SHORTS or WBL garments underneath their protective ensemble.

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Vitae

Dr. Alan Richardson's research focuses on the physiological changes and human tolerance to hypoxia and severe heat exposure. Dr. Richardson worked as a research exercise physiologist on the Centre for Aviation, Space and Extreme Environment Medicine Xtreme Everest Project in 2007 and 2009, carrying out cardiopulmonary exercise testing in trekkers ascending to Everest Base Camp. Since then Dr. Richardson has lead a research consultancy project with the National Fire Service investigating immune function and inflammatory responses in Fire Service instructors. He is course leader for the Sport and Exercise Science degree.

Miss Emily Watkins completed her B.Sc. (Hons) undergraduate degree in Sport and Exercise Science in 2014 at the University of Brighton. She began her Ph.D. at the University in October 2014, working with Fire Service Instructors to investigate their heat tolerance and immunological responses to frequent heat exposures. Emily is also a Technical Instructor for the Sport and Exercise Science degree.

Table 1. Mean $\pm$ SD for pre-test hydration measures, sweat rate and change in garment weight data for each undergarment condition.

	BOILER	SHORTS	WBL
U_{col}	2 ± 1	2 ± 0.5	2 ± 1
U_{osm} (mOsm.kgH ₂ O ⁻¹)	217 ± 133	268 ± 119	271 ± 141
U_{spg}	1.007 ± 0.003	1.006 ± 0.004	1.007 ± 0.003
Sweat rate (L.h ⁻¹)	0.95 ± 0.46	0.67 ± 0.40	0.71 ± 0.40
Garment Weight Change (kg)	0.34 ± 0.15	0.41 ± 0.15	0.30 ± 0.18

Figure 1. Schematic of the testing protocol, including a 10 min rest period and 45 min heat exposure, alternating between 5 min of exercise ($4\text{km}\cdot\text{h}^{-1}$ and 1% gradient) and 5 min of rest. Measurement time points are indicated.

Figure 2. Mean $\pm$ SD for PSI, ΔT_{re} and ΔHR . * denotes a significant effect of undergarment types at the time point.

Figure 3. Mean $\pm$ SD for T_{skin} , T_{re} and $\dot{H}_{\text{prod}}$ throughout the 45 min heat exposure period.

Figure 4. IL-6 post heat exposure mean $\pm$ SD, * denotes significant difference from the BOILER condition.

Figure 1

Figure 2

Figure 3

Figure 4

Fire Service Instructor's Undergarment Choice to Reduce Interleukin-6 and Minimise Physiological and Perceptual strain.

Highlights

- Fire Service Instructors experience high physiological and perceptual strain.
- Instructors are also at risk of sudden cardiac events.
- Interleukin-6 (IL-6) is a marker of inflammation and predictor of cardiac events.
- IL-6 response is reduced when wearing a wicking base layer or shorts and t-shirt.
- Undergarment choice has little impact on physiological and perceptual strain.