

CAN UNDERGARMENTS BE OF BENEFIT WHEN WORKING IN PROTECTIVE CLOTHING IN HOT ENVIRONMENTS?

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INTRODUCTION

The central focus of this project is the removal of sweat from the skin and the enhancement of evaporative cooling and thermal comfort for individuals working in hot-dry conditions when wearing military clothing and body armour. This sweat removal can occur either through evaporation, or its wicking away from the skin surface and through the clothing layers (Lotens and Wammes, 1993; Yasuda *et al.*, 1994), with evaporation eventually occurring from surfaces further away from the skin. Both processes remove body heat, but the former is more efficient.

Working in a hot climate can result in substantial elevations in body core temperature. This change will impact upon temperature and blood pressure regulation, and will also have a significant impact upon thermal comfort. In addition, thermal discomfort will be significantly influenced by the accumulation of moisture on the skin surface. When clothing is added, evaporation at the skin surface is impaired, with this reduction being a function of the properties of the fabric used in the clothing. Thus, less permeable fabrics restrict water vapour movement through a garment, and thereby reduce heat loss via the evaporation of sweat. Furthermore, the number of clothing layers worn by a person working in the heat will also dramatically affect the ability of the body to lose heat (Vogt *et al.*, 1983; Lottens and Wammes, 1993; Bouskill *et al.*, 2003).

The aim of this study was to assess the effect of added clothing layers, and also the effect of differences in textile composition, which may modify sweat removal from the skin surface, on physiological and perceived strain when working and wearing body armour in a hot-dry environment.

METHODS

Eight healthy, physically active males participated in this study. Subjects completed five trials lasting 140 min each. Phase one of each trial consisted of walking on a treadmill at 4 km.h⁻¹ (0% gradient) for 120 min. During phase two subjects completed a 20-min alternating running-walking protocol, consisting of 2 min running at 10 km.h⁻¹ (0% gradient), followed by 2 min walking at 4 km.h⁻¹ (0% gradient). A fan was set in front of each subject to produce a constant wind velocity (4 km.h⁻¹). Trials differed only in the clothing that was worn.

Subjects wore a standard disruptive pattern (camouflage) combat uniform (75% cotton, 25% polyester; insulation 0.29 m²K.W⁻¹), with combat body armour and helmet (total mass: 7.2 kg), but the garment (t-shirt) worn under the camouflaged shirt was altered to provide five different

ensembles: no t-shirt (ensemble A); 100% cotton t-shirt (ensemble B); 100% merino woollen t-shirt (ensemble C); 100% polyester t-shirt (ensemble D); hybrid shirt constructed using a torso segment (100% merino wool) in combination with a camouflaged shirt collar and long sleeves (75% cotton, 25% polyester; ensemble E).

Testing was conducted at the same time of day in hot-dry conditions (41.2°C (SD 0.2), 29.8% (SD 4.1) relative humidity), using fully hydrated subjects, with the trial sequence balanced across subjects to remove order effects. Physiological and psychophysical measures included: heart rate, body core (auditory canal) and skin temperatures (8 sites), clothing water vapour pressures, sweat rate, perceived exertion, thermal sensation, thermal discomfort and clothing discomfort.

RESULTS AND DISCUSSION

The mean heart rate ranged from 67.8 b.min⁻¹ (pre-exposure, temperate baseline) through to 169.9 b.min⁻¹ (last 20 min run; 138 min). The average peak heart rates were > 85% of the age-predicted maximal heart rate for these subjects, and confirmed the extent of the cardiovascular strain imposed by the protocol. However, heart rates did not differ significantly among the ensembles ($P>0.05$; Figure 1), and were remarkably consistent at each point of measurement. This consistency was also observed for the thermal data, with terminal core and skin temperatures not differing significantly among trials ($P>0.05$).

The number and thickness of the trapped air layers within different ensembles dictates dry heat transfer, and one would normally consider that an ensemble with fewer clothing layers would be the least stressful. However, this expectation was not realised, with variations in the clothing worn on the torso failing to have a significant effect upon core temperature ($P>0.05$). Indeed, the combination of the hot-dry environment, the metabolic heat production, and the clothing and body armour worn elevated physiological strain to such an extent that neither the addition of a torso undergarment (ensembles B-D), nor its removal (ensembles A and E), had any significant impact upon core temperature ($P>0.05$).

Skin temperatures reflect local metabolism, the blood-borne (convective) delivery of heat from the body core and local heat transfers. Mean skin temperatures did not differ among the ensembles ($P>0.05$). Therefore, one can assume that none of the ensembles elicited either favourable or unfavourable interactions with either the core-skin or the skin-air thermal gradients, or with the skin-air water vapour pressure gradients. Thus, regardless of the characteristics of the fabrics used to manufacture the torso undergarments, or even the presence of an undergarment, dry and evaporative heat transfers remained equivalent across trials.

From serial measures of water vapour pressure within the layers of these ensembles, one can evaluate the ability of each ensemble to permit the transmission of water vapour through to the external environment. Two microclimates, at each of two locations (upper chest and back), were investigated. For each torso clothing configuration, the water vapour pressure at the chest decreased when moving away from the skin and into the first clothing layer. Thus, a positive water vapour pressure gradient existed for all ensembles. These gradients favoured evaporation and the transmission of water vapour through the first clothing layer of each ensemble. Whilst one might predict that garments made of artificial (wicking) fibres would promote the establishment of a more favourable water vapour pressure gradient, none of the between-

ensemble comparisons were statistically different ($P>0.05$). Thus, no evaporative advantage (or disadvantage) was bestowed upon the wearer during the current trials by these different undergarment configurations, even though the climatic conditions were most favourable to the evaporation of sweat.

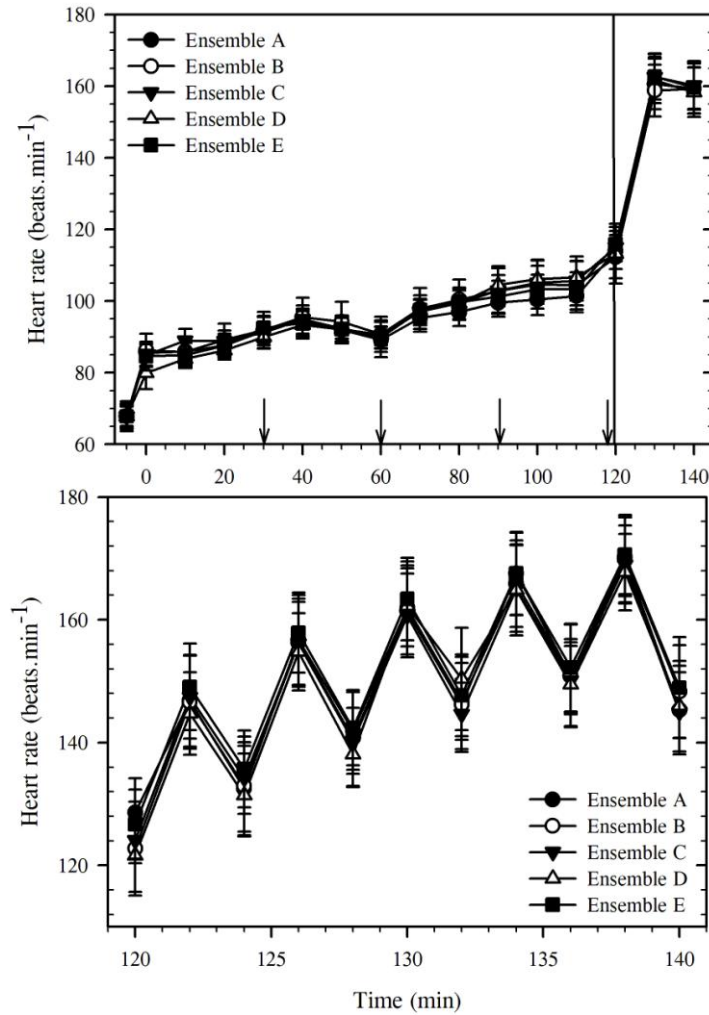


Figure 1: Heart rate responses during treadmill exercise in hot-dry conditions whilst wearing a combat uniform and body armour: 120 min at 4 km.h⁻¹ (upper Figure); then 20 min with 2 min at 10 km.h⁻¹ and 2 min at 4 km.h⁻¹ (lower Figure). Five different ensembles were used: A (no t-shirt); B (cotton t-shirt); C (woollen t-shirt); D (polyester t-shirt); E (hybrid shirt). Data are means with standard error of the means. Arrows indicate drinking.

Sweat secretion rates did not differ significantly among ensembles ($P>0.05$), and equivalent amounts of sweat were either retained within the clothing ($P>0.05$), or transmitted via evaporation to the external air ($P>0.05$). Subjective ratings of perceived exertion, thermal sensation, thermal and clothing discomfort did not reveal significant differences among any of

the five ensembles evaluated ($P>0.05$). Full details of this experiment are reported elsewhere (van den Heuvel *et al.*, 2008).

CONCLUSIONS

Under the current experimental conditions, neither the addition of a torso undergarment (ensembles B-D), nor its removal (ensemble A and E) had any significant impact upon either physiological or subjective indices of strain. It is concluded that this state resulted from the high thermal load associated with this experiment. That is, when individuals are wearing whole-body clothing and body armour, whilst working hard in hot-humid conditions, there is no benefit to be gained by wearing a torso undergarment, regardless of the claims made by manufacturers.

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