PHYSIOLOGICAL IMPACT OF FIRST-RESPONDER CHEMICAL, BIOLOGICAL AND RADIOLOGICAL PROTECTIVE ENSEMBLES.

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INTRODUCTION

Clothing has two primary affects upon workers. First, it modifies the ease with which thermal energy (heat) is transferred between the body and the environment by providing the body with a layer of insulation. This can be advantageous in a thermally dangerous environment (*e.g.* fire fighting, cold-water immersion), but disadvantageous during strenuous exercise where a significant amount of metabolic heat is produced (Gonzales, 1988). Second, it affects moisture evaporation from the skin surface, and this has a critical impact upon both thermal comfort and body temperature regulation (Candas, 2002). When clothing is worn, evaporation at the skin surface will be reduced, and the extent of this reduction is a function of the properties of the fabric that is used to manufacture the garment. Thus, less permeable fabrics allow less water vapour to pass through a garment. Some fabrics are designed to allow water vapour, but not water droplets to pass through, while others are designed to protect the wearer from chemical, biological and radiological agents and are almost impermeable. Ensembles made from minimally impermeable fabrics are the focus of this project.

Some personal protective ensembles are totally encapsulating and completely impermeable, and work tolerance time in such clothing can become a simple function of the metabolic heat production (work rate) of that individual. While new generation fabrics used in some chemical, biological and radiological (CBR) protective clothing enable some air and moisture penetration, these ensembles will dramatically reduce the capacity of individuals to sustain high work rates in the heat, or even extended moderate workloads in more temperate conditions (Montain *et al.*, 1994; Caldwell *et al.*, 2007). Indeed, such ensembles, when worn during moderate work intensities, can place an unrealistic physiological burden on personnel.

Within the current geopolitical climate, a wide range of emergency service personnel are being provided with CBR ensembles, and a need exists to evaluate the physiological impact of this protective equipment upon the wearer under operational conditions. Accordingly, the aim of this project was to study thermal strain in people performing light-moderate work in temperate-warm environmental conditions, while wearing each of three different CBR protective ensembles.

METHODS

Eight healthy, physically active adult males participated in this study. Subjects completed three trials in total, and these differed only in the type of CBR protective ensemble that was worn: ensemble A (CBCS, Melba Industries, Australia); ensemble B (SWAT, Paul Boye, France); ensemble C (CR1, Remploy Frontline, UK). Subjects wore the same t-shirt and shorts under ensembles A and B, but a special (thermal) undergarment (long-sleeved shirt and long pants) was worn under ensemble C. Each ensemble was tested with subjects using a standard respirator mask, gloves and over boots, representing the high-threat MOPP4 state. Over each ensemble, subjects also wore torso body armour (but without hard armour plates) and standard military webbing (Figure 1).

Figure 1: The chemical, biological and radiological protective ensembles.

Within each experiment, subjects exercised on a treadmill at each of two speeds: walking for one hour at 3 km.h^{-1} (0% gradient), and walking for 30 min at 6 km.h^{-1} (3% gradient), with 10 min of seated rest period between. Air velocity matched walking speed to ensure comparable convective cooling to that encountered in the field. Subjects consumed water at a rate of 4 mL.kg^{-1} every 30 min. All testing was conducted at the same time of day in temperate conditions (29.3°C (±0.3), 56.0% (±0.7) relative humidity), using fully hydrated subjects, with the trial sequence balanced across subjects to remove order effects. For details see: van den Heuvel *et al*. (2007).

Data were collected for core temperature (rectal), skin temperatures (forehead, right scapula, right chest, right upper arm, left forearm, left dorsal hand, right anterior thigh and left posterior calf), heart rate, sweat rate (gross body mass changes), and psychological state (perceived exertion, thermal sensation, thermal discomfort and clothing discomfort). In addition, local water vapour pressures were derived from local clothing temperatures and relative humidities inside the clothing layers (upper arm and thigh segments).

RESULTS AND DISCUSSION

For most indices, ensemble C was associated with the greatest elevation in physiological strain, with the least stressful being ensemble A. This pattern was significantly evident for each of the following indices ($P<0.05$): core temperature, mean skin temperature, microclimate water vapour pressure, heart rate, sweat rate and exercise tolerance times. Due to the standardisation procedures currently employed, one may assume that these differences in physiological strain can largely be ascribed to variations in the characteristics of the clothing ensembles evaluated during this experimental series. Significant differences were also evident for thermal sensation and thermal discomfort (*P*<0.05).

Mean skin temperatures reflect the thermal energy content of cutaneous tissues close to the skin surface, and also heat trapped between the skin and clothing. Since skin temperatures modify the ability of the body to dissipate heat, and also have a powerful influence on thermal discomfort, these data form an essential part of any quantification of thermal strain in individuals wearing protective ensembles. Greater mean skin temperatures were observed when wearing ensemble C relative to both protective ensembles A and B (Figure 2; *P*<0.05), and the net result of this was that heat loss from the body core was impeded. Indeed, ensemble C was associated with a greatest elevation in core temperature (Figure 3; *P*<0.05), such that the longer these trials continued, the greater the difference became between these protective ensembles (*P*<0.05). Thus, one may assume that the greater skin temperatures observed when wearing the protective ensemble C were the combined result of a higher skin blood flow, driven by a greater core temperature, and a greater heat trapping within that ensemble.

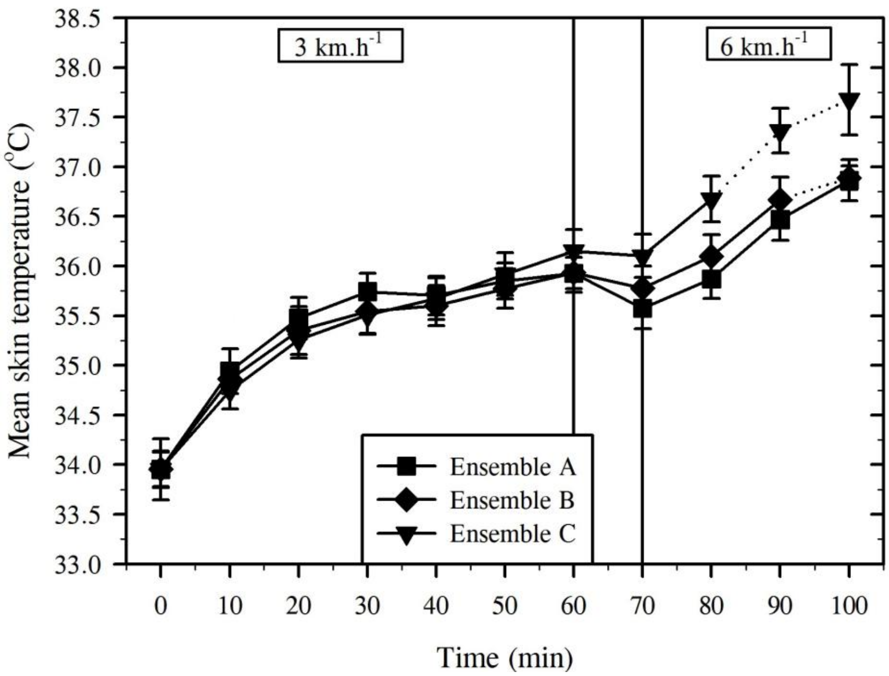

Figure 2: Mean skin temperatures during steady-state work in a temperate environment whilst wearing three different CBR ensembles. Broken lines indicate times where subjects terminated a trial prematurely. Data are means with standard error of the means.

In hot environments, evaporative cooling is the principal avenue for body heat dissipation, and for this to occur, an adequate water vapour pressure gradient must be present. When individuals were wearing personal protective clothing, the water vapour pressure of the microclimate next to the skin, and within clothing layers dictated the evaporation of sweat. Naturally, one would expect there to be a minimal transmission of water vapour within CBR ensembles, but between ensemble differences in the water vapour pressure gradient will impact upon thermal strain. For the skin-to-undergarment space (first microclimate), the ensemble A displayed significantly lower water vapour pressure than either of the other two ensembles ($P<0.05$). These differences were also evident within the next microclimate space (undergarment to inner surface of the CBR ensemble), but these vapour pressures were generally more uniform. Consequently, subjects lost significantly more sweat, relative to protective ensemble A, when wearing either of the other ensembles ($P<0.05$).

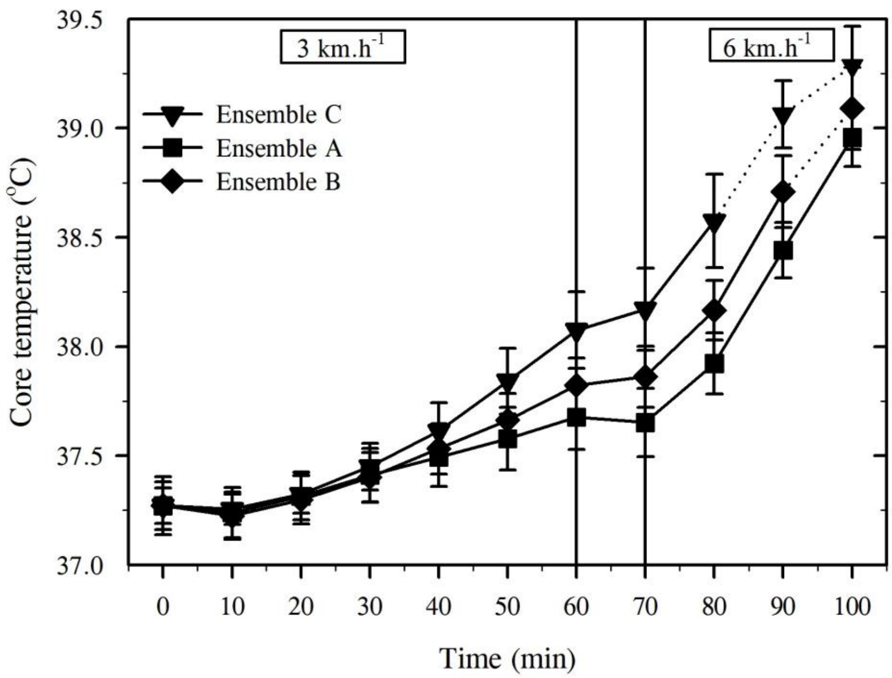

Figure 3: Rectal temperatures during steady-state work in a temperate environment whilst wearing three CBR ensembles. Broken lines indicate times where subjects terminated a trial prematurely. Data are means with standard error of the means.

Cardiovascular strain was consistent with the observed thermal pattern, with subjects terminating exercise with average heart rates of 168 $b.min^{-1}$ (ensemble A), 173 $b.min^{-1}$ (ensemble B) and 182 $b.min^{-1}$ (ensemble C). These heart rates were a function of the combined influences of the exercise intensity, the overall thermal load of the environment and differences in the characteristics of the ensembles. As a result, only 93% of subjects completed the experiment when wearing CBR ensemble C, > 98% completed testing in ensemble B and 100% were able to complete the protocol when wearing the protective ensemble A.

CONCLUSIONS

From these observations, it may be concluded that CBR ensemble C, when worn during light-moderate exercise in warm and humid conditions in the MOPP4 state, places the wearer under the greatest physiological strain. This ensemble, possibly because of its extra clothing layer, possesses the highest inherent clothing insulation, and therefore greater thermal protection for the wearer. However, this extra layer also impedes water vapour transmission. In warm-humid conditions, this is a distinct disadvantage, and one must ask whether this extra clothing layer is actually necessary, unless it is integral to the chemical, biological and radiological protection that is provided. Conversely, ensemble A had the least physiological impact under the current experimental conditions.

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