THE EFFECTS OF PROTECTIVE CLOTHING ON METABOLIC RATE

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Introduction

There are many industrial sectors where workers are required to wear personal protective clothing and equipment (PPC/PPE). Although this PPC may provide protection from the primary hazard, for example heat or chemicals, it can also create ergonomic problems. The growing concern regarding health and safety of workers has generated regulations and standards, as well as research and development in the area of PPC/PPE (1). Although these have helped to improve the quality of the PPC and increase the safety of the workers, information on the effect of the clothing on the wearer and the interactions between PPC, wearer and environment are limited. Most PPC is designed for optimal protection against the hazard present, however the protection in itself can be a hazard.

There are important side effects to protective clothing and typically with increasing protection requirements, the ergonomic problems increase. The problems of protective clothing can be split into thermal and metabolic issues. By creating a barrier between the wearer and the environment, clothing interferes with the process of thermoregulation, particularly reducing dry heat loss and sweat evaporation. Protective clothing also increases the metabolic cost of performing a task by adding weight and by otherwise restricting movement. The binding or hobbling effect of bulky, stiff or multilayered clothing adds measurably to work (2) .

Current heat and cold stress standards consider the balance of heat production and loss but focus on environmental conditions, clothing insulation and work rate metabolism. They also assume workers are wearing light, vapour permeable clothing. By failing to consider the metabolic effects of actual protective clothing, the standards can underestimate heat stress or overestimate cold stress; therefore current standards cannot be accurately applied to workers wearing PPC.

The effects of protective clothing on workers has been studied across a number of industries but studies have emphasized the thermal effects of clothing, such as heart rate, core temperature responses to different garments and performance decrements in the heat. Very few studies have considered the metabolic effects. Multilayered clothing ensembles have been reported to increase oxygen uptake by an amount significantly in excess of that which can be accounted for by the increases in the clothed weight of the subjects. Teitlebaum and Goldman (1972) walked subjects on a treadmill either wearing an additional 5 layers of arctic clothing over their standard fatigues or carrying the 11.19kg weight of the five layers as a lead-filled belt. In conclusion, the authors suggest the significant increase on average of approximately 16% in the metabolic cost of working in the clothing compared to the belt can most probably be attributed to 'friction drag' between the layers and/or a 'hobbling effect' of the clothing (3). Duggan (1988) investigated the effect using a bench stepping task in military chemical protective clothing, with long underwear and quilted thermal jackets/trousers as extra layers. When corrected for clothing weight, VO_2 was greater by an average of 9% (4).

In order to obtain data on a wider range of PPC and further investigate this possible 'hobbling effect' an experiment was performed on an extensive set of protective clothing ensembles with a focus on the metabolic effects.

Methods

14 protective garments were tested from a range of industries; firefighter's suits, general workwear suits, chemical protective suits, cold store suits as well as garments for chainsaw and welding protection. A number of military garments were also tested including a nuclear, biological, chemical protective ensemble, body armour and a waterproof jacket. All protective garments were worn with army boots and cotton work trousers and t-shirt or sweatshirt underneath, apart from the army clothing which was worn with the appropriate base layers or combat fatigues. For the control condition trainers were worn, with cotton tracksuit trousers and a t-shirt which were provided.

Metabolic rate was measured with a MetaMax 3B (Cortex, Germany) portable breath-by-breath analyser, which was calibrated before each session for pressure, gas and volume. A laptop running the Metasoft software allowed for real-time monitoring of participants, included heart rate for which a compatible sensor belt (Polar Electro, Finland) was worn.

After dressing and instrumentation, data collection was started. Participants rested for 3 minutes and then completed 4 minutes of walking on a treadmill (Tunturi T-track Gamma 300, Finland) at 5km/hr and 4 minutes of stepping at a rate of 25 steps/min on a 20cm step (Reebok aerobic step) separated by a 3 minute rest period. Participants presented at the laboratory for 7 sessions on different days, in each session they completed the test in 2 protective garments separated by a control condition. The session time was limited to reduce any thermal effects from the clothing or the exercise. The protective garments were paired (A,B) and then the order of the pairs randomised in a Latin square, within the pairs participants 1–3 completed garment A first then a control then garment B, while participants 4–6 completed garment B first then a control then garment A.

The data was exported into Microsoft Excel files for analysis, and the percentage increase in metabolic rate when wearing the protective garments from the control condition was calculated. In order to establish if walking and stepping in the protective garments significantly increased the metabolic rate above a control condition, single sample t-tests with a test value of 100 (control equals 100%) were carried out for each garment.

Results and Discussion

6 participants (3 males, 3 females, age 23±0.25years, height 176±6.5cm, weight 71±8.5kg) completed the test in 14 protective garments. The average environmental conditions for the room were 18.7°C ± 1.1 °C and 40.1% ± 4% relative humidity.

The percentage increases in metabolic rate have been plotted for the 14 protective garments and the results for walking and stepping are presented in Figures 1 and 2 respectively. Figure 1 shows that the garment with the highest percentage increase when walking was a 'Grey Fire' suit which caused a 21% increase in metabolic rate, the lowest increase was 4% for a Mountain Rescue uniform. Increases in the metabolic rate of 12% or above proved to be significant ($p<0.05$) although it is difficult to give a specific threshold as there is a gap from the 'Army+ waterproof' (jacket only) at 12% to the next lowest, 'Army+vest' (body armour) which caused a 9% increase.

For the stepping task, illustrated in Figure 2 values ranged from a 20% increase in a Workwear (2 layer) suit to just 3% for a Mountain Rescue uniform, with values recorded as significant ($p<0.05$) with an 8% increase or above.

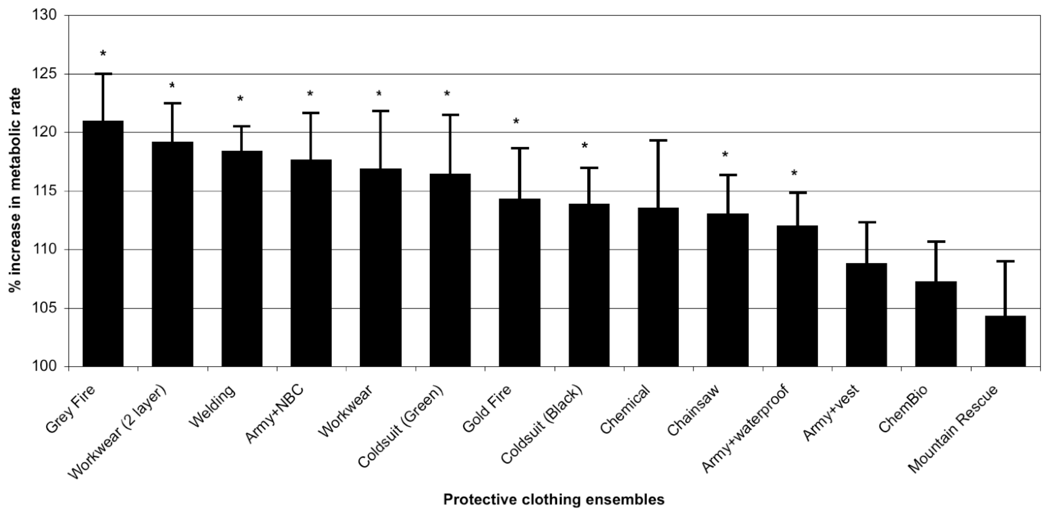

Figure 1. Average (n=6) percentage increase (100%=control value) in metabolic rate when wearing protective clothing during treadmill walking at 5km/hr. Significance of $p<0.05$ indicated by *.

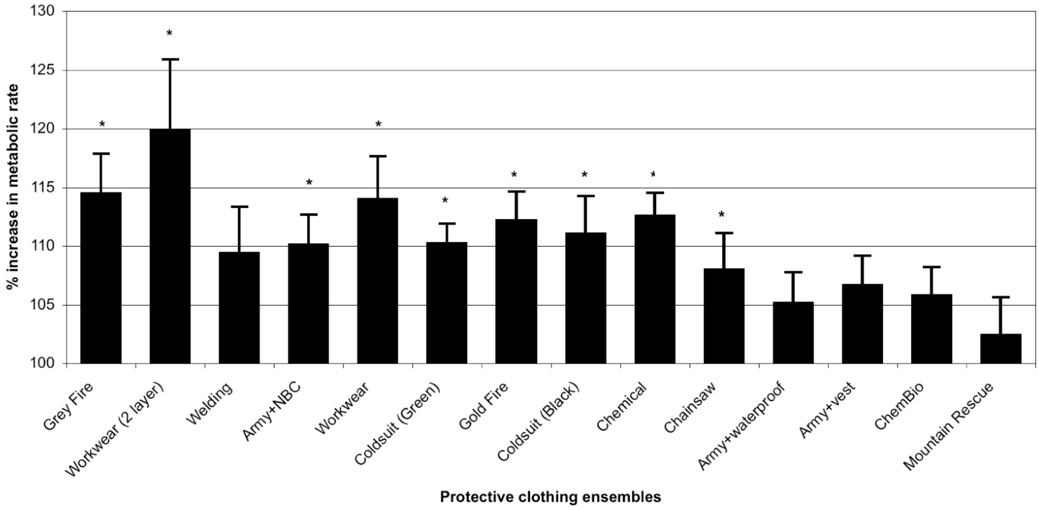

Figure 2. Average (n=6) percentage increase (100%=control value) in metabolic rate when wearing protective clothing during stepping (25 steps/min, 20cm step). Significance of $p<0.05$ indicated by *.

The two fire suits (Grey and Gold) worn in this study had significant ($p<0.05$) effects on the metabolic rate of the wearer and they were the two heaviest garments to be tested. Walking in the Grey suit (7.00kg) elicited a 21% increase, 14% in the Gold suit (6.66kg), whilst stepping increased the metabolic rate by 15% in the Grey suit and 12% in the Gold suit. These figures are similar to those reported by Graveling and Hanson (2000) from laboratory trials where standard firefighter clothing typically increased physiological cost (oxygen consumption) by 15% over control sessions (5).

The 'Army+NBC' and 'Army+vest' garments also showed interesting results. The 'Army+NBC' ensemble was made up of a norwegian shirt, combat trousers and army boots with NBC jacket and trousers over the top plus overboots and gloves, total weight 5.27kg. The 'Army+vest' ensemble was made up of base layer (top and bottoms), combat trousers, norwegian shirt and army boots and weighed 5.32kg. Even with very similar clothing weights the percentage increase values for the 'Army+vest' ensemble were only 9% when walking and 7% when stepping compared to the significant ($p<0.05$) increases of 18% when walking and 10% when stepping in the 'Army+NBC' ensemble. Despite the large body of knowledge on the performance effects of chemical protective clothing, little quantitative information exists about the energy cost. Patton *et al.* (1995) completed a laboratory study wearing standard BDU (battledress uniform) or CP clothing (chemical protective clothing with a mask, overgarment, gloves and boots) in very similar conditions, 18-22°C and 40-55% relative humidity. VO_2 corrected for differences in clothed weight was 6-11% greater in CP clothing across a range of exercise intensities again suggesting that factors other than clothing weight were responsible for the increase (6).

The significant values recorded in this study also fit in with the results of two studies highlighted in the introduction that found a 16% increase in metabolic cost during walking (3) and 9% increase in VO_2 during stepping (4).

Conclusions

It has been shown that protective clothing ensembles worn in a variety of industries increase the metabolic cost when walking and stepping. Increases of 8% and above compared to a control condition were significant ($p<0.05$). The increases cannot solely be explained by the added clothing weight. Analysis of the clothing properties such as bulk and stiffness could be carried out and further work is needed to fully understand the significance of the 'hobbling effect'.

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