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# MODELLING THE METABOLIC EFFECTS OF PROTECTIVE CLOTHING

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## ABSTRACT

Protective clothing is worn in many industrial and military situations. Although worn for protection from one or more hazards, protective clothing can add significantly to the metabolic (energy) cost of work. Suggestions put forward as to the mechanisms behind the observed increases include, the additional clothing weight of the protective garments, possible friction between the number of layers that must be worn and restriction of movement due to clothing bulk. However, despite much speculation, these areas have not received much investigation.

Wearing protective clothing from a range of industries and with quite different characteristics for example weight, bulk and stiffness significantly increased metabolic rate when walking, stepping and completing an obstacle course activity. Increases in the metabolic rate of up to 20% above control conditions (lightweight tracksuit and trainers worn) were seen. A number of clothing properties were then investigated to try and understand the causes of these recorded metabolic rate increases. Clothing bulk was measured at 3 sites, upper arm, torso and thigh. The stiffness of the clothing was also calculated, using a method which measured the clothing drape of the sleeve, main body of the garment and trouser leg.

A multiple regression carried out on the data showed body weight to be the best predictor of absolute metabolic increases across all work modes. For the % increase in metabolic rate total clothing weight was the best predictor. Torso bulk was negatively correlated with the increased metabolic rate for walking and stepping and the overall average, whereas leg bulk was a significant predictor of an increased stepping metabolic rate and leg stiffness a significant predictor for the obstacle course work mode.

## 1. INTRODUCTION

The effects of protective clothing on workers has been studied across a number of industries but most studies have emphasized the thermal effects of clothing, such as heart rate, core temperature responses to different garments and performance decrements in the heat. Few studies have considered the metabolic effects. In those that have, it has been shown that various protective clothing ensembles increase the metabolic cost of performing walking and stepping tasks by adding weight (1, 2, 3, 4).

A ‘hobbling’ effect of clothing due to the interference with movement at the body’s joints, produced by the bulk of the clothing, has also been suggested as a contributing factor to the increased energy costs documented (1, 2, 3, 4).

## 2. METHODS

Using the data from this lab on increased metabolic rate for a number of protective garments (1), further data was collected on the clothing characteristics. Clothing bulk was measured at 3 sites, upper arm, torso and thigh, Participants wore a pair of work trousers and t-shirt under the protective garments and then measurements of the excess clothing fabric were made at 3 sites; upper arm, torso and upper thigh, using a standard tape measure, by pinching the clothing fabric at each site and measuring the excess fold of material as illustrated in Figure 1.


**Figure 1.** Photographs showing site and method of measuring clothing bulk.

The stiffness of the clothing was also recorded, using a method which measured the clothing drape of the sleeve, main body of the garment and leg. Measurements were made by supporting the garment on a small platform 20cm above the ground, as illustrated in Figure 2 and allowing the section of the garment to be measured to drape over the edge. A tape was in place on the floor and the distance to the point at which the garment touched the floor was recorded, as shown in Figure 2. For the leg measurements the trousers were laid on the platform with the crotch at the edge of the platform and the left leg of the garment draped off the platform. For the arm measurement the main body of the garment was placed on the platform with the seam of the left sleeve on the edge of the platform allowing the left sleeve of the garment to drape off the platform as in Figure 2. For the torso measurement, the main body of the garment was supported on the platform with the armpits of the garment in line with the edge of the platform allowing the torso section of the garment to drape over the edge.

**Figure 2.** Photographs to illustrate platform and tape measure used for stiffness measurements and their positions during measurements of the drape of the sleeve of a garment.

A stepwise interactive multiple regression was carried out to assess if any of these clothing properties (weight, bulk, stiffness) could be used to predict the metabolic cost of wearing the protective clothing.

## 3. RESULTS AND DISCUSSION

The results of the regression modelling have been summarised in Table 1. The columns contain headings and units of the variables recorded when protective clothing was worn walking, stepping, completing the obstacle course and overall (average of the 3 work modes). Metabolic rate was measured in watts and subsequently calculated as watts per metre squared to take account of body surface area and as percentage (%) increase from a control condition. Heart rate results have also been analysed. The rows in the table contain the variables that the modelling process showed to be significant predictors of the metabolic rate and heart rate.

When the overall % increase in metabolic rate was analysed, total clothing weight was found to positively correlate with an increased metabolic rate and clothing bulk around the torso to negatively correlate with an increased metabolic rate. The effects of load, in this instance carried as extra clothing weight, on oxygen consumption and metabolic cost of work has been well documented. The modelling suggests that greater increases in metabolic rate are seen in garments with a lower clothing bulk in the torso region. When the absolute results (watts) for overall increase in metabolic rate are considered the best predictor of the increase is body weight.

When the walking work mode is considered, total clothing weight (+) and torso bulk (-) are again the best predictors of the % increased metabolic rate, total clothing weight positively and torso bulk negatively as described above. For the absolute walking results, metabolic rate (watts and watts/$m^2$) and heart rate, body weight is the best predictor of the increase.

For the stepping work mode, the % increase in metabolic rate was best predicted by increased clothing weight (+) and decreased torso bulk (-) as for the overall and walking work modes. Additionally increased leg bulk was positively related to an increased metabolic rate. During the stepping activity, the range of movement in the leg especially in the knee is much higher than when walking so bulkiness of the trousers will have a much larger effect on the energy cost of the activity. Body weight was the only predictor of the stepping metabolic rate when the absolute values were considered (watts and watts/$m^2$) and total clothing weight the only predictor of heart rate.

When the results from the obstacle course work mode are considered in isolation, the total clothing weight (+) is the best predictor of the % increase in metabolic rate. However when the absolute metabolic rate results are analysed the body weight (+) and leg stiffness (+) are the best correlates of an increased metabolic rate. The obstacle course involved a number of activities including lifting and moving crates, moving over and under wooden hurdles and crawling on hands and knees. Garments with greater material stiffness in the leg clearly made these movements harder and less efficient, as the model predicts the greater the stiffness, the greater the metabolic rate. Total clothing weight and leg bulk were also important correlates of an increased metabolic rate, they can be considered to be equally important predictors of metabolic rate but when one is included in the model the other becomes not significant and vice versa. Heart rate during the obstacle course is best predicted by total clothing weight (+) worn but also by leg bulk (+).

| | overall | | walking | | | | stepping | | | | obstacle course | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | met rate | met rate | met rate | met rate | met rate | heart rate | met rate | met rate | met rate | heart rate | met rate | met rate | met rate | heart rate |
| | % increase | watts | % increase | watts | watts / m2 | bpm | % increase | watts | watts / m2 | bpm | % increase | watts | watts / m2 | bpm |
| body weight | | + | | + | + | + | | + | + | | | + | + | |
| total clothing weight | + | | + | | | | + | | | + | + | + | + | + |
| torso bulk | - | | - | | | | - | | | | | | | |
| leg bulk | | | | | | | + | | | | | + | + | + |
| leg stiffness | | | | | | | | | | | | + | + | |

**Table 1.** Summary table of results from multiple regression

## 4. CONCLUSIONS

In summary, the stepwise interactive multiple regression carried out on the data showed body weight to be the best predictor of absolute metabolic rate increases across all work modes. For the adjusted data on metabolic rate (% increase when wearing protective clothing from control) total clothing weight was the best predictor of the increase. Torso bulk was negatively correlated with the increased metabolic rate when walking, stepping and overall. Leg bulk proved to be a good predictor of an increased stepping metabolic rate and leg stiffness a good predictor of an increased metabolic rate when completing the obstacle course work mode.

This modelling was based on data from 12 protective garments and 4 categories of predictors; subject weight, total clothing weight, bulk (measured at 3 sites; arm, torso and leg) and stiffness (measured at 3 sites; arm, torso and leg). Further work on clothing weight distribution and number of layers will hopefully add to the predictive power of the model.

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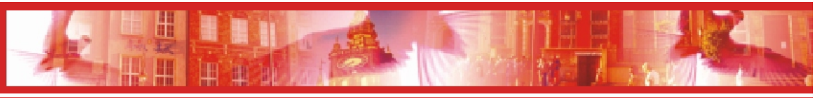

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The European Conference on Protective Clothing (ECPC) is organized every 3 years by the European Society of Protective Clothing (ESPC) which was founded in 2000 in Stockholm. The purpose of ESPC is to act as a forum for experts cooperation in the field of protective clothing (including gloves and shoes) all over the Europe, but the experts from all over the world are also welcome. The forum was created in 1984 in Scandinavia where NOKOBETEF (Nordic Coordination Group on Protective Clothing as a Technical Preventive Measure) was founded. ESPC and Nokobetef are independent organizations.

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*Despite the latest achievements in technology aimed at new solutions in safety at the work place, there are still traditional and new hazards and risks against which application of personal protective equipment and protective clothing is necessary. Risk compounded by simultaneous exposure to several harmful or dangerous factors must not be overlooked, either. At the same time it is crucial to take into account workers' growing expectations of comfort while using personal protective equipment. Thus high-performance protective clothing continues to be an important tool for creating safe working conditions and therefore research in this field is indispensable.*

*Application of new solutions, such as high-tech materials and microelectronics, in designing products can help achieve equilibrium between protection, comfort and durability of protective clothing. In accordance with the principle of balanced protection, both scientific and applied research aimed at the development of innovative materials and clothing is necessary. Smart protective clothing is a good example of successful research; it, for example, enables selt-adjustment of the microclimate under a protective barrier and indication of safe wearing time of clothing. Improvement of testing and measurement technology,which should map real-use conditions of protective clothing and make objective assessment of new products possible, also constitutes an important area in research.*

*Intensive exchange of knowledge and experience among experts is needed for successful development of optimal products.*

*That is why representatives from various institutions, organizations and enterprises involved in protective clothing, including gloves and footwear are meeting in Gdynia, Poland. The 3rd European Conference on Protective Clothing is an excellent opportunity for scientific discussions, an exchange of information and co-operation among experts.*

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