The influence of clothing weight and bulk on metabolic rate when wearing protective clothing

This item was submitted to Loughborough University's Institutional Repository by the/an author.

Citation: DORMAN and HAVENITH, 2005. The influence of clothing weight and bulk on metabolic rate when wearing protective clothing. IN: Proceedings of the Third International Conference on Human-Environmental System ICHES 05 , Tokyo, Japan, September 2005, pp 47-50

Additional Information:

- This is a refereed conference paper.

Metadata Record: https://dspace.lboro.ac.uk/2134/2546

Please cite the published version.
This item was submitted to Loughborough’s Institutional Repository by the author and is made available under the following Creative Commons Licence conditions.

For the full text of this licence, please go to:
http://creativecommons.org/licenses/by-nc-nd/2.5/
The influence of clothing weight and bulk on metabolic rate when wearing protective clothing

Lucy Dorman and George Havenith
Environmental Ergonomics Research Centre, Department of Human Sciences, Loughborough University, Loughborough, LE11 3TU, UK.

Corresponding author: Lucy Dorman
Email: l.e.dorman@lboro.ac.uk

ABSTRACT
Protective clothing is worn in many industrial and military situations. Although worn for protection from one or more hazards, the clothing can have secondary effects which may limit the ability of the worker to perform the tasks required of the job. 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, 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. The aims of this study, were to look at the effects of carrying weight close to the body centre of gravity and at the extremities and also to estimate the bulkiness of a selection of protective garments and how that might relate to the increased metabolic rate wearers may incur.

Eleven weight configurations were tested for the first part of the study, with weights of 2 to 10 kg carried around the waist. Weights of 2 and 4 kg were also carried around the ankles or wrists (1 or 2 kg on each limb) and weights of 4 and 8 kg carried around the ankles and wrists (1 or 2 kg on each limb). The increases in metabolic rate (measured by indirect calorimetry using a Cortex MetaMax analyzer) were compared to a control condition after participants had walked at 5km/hr on a treadmill and completed an obstacle course. There was a fairly linear increase in metabolic rate as the weight carried around the waist increased. A larger increase in metabolic rate was recorded when the weight was carried around the wrists and an even larger increase when the weight was on the ankles.

The clothing bulk was measured at 3 sites; upper arm, torso and thigh on six protective clothing ensembles, that had been worn in a previous study that had looked at the increase in metabolic rate when working. There seemed to be a relationship between clothing bulk in the legs and the scale of previously recorded metabolic rate increases.

Key words: protective clothing; metabolic rate; energy cost; weight

1. 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. A better understanding is needed of the interactions between the environment, clothing, task and worker (Nunneley 1989).

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. These problems 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 adds measurably to the metabolic (energy) cost of work by adding weight and by otherwise restricting movement (Nunneley 1989, Dorman and Havenith 2005). Energy cost is dependent on various aspects of the clothing, such as its weight, number of layers and motion restriction. The freedom of motion in clothing is dependent both on fabrics and construction (Lotens).

Experimental studies have demonstrated that the metabolic cost of walking, without external load, is linearly related to the weight of the body (Givoni and Goldman 1971). Heavy fabrics will show their impact in several ways. The weight of the garment has to be carried and increases the energy cost. With clothing it is obvious that some weight is moved out on to the extremities towards the hand and feet (Lotens). Soule and Goldman (1969) have demonstrated that the metabolic cost of load carriage increases when the load is placed in the hands or on the feet, i.e. away from the centre of gravity of the body. Weight on the extremities of the body has to be accelerated and decelerated at every step, causing an even higher increase in energy cost. In summary, it has been shown that various protective clothing ensembles increase the metabolic cost of performing walking and stepping tasks by adding weight (Teitlebaum and Goldman 1972, Duggan 1988, Patton et al 1995, Dorman and Havenith 2005).

Bulk is also an impeding factor, like weight. 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 described in many studies that have shown an increased energy cost with protective clothing (Teitlebaum and Goldman 1972, Duggan 1988, Patton et al 1995, Dorman and Havenith 2005). Teitlebaum and Goldman (1972) also cite the earlier work of Gray, Consolazio and Kark (1951) who noted a binding or hobbling effect of heavier clothing worn in the cold which increased work output, thus increasing caloric demand. Further, Belding (1945) recorded a trend that as the bulk of clothing worn increased, the increase in the caloric expenditure was much greater than could be accounted for by the increased weight of the clothing, again suggesting a hobbling effect of clothing.

So, the bulkiness of clothing, often expressed as the number of clothing layers, has great influence on energy expenditure. Lotens (1982) summarized this into a ‘Rule of thumb’ of 4% increase in energy cost for each clothing layer, at marching speed and 3% per layer at a slower pace. But he points out that the actual source of this effect is not well understood, friction between layers and hobbling gait are possible explanations. He concludes, it seems a logical, although yet unproven hypothesis that motion restriction does raise energy cost considerably (Lotens 1982).

Thus the aims of this study, were to look at the effects of carrying weight close to the body centre of gravity (using a weight belt) and at the extremities (weights worn around the wrists and ankles). Secondly, to estimate the bulkiness of a selection of the protective garments originally tested in this lab (Dorman and Havenith 2005).

2. METHODS

11 weight conditions were defined for the first part of the study. Weights of 2, 4, 6, 8, 10 kg were carried around the waist using a diving belt and weights (Tribord, Decathlon). 1 and 2 kg weights with velcro fastenings (Domyos, Decathlon) were carried on the ankles and wrists, the conditions being ankles 2 (1kg on each ankle), ankles 4 (2kg on each ankle), wrists 2 (1kg on each wrist), wrists 4 (2kg on each wrist), ankles/wrists 4 (1kg on each ankle and wrist) and ankles/wrists 8 (2kg on each ankle and wrist). Participants also wore lightweight tracksuit trousers and a sweatshirt which were provided and their own trainers.

During each session, participants walked at 5km/hr on a treadmill (h/p/cosmos mercury, Germany) and then completed an obstacle course that included stepping, moving under and over obstacles and moving crates. They also completed a control unweighted condition in each session. The order of
the weight conditions were balanced using a latin square.

Metabolic rate was measured with a MetaMax 3B (Cortex, Germany) 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, including heart rate for which a compatible sensor belt (Polar Electro, Finland) was worn. The data was exported into Microsoft Excel files for analysis, and the percentage increase in metabolic rate for each weight condition from the control condition calculated.

For the investigation of clothing bulk, 6 protective garments were measured. Measurements of the excess clothing fabric were taken at 3 sites; upper arm, torso and thigh using a standard tape measure.

3. RESULTS AND DISCUSSION
8 participants (4 males, 4 females, age 23.7±3.5yrs, height 1.72±0.10m, weight 69.5±16.0kg) completed all the weight conditions. The percentage increase in metabolic rate for each weight condition when walking and overall (including the obstacle course data) has been plotted in a bar chart, Figure 1.

The waist weight conditions showed a steady increase in metabolic rate as the weight carried increased from 2 kg up to 10 kg, as indicated in Figure 1, which also shows that the increase in metabolic rate when carrying weight on the ankles and wrists was higher than carrying the equivalent load around the waist. The increase was also slightly higher for the ankle weights than when the same weight was carried around the wrists. When the walking data is separated from the overall data including the obstacle course data (see the column labels in Figure 1) the increases in metabolic rate recorded were slightly lower. As the obstacle course demanded a greater range of movement, the weight seemed to have a slightly greater effect on overall metabolic rate.

The data from the weight conditions has also been combined with data on increased metabolic rate previously collected from a number of protective garments (Dorman and Havenith 2005) and theoretical data calculated from the equation of Givoni and Goldman (1971), the relationship is plotted as a scatter graph in Figure 2. The protective clothing data from the previous study showed a good relationship between the weight of the garment and an increased metabolic rate when walking. However the increases in metabolic rate were far larger than could be explained by the weight alone as many of the points were above the theoretical line created by the formula of Givoni and Goldman (1971). The data collected in this study for weight carried around the waist fits very well with the Givoni and Goldman (1971) line indicated on the graph in Figure 2. The increased metabolic costs of carrying the weight around the ankles and wrists are also clear.

The results discussed and illustrated in Figures 1 and 2 agree with the literature on the metabolic costs of
The increased metabolic cost of carrying the weight on the ankles compared to the wrists also corresponds with Soule and Goldman (1969) who state that weight may be carried in the hands without a great increase in energy cost but when weight is carried on the feet, energy cost is greatly increased.

10 participants (6 males, 4 females, age 25.9±4.6yrs, height 1.74±0.10m, weight 71.7±14.5kg) were measured for the bulk study. Figure 3 illustrates the increased clothing bulk at each of the three measured sites, upper arm, torso and thigh for the 6 garments. The garments have been ordered with those showing the highest overall increases in metabolic rate when worn in the previous study (Dorman and Havenith 2005) at the far left to those showing the smallest increase on the right. The most obvious differences can be seen in the clothing bulk measurements for the leg (measured at the upper thigh) with the workwear, gold fire and black coldsuit having almost 4cms extra bulk in the legs than the green coldsuit, chainsaw and mountain rescue garments. The 3 suits with the greater bulk in the leg also caused a greater increase in metabolic rate than the other 3 suits suggesting movements (walking and completing an obstacle course) in the bulkier suits required extra energy to complete.
4. CONCLUSIONS
So the weight of protective garments can have a significant effect on the metabolic cost of work as the wearer has to carry additional load created by the weight of the garment on their body. This extra load is particularly costly if the material on the arms and trousers of the garment is heavy as weight on the limbs has to be accelerated and decelerated with each step.

The method used in this study to measure bulk has shown some promising results, with an increased leg bulk seeming to correspond with a higher increase in metabolic rate seen in a previous study with the same garments. The fit of the garment will also have an influence on bulk, a garment that is too large for the wearer is likely to inflate the bulk measurements. As many of the studies highlighted in the introduction concluded, the area of clothing bulk, possible hobbling and motion restriction needs further attention.

5. ACKNOWLEDGEMENTS
This work was funded as European Union GROWTH programme project “THERMPROTECT, Assessment of Thermal Properties of Protective Clothing and Their Use”, contract G6RD-CT-2002-00846.

6. REFERENCES