# The effects of protective clothing and its properties on energy consumption during different activities



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**The effects of protective clothing on energy consumption during different activities.**

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## ABSTRACT

***Background:*** Protective clothing (PPC) can have negative effects on worker performance. Currently little is known about the metabolic effects of PPC and previous work has been limited to a few garments and simple walking or stepping. This study investigated the effects of a wide range of PPC on energy consumption during different activities. ***Hypothesis:*** Wearing PPC would significantly increase metabolic rate, disproportionally to its weight, during walking, stepping and an obstacle course. ***Methods:*** Measuring a person's oxygen consumption during work can give an indirect, but accurate estimate of energy expenditure (metabolic rate). Oxygen consumption was measured during the performance of continuous walking and stepping, and an obstacle course in 14 different PPC ensembles. ***Results:*** Increases in perceived exertion and in metabolic rate (2.4–20.9%) when wearing a range of PPC garments compared to a control condition were seen, with increases above 10% being significant ($p<0.05$). More than half of the increase could not be attributed to ensemble weight.



**KEYWORDS:** PPE, Protective clothing, metabolic rate, oxygen consumption, energy expenditure


**Statement**

Energy expenditure is a crucial parameter in the assessment of heat and cold stress, calculation of requirements of food (expeditions, military) and air supplies (SCBA time limits). The observed effect of protective clothing (increases up to 21% in energy use) indicates that neglecting it may put workers at risk in extreme conditions.

## INTRODUCTION

There are many industrial and military situations in which workers are required to wear personal protective clothing (PPC) and equipment. Although this PPC may provide protection from the primary hazard, for example heat or chemicals, it can also create ergonomic problems (Havenith and Heus 2004). There are important side effects to the PPC, often the main problem is the added load on the body in terms of weight, but reduced mobility is also seen due to garment stiffness, bulk and fit. These problems are often divided into thermal, metabolic and performance issues and although they all have been considered, previous studies have mainly concentrated on the thermal effects of the clothing, including core temperature and heart rate responses when wearing different garment designs and ensembles (Havenith 2002), and on performance decrements when wearing PPC (Lotens 1988).

Very few studies have investigated the metabolic effects; however Nunneley (1989) suggests that a better understanding is needed of the interactions between the environment, clothing, task and worker. She goes on to highlight that particularly challenging areas needing improvement include quantification of changes to the metabolic cost of real-world tasks due to clothing.

At present a value for the metabolic rate based on the work load of the task is used in a number of heat and cold stress prediction models and ISO standards. They typically assume workers are wearing light, vapour permeable clothing. By failing to consider the additional metabolic effects of actual PPC the standards may underestimate heat production and therefore current standards cannot be accurately applied to workers wearing PPC. Any increases in energy consumption due to PPC worn that are unaccounted for could also put workers at risk, especially if they are using Self Contained Breathing Apparatus (e.g. firefighters; the air consumption will be higher than expected).

A detailed review of the literature (Dorman 2007) highlights a significant lack of consideration of the effects of PPC on energy consumption and metabolic rate. The existing papers are also dominated by work on a few types of garments only, firefighting and chemical protection (CP), and on a limited number of work modes, most often treadmill walking or stepping. The earliest paper to look at this topic was by Teitlebaum and Goldman (1972) who walked subjects on a treadmill at 5.6 and 8.0 km/hr wearing a

5 layer arctic clothing ensemble over standard fatigues, with an 11.2 kg lead-filled belt (equivalent to the weight of the 5 extra clothing layers) over fatigues as the control condition. So, rather than determining the overall PPC effect they tried to deduct the effect of the weight of the clothing. For every subject the energy cost at a given speed was always higher with the clothing than the weight belt, with a significant increase on average of approximately 16% in the metabolic cost of working in the clothing, compared to the belt. Oxygen consumption increases of 15% when wearing modern firefighters' clothing during treadmill walking in ambient conditions have also been reported (Graveling and Hanson 2000). Other authors have estimated increases of 20 to 40% when firefighting PPC is worn but this may also be due to the weight of additional equipment (in the form of SCBA) which can add up to 25 kg and the extreme radiant heat loads encountered when fighting live fires (Bilzon et al*.* 2001; Davis et al*.* 1982; Faff and Tutak 1989; Goldman 1990).

Using a stepping work mode Duggan (1988) investigated the effect of different PPC ensembles. Standard military combat clothing was worn for the control condition, with chemical agent and cold protection garments added (resulting in 4, 6 and 6 layers respectively on the torso, 2, 3 and 4 layers respectively on the legs). Oxygen consumption ($\dot{V}O_2$) during stepping was significantly greater in all the ensembles compared to the control, with a mean increase of 9, 12 and 16% in the 3 ensembles respectively. The increases were proportionately greater than the increases in clothed subject weights, and when corrected for clothing weight, the $\dot{V}O_2$ in the last ensemble was still significantly increased by 9%.

Many studies including combined arms exercises, field trials and laboratory studies have documented the degradation of individual and unit performance when wearing CP or full Nuclear, Biological, Chemical (NBC) protection (see Taylor and Orlansky (1993) for a comprehensive review). However, despite this large body of knowledge on the performance effects of CP, little quantitative information exists about the energy cost and related physiological changes during dynamic exercise under conditions where heat stress is not a significant factor (Patton et al. 1995).

Wearing standard battledress uniform (BDU), BDU with a M17 protective mask or CP clothing (with a mask, overgarment, gloves and boots) Patton et al. (1995) walked subjects on a treadmill at 3 grades; 0, 5 and 10%. $\dot{V}O_2$ was significantly increased in CP clothing compared to BDU at all grades, with no differences seen between the BDU and BDU with mask conditions at any level of exercise. Over the range of exercise intensities (approximately 30-60% $\dot{V}O_{2max}$), $\dot{V}O_2$ increased between 13 and 18% while wearing CP clothing. Since the contribution of the mask to this response was slight, the increased energy cost was attributed to the overgarment, overboots and gloves. $\dot{V}O_2$ corrected for differences in clothed weight was still 6-11% greater in CP clothing across the range of exercise intensities (Patton et al. 1995).

A later study from the same lab investigated stationary, intermittent and continuous military tasks when wearing CP clothing (Murphy et al. 2001). The difference in energy cost between CP and BDU was significantly ($p<0.05$) higher only for the continuous tasks with the authors concluding that the CP had little impact on tasks of a stationary or intermittent nature, but a marked impact on tasks requiring whole body mobility (Murphy et al. 2001). Havenith and Heus (2004) also detail a test battery that could be used to address the effect of PPC by using task related activities, in their case firefighter clothing was studied so the tasks included, climbing ladders, through windows, over, under and through obstacles. This approach to look at more real-life tasks, rather than purely walking or stepping is an important development and needs to be expanded.

So it can be seen that the previous work has had a narrow a focus on firefighting and chemical protective clothing. Very few studies have investigated the effects of the clothing on energy consumption / metabolic rate. Of those that have, limited garments have been tested and generally whilst either walking or stepping only. Therefore the aim of the present study was to quantify the effect on metabolic rate of PPC garments from a range of industries across a number of activities. In addition to walking and stepping exercise, an obstacle course was designed including industry relevant movements (bending, stretching, lifting etc.).

## METHODS

### Participants

Six healthy adults (3 males, 3 females) volunteered for the study; age (mean ± SD) 24.0 ± 3.2 years, height 175.5 ± 6.8 cm, weight 70.0 ± 9.1 kg. The research was approved by the Loughborough University Ethical Advisory Committee and written informed consent was obtained from all participants prior to their participation in the study.

### Clothing and experimental design

Fourteen PPC garments were selected across a variety of professions with a range of weight, insulation, material type and design; details are given in Table 1. A standardised package of cotton work trousers and t-shirt were worn under the PPC and army boots (1.57 kg) and woollen socks were worn on the feet. For the control condition participants wore cotton tracksuit trousers and a sweatshirt (provided) with trainers (participants own, average weight 0.65 kg). The control condition was used as a reference, to which the PPC garments will then be compared. Unfortunately only one size for each of the PPC garments was available and thus it was not always possible to 'fit' participants with the correct size of garment. However participants recruited were of an average build i.e. not too tall or short so as to reduce the possible influence of poor garment fit.

The study is a within-subjects design, with each participant wearing all PPC garments and acting as their own control. The wearing order of the PPC was balanced to avoid order effects. To control for possible effects of a raised core temperature and fatigue on metabolic rate only two PPC garments and a control condition were completed in each session so participants were required to attend the lab for seven experimental sessions, all sessions took place at the same time of day and were separated by at least 48 hours. The average ambient conditions for the trials were 18.7±1.1°C and 40±4% relative humidity.

Work modes

A number of work modes had to be defined that would simulate the sort of work demands made on the PPC when worn in the field. Many of the studies reported in the literature used very simple tasks e.g. walking and stepping, or very specific tasks to the clothing e.g. firefighters dragging a dummy, unrolling a hose, climbing a ladder. In the present study an obstacle course was developed which included simplified tasks that would be related to actual task performance including a number of reaching, bending, crouching and crawling movements in order to 'stretch' the clothing. Walking and stepping were also used to allow comparison of the results to the literature.

Walking was undertaken at a speed of 5km/hr on a treadmill (Tunturi T-track Gamma 300 treadmill, Finland). Stepping was performed at a rate of 25 steps/min on a 20 cm Reebok Aerobics step, with the rate controlled by a metronome (Birkbeck Laboratory Timer and Signal Source).

A floor plan for the obstacle course can be seen in Figure 1 (see also supplemental electronic material). The arrows show the direction of movement, from the start, following the white arrows first, participants stepped over wooden hurdle 1, 55 cm high (1) then picked up two crates (weighing 5 kg each), one at a time from the 72 cm high Table 1 (2) and moved them to Table 3 (3). They then moved the two crates from the top of Table 3 (82.5 cm high) to the floor (4). From the floor, the participants moved the crates across and up to Table 2 (150 cm high, stacked on top of Table 1) (5), then back to Table 1 (6). This completed the crates section. They then crawled under 100 cm high wooden hurdle 2 (7), touched the wall (8) and bent down to come back under hurdle 2 (9). The black arrows now show that they walked around the table and back to the start (10, 11). For full details including photographs, see Dorman (2007). Participants completed the obstacle course circuit continuously with the rate controlled by a metronome and verbal counting. The metronome was set to give an auditory beep signal 50 times per minute, or 1 beep every 1.2 secs. The counting was given verbally in 3's, so 1 (1.2 secs), 2 (2.4 secs), 3 (3.6 secs), 1, 2, 3 etc. Each obstacle took a 3 count to complete, e.g. moving a crate, stepping over a hurdle etc. Participants were given a demonstration of the obstacle course with the metronome and counting prior to the first trial to familiarise them with the order and pace of the course.

Measurements

Metabolic rate was calculated using indirect calorimetry from measurements of oxygen uptake and carbon dioxide output with a portable breath-by-breath system (MetaMax 3B, Cortex, Germany) worn in a harness around the shoulders. Prior to each experimental session the MetaMax system was calibrated for pressure (atmospheric pressure reading), volume (using a 3 litre Hans Rudolph gas syringe) and gas concentration (using ambient air and a calibration gas 4.04% carbon dioxide, 16.13% oxygen, 20.12% argon and balanced with nitrogen (BOC gasses, UK)). In their review of the literature on portable devices used for the measurement of gas exchange Meyer et al. (2005) conclude that the results from validity studies are comparable to those for corresponding stationary systems. The mean differences with Douglas bag measurements, reported to be around 0.1–0.2 l/min in $VO_2$, reach an acceptable accuracy and are not inferior to metabolic carts. Meyer et al. (2005) also conclude that the two most often tested portable devices, the Cortex MetaMax and Cosmed K2/K4b[2] can be regarded as valid and reliable. In the last minute of each work period participants were also asked how hard they felt they were working using the Rate of Perceived Exertion (RPE) Borg scale, ranging from 6 (no exertion at all) to 20 (maximal exertion).

Statistical analysis

The percentage increase in metabolic rate for each test garment from the control garment was based on the equation below, with the control garment metabolic rate being the value measured in the same session as the test garment metabolic rate.

$$\%\ increase = \left[ \frac{test\ garment \quad metabolic\ rate}{control\ garment \quad metabolic\ rate} * 100 \right] - 100$$

The main aim of the present study was to establish if wearing a PPC garment significantly increased the energy consumption over a control condition. In order to establish if working in each of the PPC garments significantly increased the metabolic rate above a control condition, one-tailed single sample t-tests were carried out on the % increase results for each garment with 0 as the reference. Based on the fact that all results were positive (increases in clothing compared to control), it was decided that a Bonferroni or Holm-Bonferroni correction would be overly conservative, especially given the low number of participants, and would dramatically inflate the chances of a Type II error. However it was decided that for a comparison between all individual suits, insufficient statistical power was available. For all tests a significance level of $p<0.05$ was used. Wilcoxon signed rank tests were carried out on the subjective RPE data.

**RESULTS**

All PPC garments showed an increase in metabolic rate compared to the control condition. In the control condition the average metabolic rates measured during walking, stepping and the obstacle course were 325±11 W, 413±15 W, 412±29 W respectively. The overall average percentage increase (with all work modes weighted evenly to produce an average) in metabolic rate have been plotted for the 14 protective garments in Figure 2. The highest recorded increase in metabolic rate (18.7%) was seen in the Workwear (2 layer) (A) garment, with the other Workwear (C) and the two fire suits, Grey fire (B) and Gold fire (D) also showing increases of 14.5 –15.7%. All suits showing an increase in metabolic rate of 10% or more over the control proved to be significant ($p<0.05$). At 6.8% the Army+waterproof (M) ensemble increase also proved to be significant ($p<0.05$). The only 2 garments whose increases did not reach significance were the Army+vest (L) and Mountain Rescue (N) ensembles.

The work modes are now considered individually and illustrated in the 3 panels of Figure 3. The graph shows that the garment with the highest percentage increase when walking (Panel A, bottom) was the Grey fire (B) suit which caused a 20.9% increase in metabolic rate, the lowest increase was 4.2% for the Mountain Rescue (N) uniform. Increases in the metabolic rate of 12% or above proved to be significant ($p<0.05$), which applied to 10 of the 14 garments, although due to a large standard deviation, the Chemical (E) suit, with an average 13.4% increase in metabolic rate, did not prove to be significant.

The results for the stepping work mode (panel B, middle) show a similar pattern of increase to the overall results in Figure 2, with the highest increase recorded for the two workwear garments, Workwear (2 layer) (A) and Workwear (C), 19.8% and 14.0%, and Grey fire ensemble (B) 14.5%. The increases recorded for 6 other ensembles also reached significance, Gold fire (D) and Chemical (E), 12.2% and 12.6% respectively, Coldsuit (Black) (H) and Coldsuit (Green) (I), 11.1% and 10.2% respectively. A 10.1% increase for the Army+NBC (F) and 8.0% for the Chainsaw (J) also proved to be significant but the 9.4% increase from the Welding (G) ensemble did not reach significance probably due to a larger standard deviation.

The pattern of increases for the obstacle course (panel C, top) is quite different to those seen in the other panels, the error bars are also larger with the individual garment increases recorded showing a wider range. The Workwear (A, C) and Fire (B, D) ensembles, again proved to be significant, even though the increase recorded in the Grey fire (B) suit was only 11.8%. The 17.1% increase in metabolic rate noted for the ChemBio (K) ensemble, although in the range of the 15.9–17.4% increases which were significant for the Workwear (A, C) and Fire (B, D) ensembles, was not significant, perhaps again due to a large standard deviation. Statistical analysis also returned significant differences (8.8-10.3%) in three other garments, Welding (G), Chainsaw (J) and Mountain Rescue (N).

The thresholds for significance can be seen to differ slightly with work mode. In panels A to C in Figure 3 there were 16 results in which the increase in metabolic rate in the clothing compared to the control were not significant, 4 for the walking work mode, 5 for the stepping and 7 for the obstacle course.

The RPE data collected showed that during the control condition walking was on average perceived as very light (8.8), stepping as light (11.0) and the obstacle course between light and somewhat hard (11.9). The general trend when the PPC was worn followed the control, with the perception of exertion increasing for walking, stepping and the obstacle course respectively. However the levels of perceived exertion shifted upwards and were always higher when the PPC was worn. The 2 Fire suits, Grey fire (B) and Gold fire (D) caused the greatest shift in RPE with the ratings recorded for walking, stepping and the obstacle course rising to 11.5, 13.0 (somewhat hard) and 14.5 – 15.0 (hard) respectively. The Chainsaw (J) and Coldsuit (Green) (I) also caused large increases in the perceived exertion with values of 11.3, 13.0, 14.0 for each work mode respectively. At the other end of the spectrum, the Army+waterproof (M) and Mountain Rescue (N) garments caused the smallest increases in perceived exertion (which were not significant), with ratings rising to only 10.0, 11.5 and 12.5 for the walking, stepping and obstacle course work modes compared to the control values of 9.0, 11.0 and 12.0 respectively.

**DISCUSSION**

In summary the metabolic rates recorded when wearing protective garments were 2.4 – 20.9% above those recorded in a control condition. The rank order of the suits in the stepping test was most representative of the rank order over all tests combined. The two heaviest garments to be tested were the two fire suits, (B and D), eliciting overall average metabolic rate increases of 15.7 and 14.5% respectively from the control. These figures are similar to those reported by Graveling and Hanson (2000) from laboratory trials where standard firefighter clothing (without SCBA) typically increased physiological cost (oxygen consumption) by 15% over control sessions.

The Army+NBC (F) and Army+vest (L) garments provided an interesting comparison. The Army+NBC (F) ensemble was made up of an NBC jacket and trousers as outer layers plus overboots and gloves, total weight 5.27 kg. The Army+vest (L) ensemble weighed 5.32 kg with 2.45 kg of the extra weight due to the protective vest. Despite the similar total clothing weights the overall average percentage increase values were very different, 7.3% for the Army+vest (L) and 12.4% for the Army+NBC (F), indicating that the distribution of the clothing weight and the extra clothing layers may also be important factors which affect how easily and efficiently work can be performed. In this example it seems that when the weight was carried around the torso in the Army+vest (L) ensemble it had a smaller impact on movement and therefore the effect on the metabolic rate was much lower than the Army+NBC (F) where the extra bulk and layers may have caused increases in metabolic rate due to a hobbling effect or friction drag. Similar effects have been described for the influence of clothing on performance (Lotens 1988). Duggan (1988) and Patton et al. (1995) both used chemical protective garments and the results for the present study fit well with their 9% and 6-11% increases respectively.

Some of the results may have failed to reach significance due to the sensitivity of the method ($VO_2$ measurement) and the small sample size. A greater number of participants would have been preferred however the within-subject design of the study, the very limited overall session duration to avoid body temperature changes, the desire to look at a number of work modes, have a control condition in each session and the number of protective garments to be investigated increased the number and duration of experimental sessions markedly. Another factor that may have reduced the number of significant findings were a few results with large standard deviations, for example during the obstacle course in the ChemBio (K) ensemble. As mentioned in the methodology, participants all had to wear the same size garment and this was not an ideal fit for some. Thus particularly during the obstacle course which required the greatest range of movement this may have impeded the movements of some participants more than others, increasing their metabolic cost, resulting in a greater range of metabolic rates and thus higher standard deviations. It is speculated that if a better garment fit for all participants had been achieved, standard deviations could have been reduced, possibly resulting in further significant findings.

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).

These studies have also demonstrated that the metabolic cost of carrying normal loads on the trunk is the same as that of carrying an equivalent additional weight of the body itself (Givoni and Goldman 1971). If bodyweight and the weight of external loads are combined, the metabolic cost of walking at any speed is then expressed as a linear function of the total weight (Givoni and Goldman 1971).

Using the equation devised by Givoni and Goldman (1971), a theoretical relationship for the increase in metabolic rate when walking at 5 km/hr carrying an additional weight of 1 to 10 kg (covering that of the clothing tested in the present study) was calculated. The results are shown in Figure 4, along with the weight and increase in metabolic rate data for the PPC in the present study, and a line of best fit for these data (forced through origin). Higher increases in metabolic rate can be seen in the heavier PPC ensembles, this can be expressed as an increase of 2.7% per kg of clothing weight from the slope of the linear regression line. This is close to the 3% per kg reported by Rintamaki (2005) for some cold weather clothing. However this is considerably higher than the calculated theoretical cost of 1% per kg of added load from Givoni and Goldman (1971). Some garments seem to be more expensive in terms of metabolic cost for their weight than others. For example, the ChemBio garment (K) had a much lower increase in metabolic rate than the Coldstore garments (H and I), despite their similar weights. Hence, although the weight of the PPC garments can explain some of the increase in metabolic rate seen wearing the PPC, it clearly does not explain all of the effect for the majority of the PPC. Other characteristics of the PPC, for example, bulk and number of layers may well also be making a significant contribution to the raised metabolic rates. This will be the topic of further study.

The present study has shown that protective clothing ensembles designed for a variety of industry and military requirements increase the metabolic cost of walking, stepping and completing an obstacle course including lifting and moving crates, crawling on hands and knees, and moving under and over obstacles. The garments studied caused metabolic rate increases of 2.4 to 20.9% compared to a control condition. In addition, significant ($p<0.05$) increases were seen in the Rating of Perceived Exertion when wearing many of the protective garments. The results for the fire and army ensembles have been explored as these are the types of garments that have been previously studied. The results in the present study fit with those previously documented in the literature. Further analysis concluded that wearing a range of PPC caused an increase in energy consumption of 2.7% per kg of clothing weight, compared to a theoretical prediction based purely on weight which would predict only 1% per kg added weight. Theoretical models need to take into account these increases and further work is required to investigate the other factors that may be contributing to the extra energy costs seen when wearing PPC.

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**Legends**

Table 1. Descriptions and details of all PPC garments used. Note: weight of army boots: 1.57 kg; control trainers: 0.65 kg.

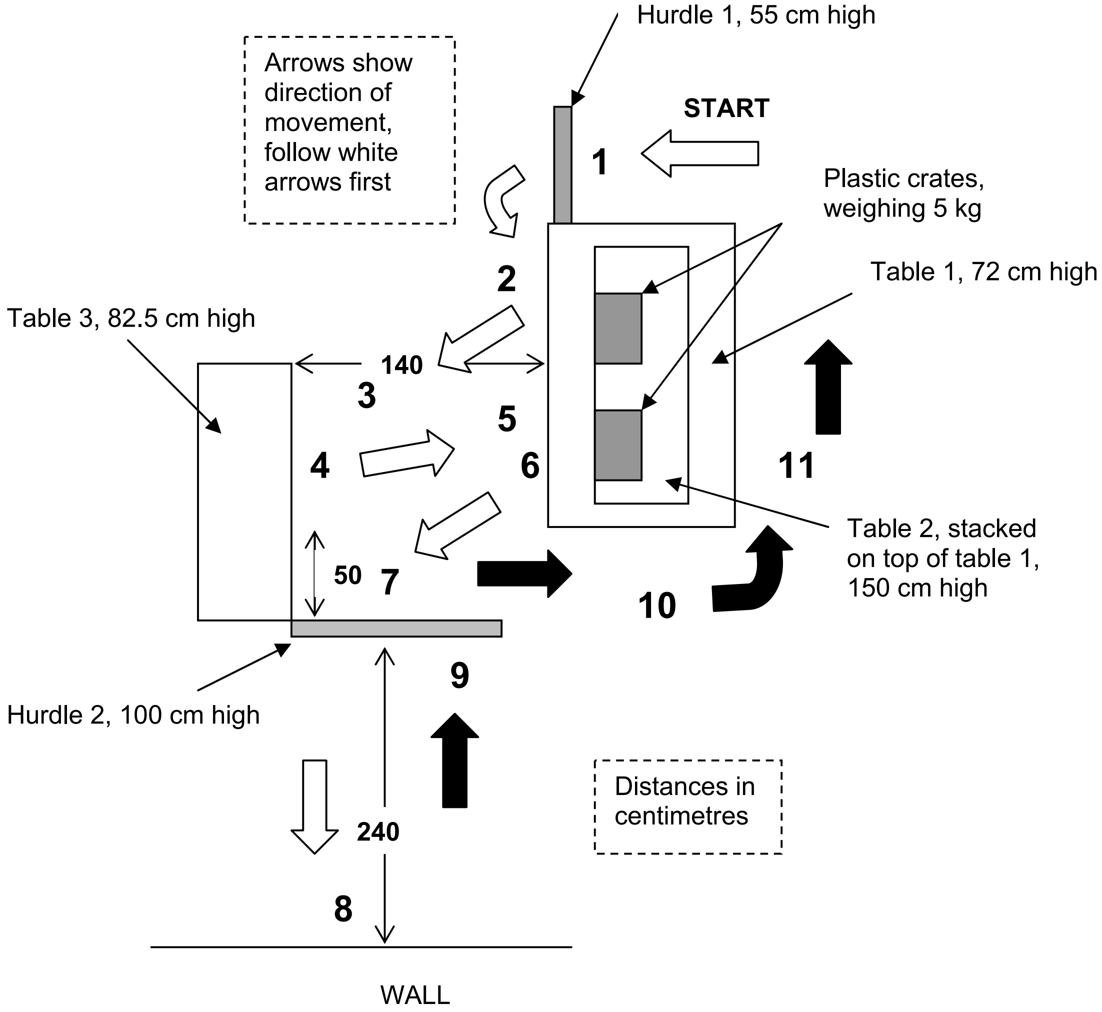
Figure 1. Floor plan, dimensions and order of obstacle course.

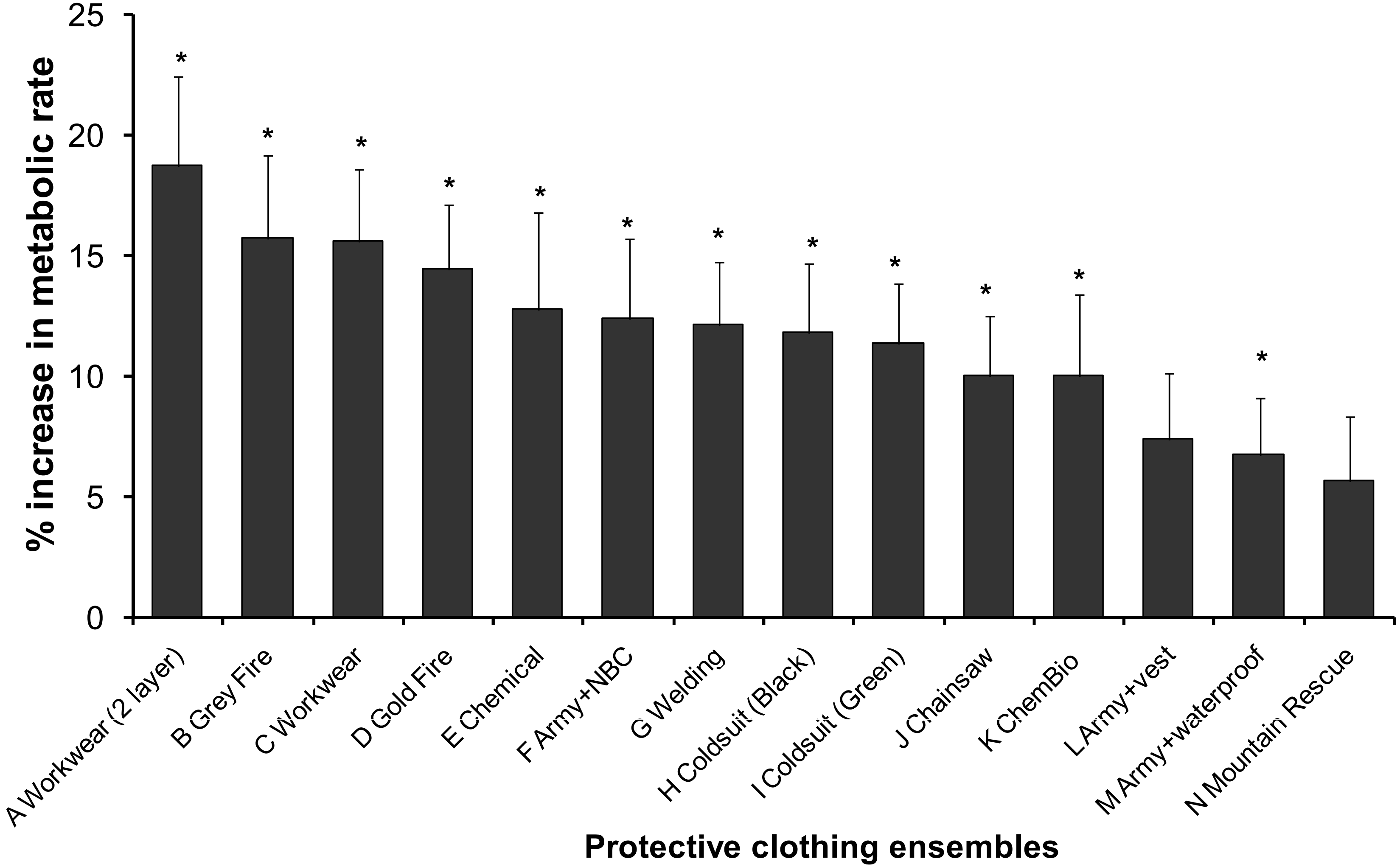
Figure 2. Overall average percentage increase in metabolic rate relative to a control condition when wearing protective clothing during work. Significance ($p<0.05$) indicated by *.

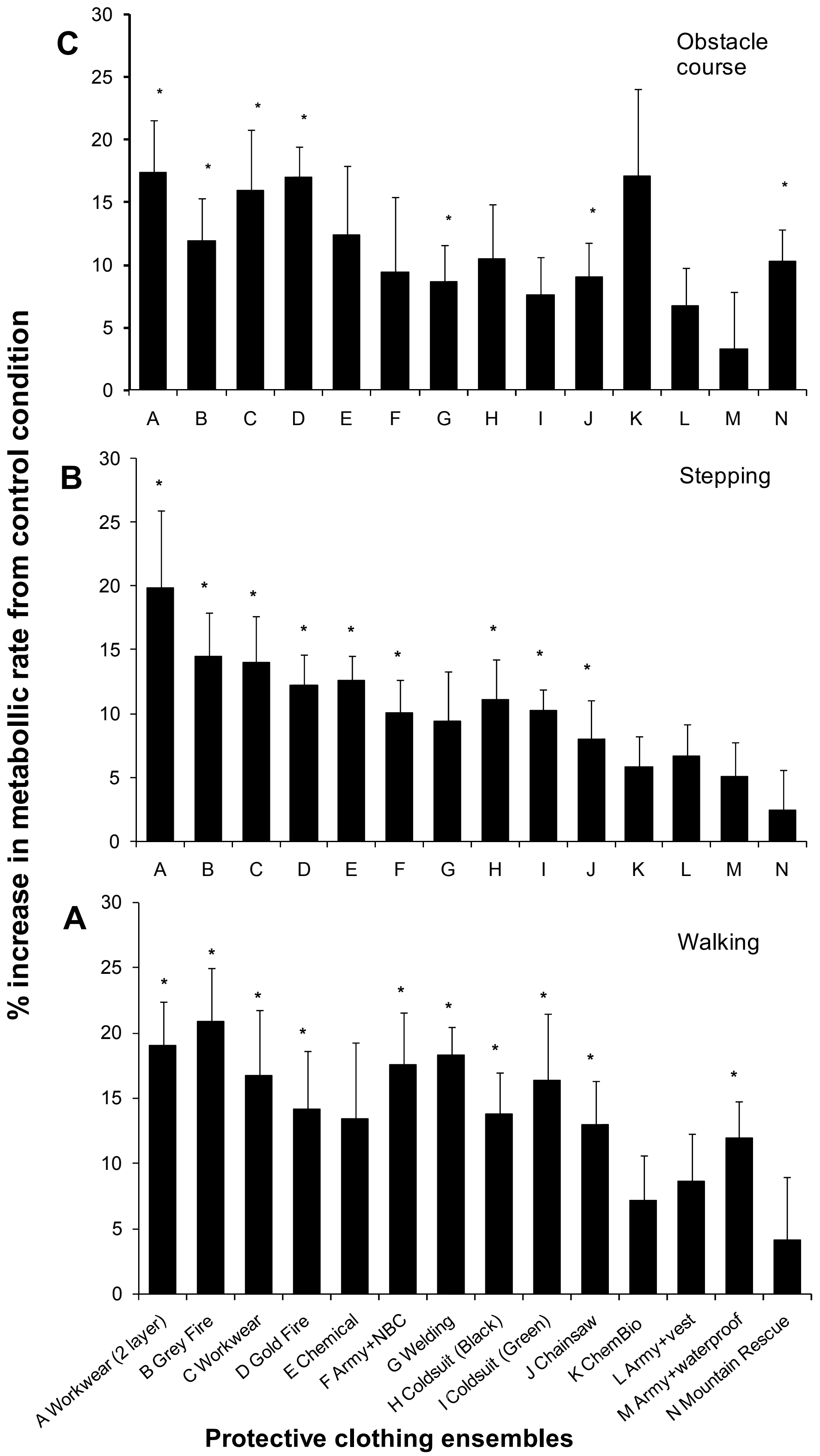
Figure 3. Average percentage increase in metabolic rate relative to a control condition when wearing protective clothing during walking (Panel A, bottom), stepping (Panel B, middle) and completing an obstacle course (Panel C, top). Significance ($p<0.05$) indicated by *.

Figure 4. Graph to illustrate metabolic rate increase recorded in relation to the weight of protective clothing garments, as well as the theoretical implication (using Givoni and Goldman (1971) equation) of carrying additional weight on metabolic rate. See Table 1 for garment codes.

| Code | PPC | PPC purpose | Garment details | Ensemble weight incl shoes |
|---|---|---|---|---|
| A | Workwear (2 layer) | General outdoor workwear with added insulation | Goretex workwear. Jacket included zip in fleece inner jacket. Conforms to EN 471, ENV 343, EN 533. | 5.86 kg |
| B | Grey fire | Standard firefighting ensemble | GLOBE firefighters suit (made in the USA) meets NFPA 1971 standard. | 7.00 kg |
| C | Workwear | General outdoor workwear | Goretex workwear by Bardusch, jacket and dungaree style trousers. | 4.36 kg |
| D | Gold fire | Standard firefighting ensemble | Leicestershire Fire and Rescue service. | 6.66 kg |
| E | Chemical | Protection from chemical splash and spills | Alpha Solway Chem master chemical protective clothing, conforms to EN 467: 1995. | 3.66 kg |
| F | Army+NBC | Protection from Nuclear, Chemical, Biological threat | Army fatigues and base layer worn instead of cotton work trousers and t-shirt. NBC Protective suit by Remploy Ltd. Jacket; Mk IV DPM smock. Trousers; Mk IV DPM. | 5.27 kg |
| G | Welding | Protection from sparks and molten metal splash | Chrome Leather Welders Jacket. Chrome Leather Split Leg Apron. Heat Resistant Leather Gaiters. | 5.58 kg |
| H | Coldsuit (Black) | General coldstore suit (one piece suit) | Tempex Protectline Coldstore Mentmore Range coverall rated to -25 $^{o}$C. | 4.92 kg |
| I | Coldsuit (Green) | General coldstore suit (two piece suit) | Tempex Protectline Coldstore Mentmore Range jacket and trousers rated to -25 $^{o}$C. | 4.83 kg |
| J | Chainsaw | For outdoor forestry work, chainsaw protection in the legs and arms, waterproof coating on jacket and trousers | Oregon Extreme Protective Chainsaw Jacket. Conforms to prEN 381-11. Oregon Extreme Chainsaw Type C Wet Weather Trousers, conforms to EN 381-5. | 5.68 kg |
| K | ChemBio | Worn during threat from chemical warfare | Netherlands Army Chemical Warfare protection suit | 4.87 kg |
| L | Army+vest | Upper body protective armour, covers torso only (not arms) | Army fatigues and base layer worn instead of cotton work trousers and t-shirt. Combat body armour Mk 1 UN blue with filler combat armour. | 5.32 kg |
| M | Army+waterproof | Waterproof jacket | Army fatigues and base layer worn instead of cotton work trousers and t-shirt. DPM waterproof jacket. | 3.51 kg |
| N | Mountain rescue | Over jacket and trousers (ski suit style) | Save Pro Life ski jacket and trousers. | 4.14 kg |
| | **Control** | | cotton tracksuit trousers,sweatshirt with trainers | **1.4kg** |


Hurdle 1, 55 cm high
Arrows show direction of movement, follow white arrows first
START
1
Plastic crates, weighing 5 kg
2
Table 1, 72 cm high
Table 3, 82.5 cm high
140
3
5
4
6
11
Table 2, stacked on top of table 1, 150 cm high
50
7
10
9
Hurdle 2, 100 cm high
Distances in centimetres
240
8
WALL


% increase in metabolic rate
25
20
15
10
5
0
A Workwear (2 layer)
B Grey Fire
C Workwear
D Gold Fire
E Chemical
F Army+NBC
G Welding
H Coldsuit (Black)
I Coldsuit (Green)
J Chainsaw
K ChemBio
L Army+vest
M Army+waterproof
N Mountain Rescue
Protective clothing ensembles



C
Obstacle course
B
Stepping
A
Walking
% increase in metabolic rate from control condition
0
5
10
15
20
25
30
A
B
C
D
E
F
G
H
I
J
K
L
M
N
A Workwear (2 layer)
B Grey Fire
C Workwear
D Gold Fire
E Chemical
F Army+NBC
G Welding
H Coldsuit (Black)
I Coldsuit (Green)
J Chainsaw
K ChemBio
L Army+vest
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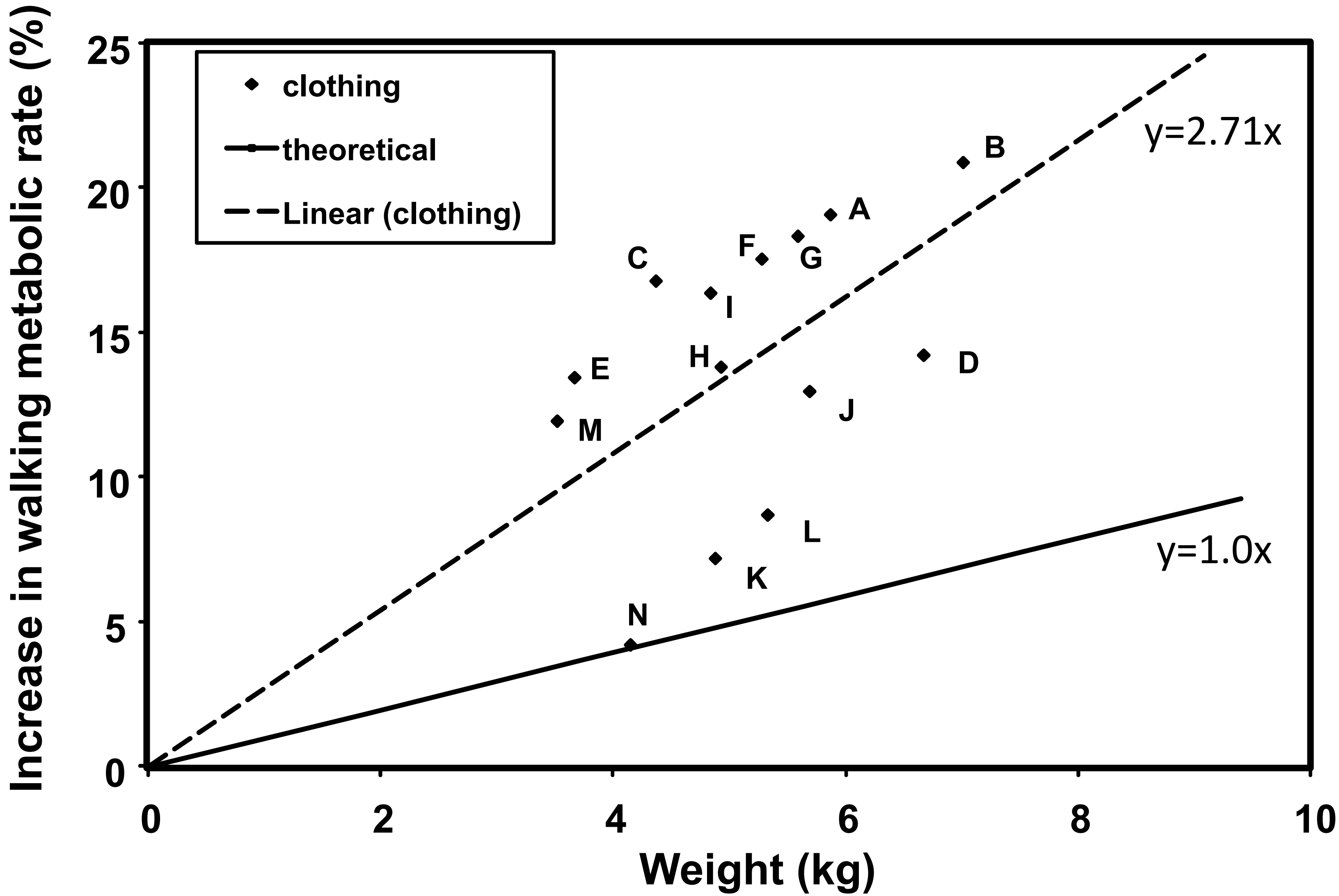
Increase in walking metabolic rate (%)
Weight (kg)
clothing
theoretical
Linear (clothing)
y=2.71x
y=1.0x
A
B
C
D
E
F
G
H
I
J
K
L
M
N
0
5
10
15
20
25
0
2
4
6
8
10