International Journal of Occupational Safety and Ergonomics (*JOSE*) 2010, Vol. 16, No. 2, 185–197

The Effect of Cold Protective Clothing on Comfort and Perception of Performance

Kirsi Jussila
Anita Valkama
Jouko Remes
Hannu Anttonen

Finnish Institute of Occupational Health, Oulu, Finland

Ari Peitso

Finnish Defence Forces, Centre for Military Medicine, Lahti, Finland

The physiological properties of clothing designed to provide protection against cold, windy and damp conditions affect comfort. The weight, thickness, stiffness of the fabrics and friction between the clothing layers affect physical performance. The comfort and perception of performance associated with 3 military winter combat clothing systems from different decades (the new M05 system, the previous M91 system and traditional clothing) were observed during a winter military manoeuvre. Subjective experiences concerning comfort and performance were recorded for 319 subjects using questionnaires. The most challenging conditions for comfort and performance were perspiration in the cold and external moisture. The new M05 system provided warmer thermal sensations ($p < .010$), dryer moisture sensations in the presence of external dampness ($p < .001$), dryer perspiration moisture sensations ($p < .050$) and better perception of physical ($p < .001$) and mental performance ($p < .001$) than the other systems. Careful development of the clothing system guarantees good comfort and performance during cold exposure.

cold protective clothing   clothing comfort   perception of performance

1. INTRODUCTION

Cold injuries have been a major issue even in recent military conflicts. Cold stress can cause local and whole-body cooling, which can lead to cold injuries and hypothermia. Performance, such as marksmanship, is negatively affected when core body temperatures are not between 36.5 and 37.5 °C [1]. Cold protective clothing has to provide protection not only against cold but also against windy and damp conditions at temperatures from above freezing point to extreme cold (–40 °C). The optimum total thermal insulation of the clothing system must be selected on the basis of the environmental conditions and physical work level, such as the weight, thickness and stiffness of the clothing, and the friction between the layers will affect physical performance and limit movement of the extremities. This research was carried out in the form of an observational questionnaire-based study administered during winter military training.

The hypothesis was that careful development of clothing materials and systems, taking into account

This research was carried out during the “Soldier in the Cold: Health, Performance and Cold Protection” project supported financially by the Finnish Defence Forces, to which the authors wish to express their thanks. In particular, they would like to thank the Western Finland Logistics Regiment for practical co-operation during the project.

Correspondence and requests for offprints should be sent to Kirsi Jussila, Finnish Institute of Occupational Health, Aapistie 1, FI-90220 Oulu, Finland. E-mail: <kirsi.jussila@ttl.fi>.

the user, tasks and environmental conditions, can guarantee good clothing comfort and performance during long-term exposure to cold weather.

1.1. Clothing Comfort

Clothing comfort is affected by the physiological properties of clothing, such as thermal insulation, water penetration properties and air permeability, and can be assessed in term of thermal sensations, the amount of external wetness and perspiration moisture. Comfort as experienced by the user can be influenced greatly by the protective properties of clothing against cold, wind and moisture and by the drying time.

Insufficient thermal insulation will lead to cooling of the body, whereas too high thermal insulation will result in sweating during physically demanding tasks. The size of the clothing and thickness of the air layer entrapped between the layers will affect both thermal insulation and the water vapour permeability of the clothing ensemble. Previous research has shown that thermal insulation and water vapour permeability increase with a thicker air layer, but there is obviously an optimum air layer thickness beyond which the values start to drop [2]. Thus the clothing must not be too small or too big. Size is very important when seeking to maximise protection against cold [2, 3].

It has also been shown that sweating reduces thermal insulation and that a dramatic fall in cooling efficiency occurs when moisture is absorbed from the skin before it evaporates [4, 5]. According to a recent study [6], fabrics that have a higher thermal insulation and air permeability, such as fleece, achieved a higher temperature and lower vapour pressure under cold conditions than a microporous membrane (MPM) fabric. The higher vapour pressure in MPM was attributed to condensation, which blocks the pores that transport water vapour [6]. It has been shown elsewhere that effective water vapour resistance increases greatly as the outside temperature decreases [7]. The amount of moisture absorbed is influenced by the properties of both the underwear and outer clothing.

The significance of air permeability is most pronounced at higher wind speeds and higher levels of physical activity, where heat loss needs to be increased. Air movements cause ventilation inside the clothing, which can be used to remove excess heat and water vapour [8]. The use of a combat vest and body armour will compress the clothing layers, reducing the thickness of the air layers and blocking air movements inside the clothing. Body armour and a combat vest will increase protection against wind but detract from the amount of moisture evaporating from the clothing.

Attempts have been made to reduce the weight of cold protective clothing to lighten the workload and improve performance, but little attention has been paid to the friction properties of military clothing. It has been shown that an increase in weight and the number of clothing layers will increase the work load [9, 10, 11].

1.2. Performance

Cold protective clothing increases the physical work load and energy expenditure, the weight of the clothing having the greatest influence, while its stiffness is the second most important factor. Friction between the clothing layers and the effect of thick clothing in hindering movement of the extremities add to the physical work load [9, 10, 11].

Mental performance has a substantial impact on orientation, safety, decision making, work efficiency and reactivity in demanding situations, and the physiological effects of cold exposure have a direct influence on mental performance. These effects can be seen even when no actual hypothermia can be diagnosed [12]. Cold conditions lengthen reaction times and increase errors in tasks that demand high levels of mental performance [13].

1.3. Objective

The objective of this research was to examine the effects of cold protective clothing systems from different decades on clothing comfort and perception of performance during 11 days of winter military training. The results obtained with the new clothing system were compared with two clothing systems from earlier decades.

2. MATERIAL AND METHODS

2.1. Cold Protective Clothing Systems

The newly developed winter clothing system of the Finnish Defence Forces (model 2005, M05) was assessed and compared with corresponding systems from earlier decades (model 1991, M91, and traditional coarse cloth). The same underwear was used with all the systems, and they all had a similar utilization rate. The specialities of the new M05 system include increasing adjustability of the thermal insulation and wind protection, higher resistance to water penetration and lower weight. Table 1 provides a more detailed description of the cold protective clothing systems. Figure 1 presents the combat clothing systems with the combat clothing as the outermost layer. Table 2 shows the physiological properties of clothing of the systems are given.

The middle layer clothing belonging to M05 is of a closer fit and stretches more than does M91 middle layer clothing, with the aim of reducing the impairment of movement due to clothing. A long zip from the neck to the hem of the middle layer shirt is used in M05 to facilitate the putting on and taking off of the shirt relative to the M91 shirt, where a short zip was used. The absorption properties of the middle layer clothing were improved by increasing the wool content. The wetting of the combat clothing layer was alleviated by reducing the amount of hydrophilic cotton in the cloth. The materials and fibre contents of the snow and cold weather clothing

TABLE 1. Descriptions of the Cold Protective Clothing Systems (M05, M91 and Traditional Clothing), Their Fabric Constructions and Fibre Content

Clothing Layers	M05	M91	Traditional Clothing
Underwear	2 × 2 rib knit (PES 50%, CO 33%, MAC 17%)	2 × 2 rib knit (PES 50%, CO 33%, MAC 17%)	2 × 2 rib knit (PES 50%, CO 33%, MAC 17%)
Middle clothing	shirt: terry knit (WO 70%, PA 30%) trousers: terry knit (WO 60%, PES 25%, PA 15%)	knitted fibre pile (PA 80%, PES 20%)	knitted fibre pile (PA 80%, PES 20%)
Combat clothing	satin weave (CO 50%, PES 50%)	satin weave (CO 65%, PES 35%)	felt (WO 85%, PA 15%)
Snow clothing	twill (PES 70%, CO 30%)	twill (PES 70%, CO 30%)	twill (PES 70%, CO 30%)
Cold weather clothing	outer fabric: twill (PES 70%, CO 30%) lining: taffeta (PES 100%)	outer fabric: twill (PES 70%, CO 30%) lining: taffeta (PES 100%)	outer fabric: twill (PES 70%, CO 30%) lining: taffeta (PES 100%)
Cap	single knit (WO 100%)	single knit (WO 100%)	single knit (WO 100%)
Facemask	fleece (PES 100%)	—	—
Gloves	1. leather 2. insert gloves: terry knit (WO 100%), technical side single knit (PES 100%)	1. leather 2. insert gloves: terry knit (WO 57%, PA 25%, PES 18%)	1. leather 2. insert gloves: terry knit (WO 57%, PA 25%, PES 18%)
Socks	1. liner: single knit (PP 20%, PA 30%,WO 50%) 2. winter sock: 5 × 1 rib knit, terry stitched inside, reinforced sole, heel and toes (WO 85%, PA 15%)	1. liner: single knit (WO 75%,PA 25%) 2. winter sock: 5 × 1 rib knit, terry stitched inside, reinforced sole, heel and toes (WO 85%, PA 15%)	1. liner: single knit (WO 75%, PA 25%) 2. winter sock: 5 × 1 rib knit, terry stitched inside, reinforced sole, heel and toes (WO 85%, PA 15%)
Felt lining for boots	felt (WO 75%, PA 25%)	felt (WO 75%, PA 25%)	felt (WO 75%, PA 25%)

Notes. PES—polyester, CO—cotton, MAC—modacrylic, WO—wool, PA—nylon, PP—polypropylene.

TABLE 2. Clothing Physiological Properties of the Clothing Systems (M05, M91 and Traditional Clothing)

Property	M05	M91	Traditional Clothing
Air permeability (L/m²s)			
combat clothing	33	53	160
cold weather clothing	7	5	5
Thermal insulation (m²K/W) without cold weather clothing layer			
dry	0.415	0.413	0.444
damp	0.383	0.390	0.414
Resistance to water penetration (Pa)			
combat clothing layer	2720	2190	2000

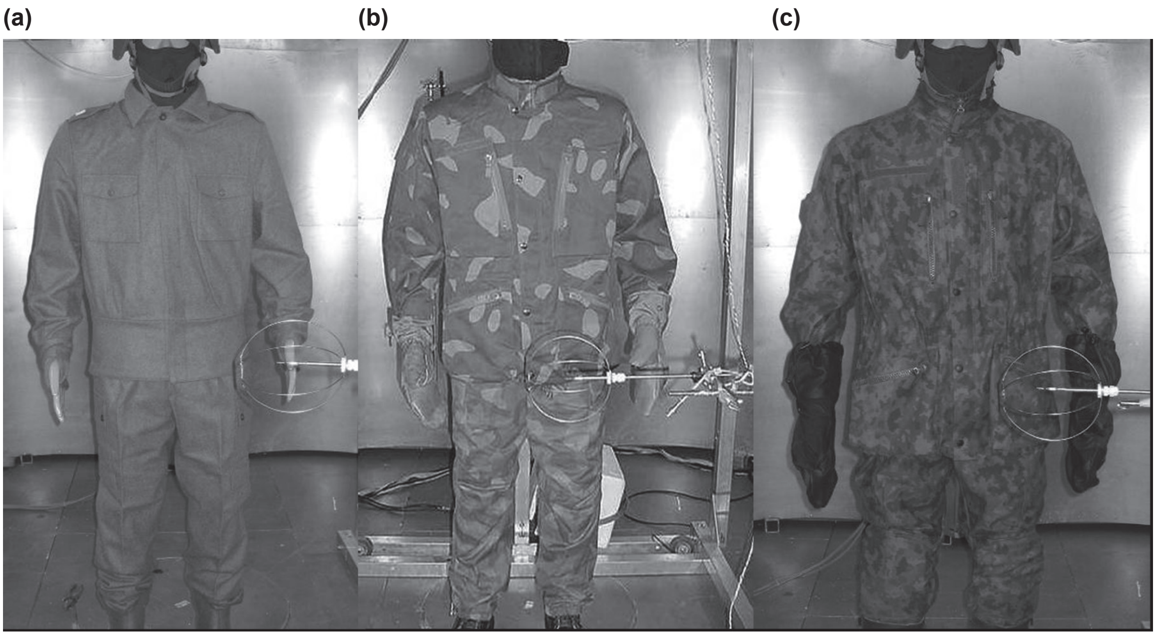

Figure 1. Clothing systems from different decades, when the outermost layer is combat clothing: (a) traditional clothing, (b) previous M91, (c) new M05.

layers remained the same, but their wetting was reduced with more efficient repellent finishes.

Protection of the face was enhanced with a face mask in M05, and the hands are now better protected from the wind and wet by means of an improved design of leather mittens. The structure of the knitted insert mitten has been altered by providing a separate forefinger to enable improved performance in military tasks.

The moisture transfer properties of M05 liner socks have been increased by decreasing the wool content. The winter boots in the M05 system have more efficient thermal insulation than the previous models and their rotational stiffness has also been increased. The M05 winter boots also contain breathing insoles.

The other reference clothing system, used in addition to M91, was traditional coarse cloth clothing. These two systems were otherwise similar except that traditional coarse cloth outerwear made of a dense felted material was replaced with combat clothing in M91 (Figure 1). The dense felted material has good air trapping properties and thickness, giving it good thermal insulation values but high levels of moisture absorbance and stiffness.

The total weight of the M05 winter clothing system was ~2 kg, or 10%, lower than that of the corresponding M91 clothing system. The greatest economies in the weight of the actual garments were achieved in the middle layer garments (–30%) and the cold protective clothing (–7%).

2.2. Field Questionnaires

Test subjects assessed the effects of the three cold protective clothing systems on human thermal and moisture protection and on physical and mental performance in long-term cold exposure during winter military training in northern Finland in December 2005. The training was divided into two parts, physically demanding combat training and combat shooting training. The clothing systems were not rotated between the users for practical and hygienic reasons in view of the long military manoeuvres carried out in the forest. The test subjects were healthy volunteers from among the male conscripts, average age 20 years; participation in the training and the clothing systems were distributed at random. Subjective experiences in terms of clothing comfort and physical and mental performance were elucidated using two daily questionnaires, a clothing questionnaire and a surveillance card. The data were analysed separately for the three clothing systems to enable comparison.

The clothing questionnaires were used to monitor the clothing used, the coldest thermal and general moisture sensations in different parts of the body, ease of using the middle layer clothing and the effect of clothing on survival and performance. Table 3 gives the generally used scales for the thermal [14] and moisture [15] sensations employed in the clothing questionnaire. The thermal sensation *very hot* was left out as being irrelevant in this case. The sensations were given in verbal form in the questionnaire. The detailed instructions about what to wear during training were prepared in co-operation with clothing experts from the Western Finland Logistics Regiment of the Finnish Defence Forces. The ballistic protection and armoury of all the test subjects conformed to regulations.

TABLE 3. Thermal [14] and Moisture Sensation [15] Scales Used in the Clothing Questionnaire

Thermal Sensation		Moisture Sensation	
very cold	0	*dry*	0
cold	1	*almost dry*	1
cool	2	*slightly moist*	2
slightly cool	3	*moist*	3
neutral	4	*almost wet*	4
slightly warm	5	*wet*	5
warm	6	*soaking wet*	6
hot	7		

Surveillance cards distributed and collected on a daily basis were used to allow the conscripts to evaluate their state of health, mental and physical performance, mood, motivation, stress level, nutrition and cold experiences, all on separate 10-point scales. The results were used in combination with those from the clothing questionnaires to assess the significance of the clothing used.

The questionnaires were distributed 11 times during the training and a total of 319 completed forms were obtained. Of the test subjects who answered daily, 10 were wearing M05, 7 the M91 clothing system and 12 the coarse cloth system. Some changes to the garment combinations used during the training were made by the users because of the weather and the activities to be performed. The winter combat clothing was worn on 41 occasions altogether and the ballistic vest 48 times, which contained 23 answers given by test subjects using M05 and 25 using M91.

Ambient conditions were measured throughout the training with a portable weather station (DAVIS Vantage Pro; DAVIS, USA) placed near the training area in the field and readings taken every 10 min. Weather information was also gathered from the Finnish Meteorological Institute's weather station in Salla. Day time weather was calculated as the average of the measurements made between 6:00 and 18:00 and night time weather from the data measured between 18:00 and 6:00. Any major variations from the mean weather parameters were also taken into account when assessing the functioning of the clothing. Figure 2 summarises the ambient conditions during the manoeuvres.

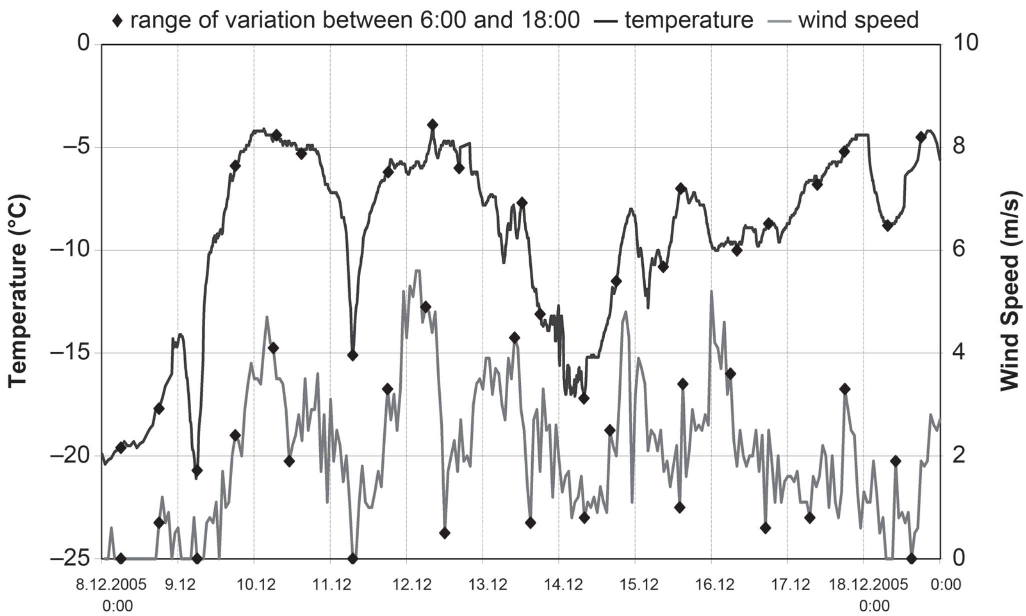

Figure 2. Wind speed and ambient temperature during winter military training. Daily highest and lowest ambient temperatures and wind speeds measured between 6:00 and 18:00.

2.3. Analysis of Questionnaire Data

The data were analysed statistically using SPSS version 15.0 for Windows. This enabled direct analysis of each question and cross-tabulation of the data. The test subjects were given code numbers in the database, so that their identities were not revealed at any stage in the research.

The independent samples *t* test was used to test differences in the means for two clothing system groups in terms of thermal sensation, experience of external moisture and perspiration sensation and for physical and mental performance. Means and standard deviations were calculated.

Percentage differences between the clothing systems for were analysed using the χ^2 test, and differences in measured values in the surveillance data were assessed with an analysis of variance (ANOVA) with repeated measures. The level of significance in all the statistical tests was taken to be $p < .05$.

3. RESULTS

3.1 Clothing Comfort

The test subjects' daily assessments of the coldest thermal sensations in the body are given in Figure 3. The mean value (*SD*) of the thermal sensations with M05 was 3.9 (1.7), corresponding to a *neutral* thermal sensation, the corresponding figures with the other systems being 3.3 (1.4) for M91 and 3.4 (1.6) for traditional clothing. The thermal sensations became warmer with drier moisture sensations (χ^2 test, $p < .001$).

Protection against cold and wind was experienced as significantly better with M05, as can be seen in Figure 4 (*F* test, $p < .001$). According to the daily clothing questionnaire, 62% of the test subjects using M05 considered the cold protection afforded by their clothing to be adequate, implying that the coldest thermal sensation of the day was *neutral* or warmer. The equivalent value for M91 was 46% and that for traditional clothing 45%.

Figure 5 presents the moisture sensations caused by snow, sleet or water with the different cold protective clothing systems. The mean value (*SD*) of the moisture sensations caused by external dampness when wearing M05 was 1.3 (1.2), corresponding to an *almost dry* sensation. The corresponding mean values for the other systems were 1.8 (1.5) for M91 and 2.1 (1.3) for traditional clothing. According to the daily clothing questionnaire, 66% of the test subjects using M05 considered their clothes to have been

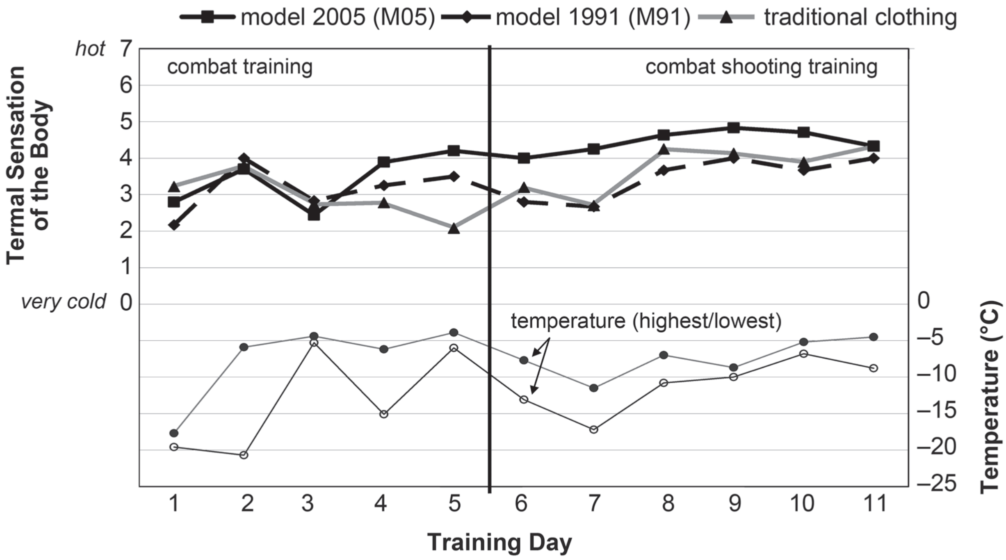

Figure 3. Coldest thermal sensations (mean values) experienced by test subjects in 3 winter clothing systems: M05 (N = 86), M91 (N = 39), traditional clothing (N = 99). Differences between clothing systems: F test, $p < .05$ (*ns*). Daily highest and lowest ambient temperatures measured between 6:00 and 18:00.

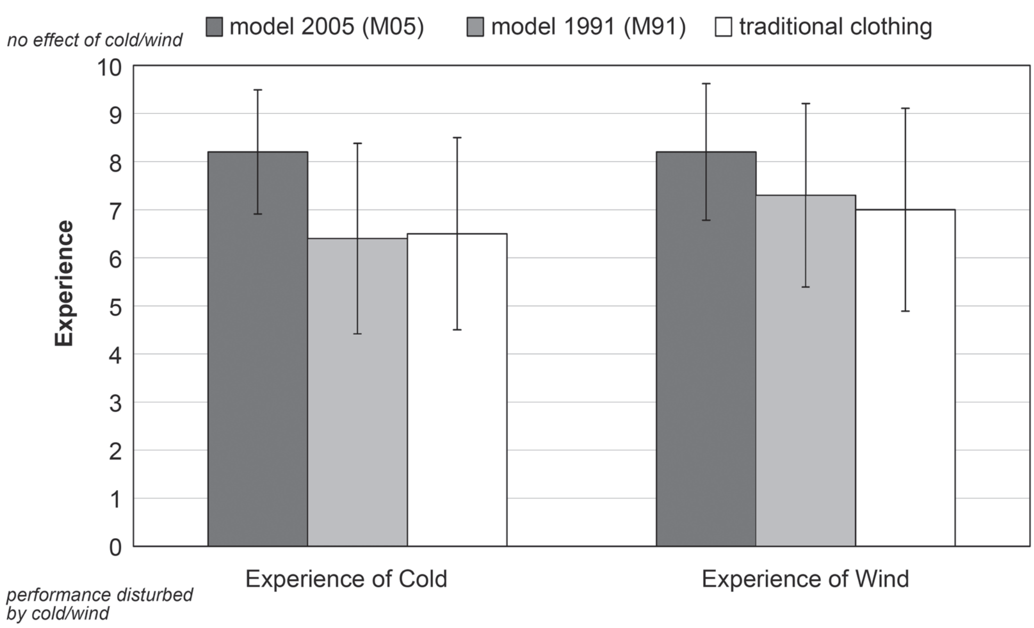

Figure 4. Protection against cold and wind ($M \pm SD$) as experienced by test subjects in different clothing systems: M05 (N = 110), M91 (N = 77), traditional clothing (N = 132). Differences between clothing systems: χ^2 test, $p < .001$.

dry or *almost dry* (values 0 or 1), as compared with 47% of those using M91 was and 31% for traditional clothing. There was a close statistical correlation (χ^2 test, $p < .001$) between the external moisture sensations and environmental temperature, implying that the clothing was considered damper in warmer than in colder weather.

Figures 6–7 present the moisture sensations caused by perspiration with the different cold

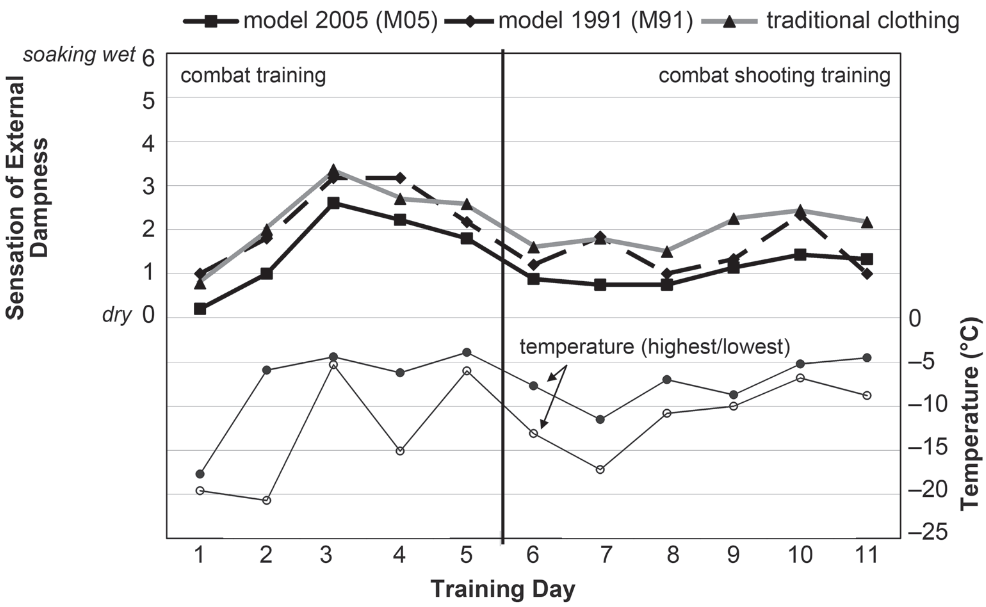

Figure 5. Moisture sensations caused by external moisture (mean values) as experienced by test subjects indifferent winter clothing systems: M05 (*N* = 88), M91 (*N* = 43), traditional clothing (*N* = 99). Differences between clothing systems: *F* test (*ns*). Daily highest and lowest ambient temperatures measured between 6:00 and 18:00.

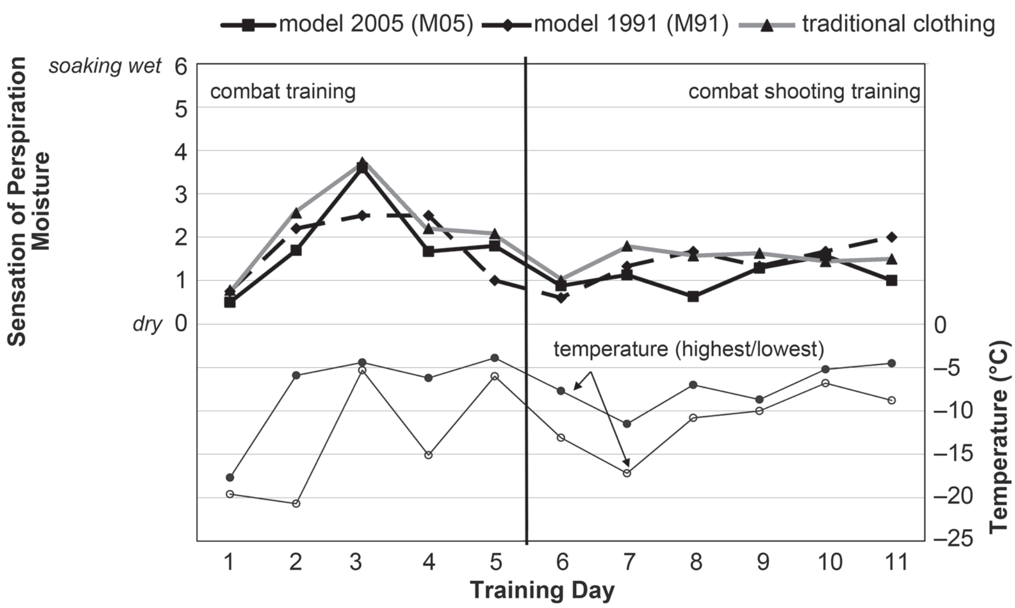

Figure 6. Daily variations in moisture sensations caused by perspiration (mean values) as experienced by test subjects in different winter clothing systems: M05 (*N* = 88), M91 (*N* = 41), traditional clothing (*N* = 96). Similar underwear was used with all systems. Differences between clothing systems: *F* test, *p* < .05 (*ns*). Daily highest and lowest ambient temperatures measured between 6:00 and 18:00.

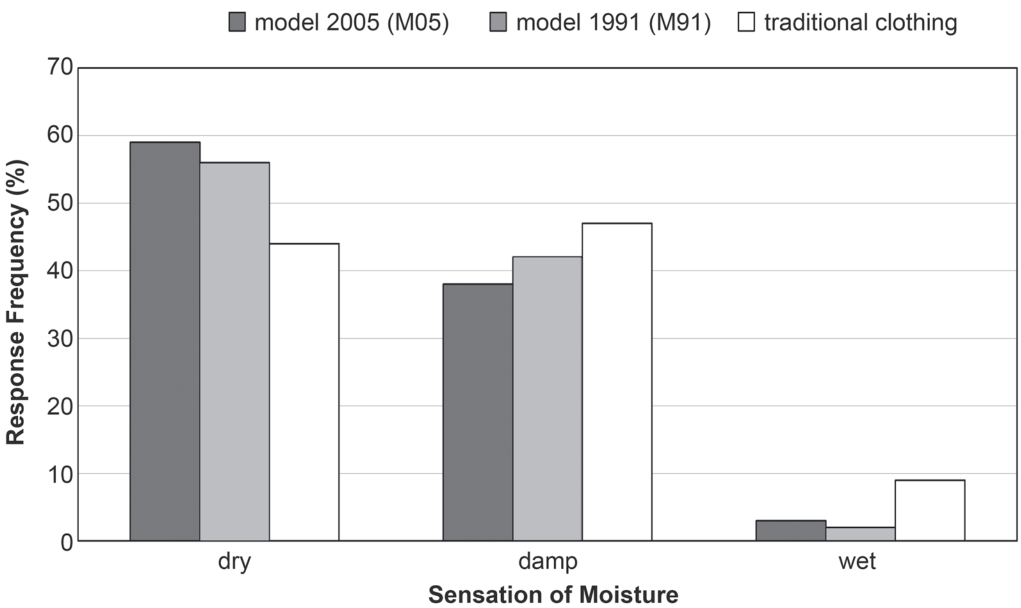

Figure 7. Moisture sensations caused by perspiration as experienced by test subjects in different winter clothing systems: M05 (N = 88), M91 (N = 41), traditional clothing (N = 96). Similar underwear was used with all systems. Differences between clothing systems: χ^2 test, p < .05 (*ns*).

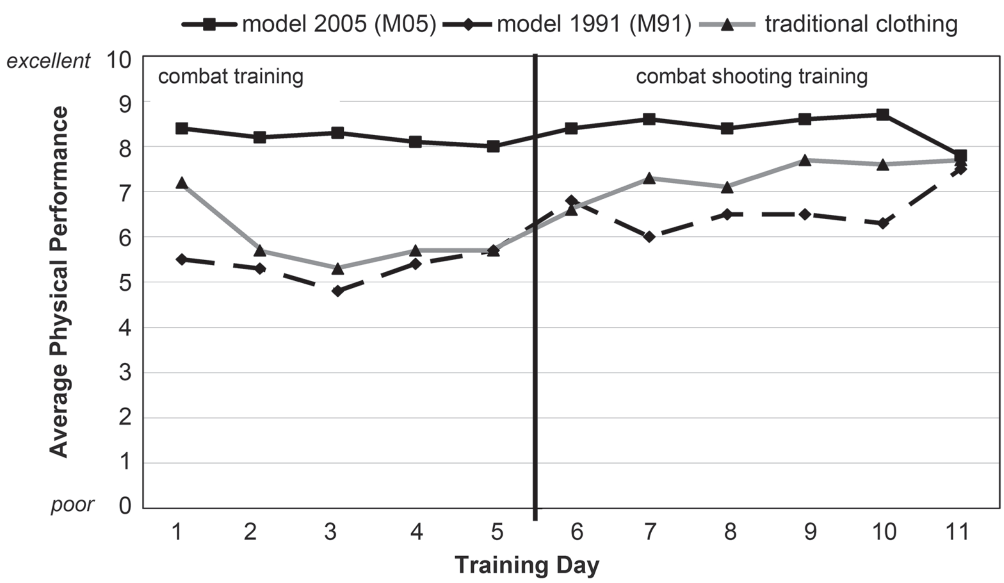

Figure 8. Perception of physical performance (mean values) as indicated in the daily clothing questionnaires by subjects using the different clothing systems: M05 (N = 110), M91 (N = 77), traditional clothing (N = 132). Differences between the clothing systems: F test, p < .001.

protective clothing systems. Figure 6 presents daily results. Similar underwear was used with all of the systems. The mean value (*SD*) of the moisture sensations caused by perspiration when wearing M05 was 1.5 (1.2), which corresponds to *almost dry* or *slightly moist*, while the mean value obtained with the other systems were 1.6 (1.3) for M91 and 1.8 (1.6) for traditional clothing.

3.2. Perception of Performance

The test subjects using M05 rated their physical performance higher in the daily questionnaires (T test, p < .001) than did the others (Figure 8), with a mean value (*SD*) of 8.3 (1.0) as opposed to 5.9 (2.1) for M91 and 6.8 (1.9) for traditional clothing.

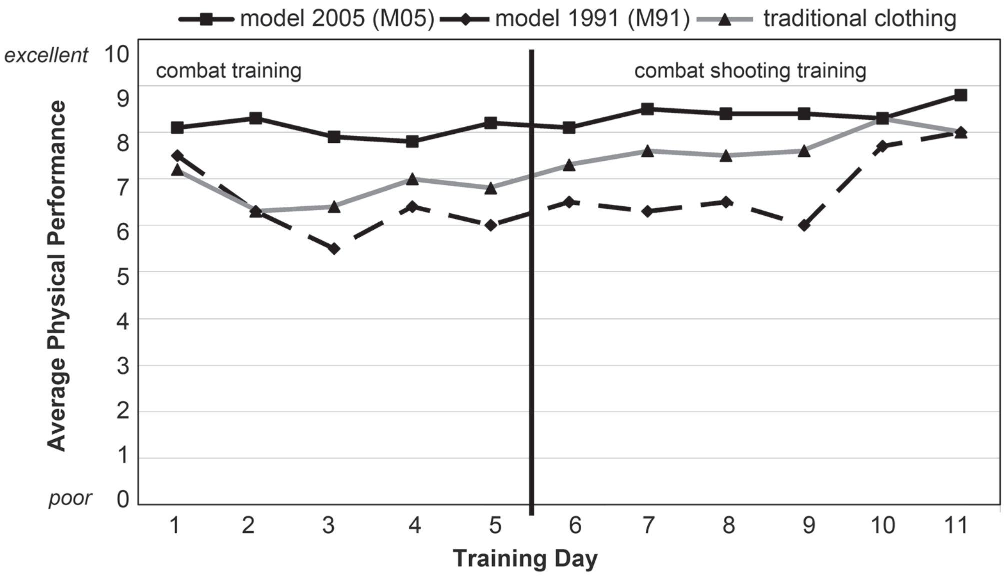

Figure 9. Perception of mental performance (mean values) as indicated in daily clothing questionnaires by subjects using different clothing systems: M05 (*N* = 110), M91 (*N* = 77), traditional clothing (*N* = 132). Differences between clothing systems: *F* test, *p* < .001.

Significant differences in perceptions of mental performance were also found between the test subjects using the different clothing systems (Figure 9), and there was a close correlation ($p < .001$) between the protective properties of the clothing (protection against both cold and moisture) and mental and physical performance. The mean value (*SD*) for perception of mental performance was 8.2 (1.3) with M05, 6.5 (2.4) with M91 and 7.3 (1.8) with the traditional clothing.

4. DISCUSSION

This assessment of the effectiveness of three different military cold protective clothing systems from different decades, the new M05 model, the previous M91 model and traditional coarse clothing, on clothing comfort and both physical and mental performance was carried out in long-term (11 days) cold exposure during winter field training in northern Finland. The most challenging environment was not the cold as such but a combination of cold with perspiration during physical activity, external moisture and wet snow.

The physiological and subjective results for the new M05 clothing system were more positive than for the other clothing systems from earlier decades. M05 gives sufficient protection to enable the user to maintain a good thermal balance under extreme cold conditions, and the thermal insulation and ventilation of the new clothing system is easy to adjust to prevent overprotection and the resulting sweating during the performing of physically demanding tasks under changing environmental conditions. The total weight of M05 is ~10% lower than of the previous cold protective clothing system, which improves the user's physical performance. M05 provided for warmer thermal sensations ($p < .01$), dryer moisture sensations in the presence of external dampness ($p < .001$), dryer moisture sensations caused by perspiration ($p < .05$) and better perceived physical and mental performance ($p < .001$) than the other cold protective clothing systems (M91 and traditional clothing). Equivalent results, that the fabric properties of cold protective clothing systems could significantly affect humidity and temperature distributions and comfort, have been shown in an earlier study [15].

If the thermal insulation of cold protective clothing is too low, the test subject will lose body heat to a harmful extent and the probability of frost damage will increase. According to earlier research, the values of thermal insulation are highest when the thickness of the air layer is 0.6–1 cm [2]. This required air layer thickness was obtained by using multiple (3–5) layers of clothing and choosing clothing of the correct size. Underwear must be snug, and the outer layers must not compress the layers underneath. It has been shown that sweating reduces thermal insulation proportionally to moisture retention [4] and that there is a dramatic fall in cooling efficiency when moisture is absorbed from the skin before it evaporates [5]. According to previous studies, energy consumption at work increases ~3–4% per clothing layer because of the weight of the layers and friction between them [10]. It has also been shown that the weight of the clothing causes a 2.7% per kg increase in energy consumption [11]. M05 is ~2 kg lighter than M91 and traditional clothing, and the middle layer in particular is more flexible, resulting in a smaller increase in load. These results are in line with other findings that thick, heavy, stiff clothing increases the physical load involved in performing tasks [9, 10, 11].

Relating to clothing comfort, M05 allows increased adjustability of the thermal insulation even though the total thermal insulation is similar to that in other systems. Experiences of cold and wind were examined on a daily basis, and it was evident that the test subjects wearing M05 were not affected by the cold and windy conditions during training as much as the other test subjects. The differences between the clothing systems were caused by the lower air permeability and higher resistance to water penetration of M05, which also preserved its thermal insulation properties better under difficult ambient conditions and during physical labour than the other clothing systems. Thermal sensations were closer to neutral when wearing M05 than the other systems except in the first 3 days of training, when the moisture sensations caused by external and perspiration moisture were also wettest, which directly affects thermal sensations. Also, on the third day of training, the level of physical activity was highest and the ambient temperature was warmer than on the other days. Traditional clothing was affected most by external moisture, on account of the hydrophilic nature of its cloth, with high wool content (WO 85%). Since all the test subjects were wearing the same underwear, the differences must have been caused by the absorption and wicking properties of the middle layer and the water vapour penetration properties of the outer layer. The middle layer clothing of M05 and M91 differs in terms of both material and fit, that of M05 fitting snugly and enabling quicker moisture transfer from the underwear.

M05 helped the test subjects to keep their thermal balance stable, resulting in less daily variation in perceived physical performance. The effect of the clothing on physical performance can be seen clearly in the day-to-day variation, the differences being greater during the physically more demanding combat training. The better water repellence of M05 kept it drier and meant that the decrease in thermal insulation was smaller than with the other clothing systems, and this may also have affected perceived mental performance. To account for the psychological effect of the new clothing on perceived performance two separate questionnaires were used, the clothing questionnaire and the surveillance card. The latter contained no questions referring to the clothing used, the emphasis being on other matters, such as state of health, mental and physical performance, mood, motivation, stress level, nutrition and cold experiences, the results of which were used in other ongoing research as well. In addition, the surveillance cards were distributed by the military personnel throughout the winter military training, whereas the clothing questionnaire was administrated by the researchers themselves. The clothing systems were not rotated between the users because of practical and hygienic issues associated with the long period of military manoeuvres in the forest. This means that the test subjects could not be asked to compare the clothing systems. However, the moisture sensations experienced on a daily basis on account of perspiration showed no significant differences between the three clothing systems, because similar underwear was used in all clothing systems. This shows that the new clothing had no psychological effect on the test subjects' sensations.

5. CONCLUSIONS

The physiological and subjective results for M05 were more positive than for the other clothing systems from earlier decades. The M05 winter clothing system gives sufficient protection to enable the user to maintain a good thermal balance under conditions of extreme cold. The thermal insulation and ventilation properties of the new clothing system are easier to adjust than those of the other systems to prevent overprotection and the resulting sweating during the performance of physically demanding tasks under changing environmental conditions. The total weight of M05 is lower than that of the previous cold protective clothing system, which partly enables improved physical performance on the part of the user. The results indicate that careful development of clothing materials and system, taking into account the user, the tasks to be performed and the environmental conditions, can guarantee comfortable sensations and good performance during exposure to cold weather.

REFERENCES

1. Tikuisis P, Keefe AA, Keillor J, Grant S, Johnson RF. Investigation of rifle marksmanship on simulated targets during thermal discomfort. Aviat Space Environ Med. 2002;73(12):1176–83.
2. Chen YS, Fan J, Qian X, Zhang W. Effect of garment fit on thermal insulation and evaporative resistance. Text Res J. 2004;74(8):742–8.
3. Meinander H, Anttonen H, Bartels V, Holmér I, Reinertsen RE, Sołtyński K, et al. Manikin measurements versus wear trials of cold protective clothing (Subzero project). Eur J Appl Physiol. 2004;92(6):619–21.
4. Chen YS, Fan J, Zhang W. Clothing thermal insulation during sweating. Text Res J. 2002;73(2):152–7.
5. Havenith G, Bröde P, Candas V, Hartog E, Holmér I, Kuklane K, et al. Evaporative cooling in protective clothing: efficiency in relation to distance from skin. In: Proceedings of the 13th International Conference on Environmental Ergonomics. Wollongong, NSW, Australia: University of Wollongong; 2009. p. 20–24. Retrieved March 9, 2010, from: http://www.lboro.ac.uk/departments/hu/groups/EEC/ICEE/textsearch/09proceedings/ICEE13-Proceedings.pdf
6. Kim E, Yoo SJ, Shim H. Performance of selected clothing systems under subzero conditions: determination of performance by a human-clothing-environment simulator. Text Res J. 2006;76(4):301–8.
7. Rossi RM, Gross R, May H. Water vapor transfer and condensation effects in multilayer textile combinations. Text Res J. 2004;74(1):1–6.
8. Reed L, Osczevski RJ, Farnworth B. Cold weather clothing systems: recent progress and problems for future research. In: Goldman RF, Kampmann B, editors. Handbook on clothing. Biomedical effects of military clothing and equipment systems (Report of NATO Research Study Group 7). 2nd ed. 2007. p. 5-1–12. Retrieved February 8, 2010, from: http://www.lboro.ac.uk/departments/hu/groups/EEC/ICEE/textsearch/Handbook%20on%20Clothing%20-%202nd%20Ed.pdf
9. Dorman L, Havenith G, Bröde P, Candas V, Hartog E, Havenith G, et al. Modelling the metabolic effects of protective clothing. In: 3rd European Conference on Protective Clothing (ECPC) and NOKOBETEF 8. Protective Clothing Towards Balanced Protection [CD-ROM]. Warszawa, Poland: Central Institute for Labour Protection – National Research Institute; 2006.
10. Duggan A. Energy cost of stepping in protective clothing ensembles. Ergonomics. 1988;31(1):3–11.
11. Dorman L, Havenith G. The effects of protective clothing on energy consumption during different activities. Eur J Appl Physiol. 2009;105:463–70.

12. Palinkas L. Mental and cognitive performance in the cold. Int J Circumpolar Health. 2001;60(3):430–9.
13. Mäkinen T, Palinkas L, Reeves D, Pääkkönen T, Rintamäki H, Leppäluoto J, et al. Effect of repeated exposures to cold on cognitive performance in humans. Physiology & Behaviour. 2006;87:166–76.
14. International Organization for Standardization (ISO). Ergonomics of the thermal environment—assessment of the influence of the thermal environment using subjective judgement scales. (Standard No. ISO 10551:1995). Geneva, Switzerland: ISO; 1995.
15. Wang SX, Li Y, Tokura H, Hu JY, Han YX, Kwok YL, Au RW. Effect of moisture management on functional performance of cold protective clothing. Text Res J. 2007;77(12):968–80.