RELATIONSHIPS BETWEEN PHYSIOLOGICAL STRAIN AND PHYSICAL PROPERTIES OF DIFFERENT PROTECTIVE GARMENTS.

U. Bergh, U. Danielsson, I. Holmér and H. Nilsson.
National Defence Research Establishment, Sundbyberg and National Institute of Occupational Health, Solna
Sweden

INTRODUCTION

Protective garments induce an increased load on the wearer. Hence, it is natural to look for the garment that causes the least strain while offering sufficient protection. Therefore, there is an interest in methods by which differences in physiological strain can be accurately assessed or estimated, preferably without using human subjects. For ensembles designed for different purposes parameters such as thermal insulation and water vapor resistance have been shown to be valuable predictors of physiological response (1). However, the problem is often to chose one out of several ensembles designed for a given purpose where the range in vital parameters tends to be reduced. The aim of the present study was (i) to investigate the possibilities to use physical parameters as indicators of physiological strain of protective garments which are made for a specific task, (ii) to compare the level of physiological strain induced by different garments designed for a given purpose, (iii) to compare different methods for measuring thermal insulation.

METHODS

Six different ensembles (A to F), which gave sufficient protection against external heat, were studied regarding physiological response to exercise, thermal insulation of ensembles and heat and water vapour resistance of the materials. Ensembles D and E were coveralls while the other ensembles were composed of a jacket and trousers. The exercise consisted of three 25 min workbonts (stationary cycling at 75 W and walking at a speed of 1 m/s) interspersed by 5 min of rest Six male fire-fighters volunteered as subjects. Mean values and range for age, stature, and weight were: 37 (16) years, 178 (14) cm, 75 (17) kg, respectively. Measurements and subjective ratings: maximal reach in five different body positions, 5 min before the first exercise bout; heart rate (HR) every min; metabolic rate (MR) every min during cycling; rectal temperature (T_{re}) and body mass nude (BM_n) before dressing and after undressing; mass of body + equipment (M_t); perception of exertion (RPE), temperature (RPT) and comfort (RPC), before and after each exercise bout; thermal insulation of the ensembles (i) on the thermal manikin Tore (I_{manik}) and (ii) with heat flux sensors (2) on six male subjects during standing (I_{stand}) and treadmill walking at a velocity of 1 m/s and a windspeed of 1 m/s (I_{walk}), thermal insulation (I_{mat}) and water vapor resistance (R_{mat}) of the samples cut from these ensembles according to the standards BS 47451986 and DIN 54 101, respectively. Systematic differences between the methods for measuring the thermal insulation were evaluated by comparing the values obtained for all garments. Analysis of variance was applied to test differences. Regression analysis (simple or multiple) was used to test the strength of correlations between physical and physiological variables. A critical level of 0.05 was used.

RESULTS

Extreme values for the mean values over subjects for the different garments are displayed in table 1 and 2. No significant differences were found between ensembles regarding HR, MR, I_{mat}, R_{mat}, RPE, RPT and RPC. Significant differences were found in: ΔBM_n and ΔM_t for which B was < C; $\Delta M_t / \Delta BM_n$ where B was > C; ΔT_{re} for which A was < C and E; maximal reach where B and C were > E I_{stand} where D < A and E; I_{walk} where D was < A, B and E while E was > C, D and F. Between coveralls and two-piece garments no significant difference was found.

Table 1. *Physiological* variables *for the different* ensembles. Lowest *and highest mean value.*

HR (beats/min)	MR (W)	ΔT_{re} (°C)	ΔBM_n (kg)	ΔM_t (kg)	$\Delta M_t/\Delta BM_n$	Reach (m)
132-143	613-641	0.9-1.4	1,387-1.629	0.486-0.534	32-38	0.81-0.86

Table 2. *Physical parameters for the different* **ensembles.** Lowest *and highest mean value.*

I_{manik} (m^2K/W)	I_{stand} (m^2K/W)	I_{walk} (m^2K/W)	I_{mat} (m^2K/W)	R_{mat} (m^2Pa/W)
0.384-0.405	0.352-0.413	0.234-0.283	0.176-0.296	24-34

Table 3. *Correlation coefficients* **between** *physical and physiological parameters.*

	I_{manik}	I_{stand}	I_{walk}	I_{mat}	R_{mat}	Thickness
HR	0.23	-031	-0.05	-0.05	-0.22	0.05
MR	0.78	0.06	0.25	0.20	0.17	0.25
ΔBM_n	0.27	-0.26	-0.07	-0.02	-0.11	0.04
ΔM_t	0.13	0.15	0.52	-0.01	-0.07	-0.02
T_{re}	-0.03	-0.51	-0.24	-0.19	-0.04	-0.22
Reach	0.44	-0.20	0.37	-0.87	0.46	-0.73

None of these physical variables was significantly correlated to more than one of the physiological ones (table 3). Combining different physical parameters (multiple regression analysis) did not produce more significant relationships than what would be expected to occur by pure chance. For I_{manik}, I_{stand}, I_{walk} and I_{mat} average values wen 0.393, 0.392, 0.252, and 0.237 m^2K, respectively. Thus, no systematic difference was found between the heat flux sensor and the thermal manikin techniques. On the other hand, I_{walk} and I_{mat} differed significantly from I_{manik} and I_{stand} but not from each other. The explanation is that I_{manik} and I_{stand} were measured at natural convection conditions, while I_{walk} and I_{mat} measueremeats included forced convection. For all physiological variables, *except* ΔT_{re}, *the* differences *were* much (two to three times) greater between subjects than between *garments.*

CONCLUSIONS

If ensembles are designed for a specific purpose the choice of materials, ensemble thickness and design tends to become restricted to such an extent that the differences in physical properties and physiological strain will be close to what *can* be detected with available methods and with a limited number *of* subjects and garments. In these type *of* investigations the inter-individual differences are likely to be considerably greater than the differences caused by the garments.

REFERENCES

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