EVALUATION OF INTERIOR MOISTURE ON HANDWEAR COLD PROTECTION

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INTRODUCTION

The presence of moisture reduces the effectiveness of clothing insulation. The source of moisture may be external (rain, melting snow) or internal sweat. A water-repellent layer may be used to resist external moisture, but during high levels of activity, sweat may dampen handwear insulation and reduce effective insulation. This paper describes an approach to investigating the problem of interior moisture (sweat) on handwear insulation.

The evaluation of cold weather handwear generally consists of two phases. The first phase involves testing on a biophysical hand model (1). The normal test procedure is to mount the *dry* handwear on the model to measure total *dry* insulation (I_T). To simulate the effect of moisture on clothing, wet clothing may also be mounted on the model (2). The second phase of testing involves human subjects who are normally either sedentary or walking at a fixed rate on a treadmill in an environmental chamber (3,4). The test variables for human studies are tolerance time, rate of temperature decrease in the extremities and subjective responses of comfort or thermal sensation. When subjects were sedentary, sweat was minimal whereas when subjects walked, sweat was a factor, but the relatively high rate of metabolic heat production offset any effect of sweat wetting on handwear insulation and the rate of heat loss from fingers. In this protocol, subjects participated in a walk-sit exercise designed to induce sweating prior to sedentary cold exposure to investigate the impact of internal moisture on handwear.

METHODS

All test gloves consisted of an outer leather shell and a removable inner liner. Of the four prototype Intermediate Cold Weather Gloves (ICWG), two had a "breathable" water barrier of polytetrafluoroethylene (PTFE) and two had a polyethylene "vapor barrier" *(5)*. All prototypes had either a thin or thick knit synthetic liner. Shells with the thinner liner had micro-fiber insulation and shells with the thicker liners had foam insulation. The total *dry* insulation (I_T) of the different glove systems were nearly equivalent. The control glove was a Light-duty glove (LD), which has an unlined leather shell and nylon reinforced knit wool liner.

Human testing was conducted with nine volunteer test subjects. Informed consent was obtained from each subject in accordance with *AR* 70-25 and USARIEM 70-25. During 34 days of testing, the subjects participated in several different test activities. For the purposes of this paper, only the walk-sit activity in the -18°C and -7°C environments (1.1 $m \cdot s^{-1}$ wind speed) will be described. Subjects wearing a full Extended Cold Weather Clothing System (ECWCS) ensemble walked on a level treadmill at 1.56 $m \cdot s^{-1}$ for **45** min. The combination of heavily insulated clothing and a high activity level increased core temperature and induced sweating inside both clothing and handwear. The subjects then attempted to sit in the chambers for **75** minutes. Subjects left the chamber when they were uncomfortably cold or when measured finger temperature reached 5°C. Test variables were nail-bed finger temperature or tolerance (sitting only) time. Rectal temperature and heart rate were also monitored for safety purposes during the study.

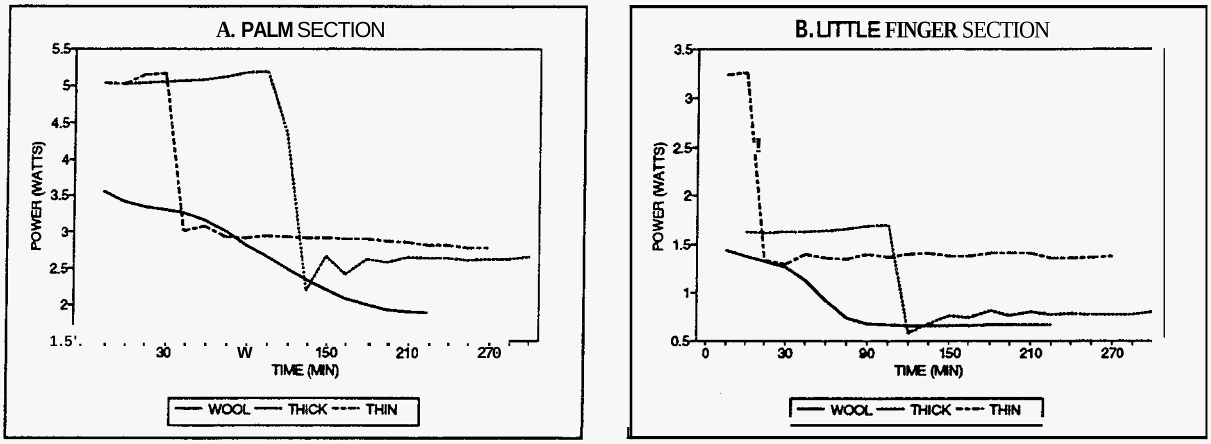
Dry insulation of each handwear system was determined with a static, thermal hand model by measuring the power demand required to maintain a 30°C surface temperature in a 10°C test chamber. In an additional pilot study, each of the liners was run *dry* on the model, removed, wetted and replaced. Plots for each of the liners indicate the pattern of recovery of the power demand to initial values.

Table 1. Total sitting time *(ET)* and finger cooling rate ($\Delta °C \cdot min^{-1}$)

Environment	-18°C		-7°C	
Glove	ET* (min)	$\Delta °C \cdot min^{-1}$	ET*	$\Delta °C \cdot min^{-1}$
LD (CONTROL)	42 (15)**	0.61 (0.23)**	75 (0)	0.26 (0.07)
PTFE-THICK	46 (15)	0.52 (0.14)	75 (0)	0.25 (0.09)
PTFE-THIN	59 (17)**	0.40 (0.17)**	75 (0)	0.28 (0.06)
VB-THICK	53 (18)	0.47 (0.17)	75 (0)	0.27 (0.06)
VB-THIN	46 (19)	0.50 (0.18)	75 (0)	0.24 (0.09)

Values in ( ) are SD * sit only ** significantly different

Figure 1. Power demand vs. time as an indication of liner drying



RESULTS

Human study: Overall differences (MANOVA) between handwear were found for tolerance time and the rate of change in finger temperature (Table 1). A post hoc (Tukey's) between pairs, determined that only the differences at -18°C between the control LD gloves and the PTFE glove with thin liner (PTN) were significant (a= 0.05). For the LD glove, the mean sitting time was 42 **min** versus 59 min for PTN and the rate of decrease in finger temperature was 0.61°C·min^{-1} versus 0.40°C·min^{-1}. Both VB gloves did not dry adequately when hung at room temperature (approx. 20°C) for several days.

Insulation measurements: I_T for the LD control was 0.12 m^2·K·W^{-1} (0.8 clo) and values for the four prototypes ranged between 0.18 and 0.20 m^2·K·W^{-1} (1.2-1.3 clo). The I, for the wool/nylon LD glove liner was 0.09 m^2·K·W^{-1} (0.6 clo) and the synthetic liners were 0.08 m^2·K·W^{-1} (0.5 clo) and 0.06 m^{-1}·K·W^{-1} (0.4 clo) for the thick and thin variations. As the wetted liners dried, the power demand for the wool liner displayed a smooth, sigmoidal curve whereas both synthetic liners maintained a high power demand followed by an abrupt drop to pre-soak levels (Figure 1). Both synthetic liners recovered to the initial power demand levels, but the duration of the high demand for the thicker glove was nearly three times greater.

CONCLUSIONS

Based on I_T values, all prototypes should have outperformed the control. Only the PTFE glove with the thin liner was significantly better than the control. The retention of sweat inside the glove next to the *skin,* altering the effective thermal resistance, likely caused the difference between gloves. For the moisture permeable gloves, the difference may also be due to slower drying of the thicker liner.

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