PHYSIOLOGICAL EVALUATION OF PROTOTYPE MILITARY HANDWEAR WORN IN COLD-WET AND COLD-DRY ENVIRONMENTS

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INTRODUCTION

Military combat personnel deployed to cold-wet operational regions face a multitude of occupational and environmental hazards. Prolonged exposure to cold and wet conditions can reduce blood flow to the hands resulting in a loss of manual dexterity while increasing the potential for severe cold injury. A recent study showed that even well-trained soldiers wearing modem combat clothing experienced a high incidence of non-freezing cold injury during a large-scale military conflict conducted in a typical cold-wet environment (1). Results from a post-combat survey of participants in that campaign showed that cold hands constituted a major medical problem. This present study evaluated recent design and material developments aimed at improving the protective capabilities of the U.S. Army Men's and Women's Intermediate Cold-Wet Glove (ICWG).

METHODS

Eight volunteers wore the ICWG (control) and a series of six prototype cold weather gloves in a climatic chamber on separate days while attempting a 4 hour sedentary exposure in the following simulated environments: COLD-DRY with a dry-bulb temperature (T_{db})= -17.21°C, dew-point temperature (T_{dp})= -25.07°C; COLD-WET with T_{db}= 0.01°C, T_{dp}= -8.44°C. Volunteers wore an extended cold weather clothing system (thermal resistance, R_c ($m^2 \cdot K \cdot W^{-1}$)=0.56, water vapor resistance, R_e ($m^2 \cdot kPa \cdot W^{-1}$)=0.082 when measured on a thermal manikin) and a pair of vapor-barrier boots (R_c=0.28 measured on a thermal foot model). Gloves were dry during COLD-DRY and externally-wetted in a 1 hour immersion of all fingers and thumb prior to COLD-WET exposures. Gloves were weighed to the nearest gram pre-immersion and post-COLD-WET. Individual endurance time was measured from the completion of a 5 minute base-line period to the time the volunteer exited the chamber. Rectal temperature (T_{re}), a four-point mean-weighted skin temperature ($\bar{T}_{sk}$), and the temperature of both middle finger tips (T_{tip}) were continuously monitored with an automated data acquisition system. Prior to human testing, a new sample of all seven test gloves was evaluated for thermal resistance using a thermal hand model. All gloves were tested with a removable insert made of 55% acrylic, 25% wool, and 20% hollowcore polyester. All gloves were similar in terms of configuration of the various layers of materials, i.e., outer shell/moisture barrier membrane/insulating layer/inner lining/insert. Table 1 describes various physical characteristics of the test handwear.

Table 1. Phvsical characteristics of the various test handwear

Glove	Design	Outer	Barrier	Insulation	R_c
Control	Flexor	Cowhide	Gore-Tex®[1]	Thermolite®[1]	0.21
Prototype 1	Flexor	Cowhide	Gore-Tex	Thermolite	0.18
Prototype 2	Gunn-Cut	Cowhide	Gore-Tex	Thermolite	0.20
Prototype 3	Forchette	Cowhide	Gore-Tex	Thermolite	0.18
Prototype 4	Flexor	Sheepskin	Drypel®[1]	Liteloft®[1]	0.18
Prototype 5	Flexor	Spandura®[1]	Porelle®[1]	PE Fleece	0.16
Prototype 6	Flexor	Spandura	Drypel	PU Foam	0.18

'Gore-Tex (W.L. Gore & Associates, Inc., Elkton, MD, USA). Drypel (S. Haber and Sons, USA), Porelle (Porvair International Ltd.. King's Lynn, UK). Spandura and Thermolite (E.I. du Pont de Nemours, Wilmington, DE, USA), Liteloft (3M, St. Paul. MN, USA) are registered trademarks. PE = polyester, PU = polyurethane.

RESULTS

Table 1 shows that the control glove had the highest measured R_c value. Table 2 shows that the control glove also provided the longest COLD-WET endurance time as well as comparably-high COLD-DRY protection. 61% of the COLD-WET tests and 59% of the COLD-DRY tests were voluntarily-terminated by the test participants due to general discomfort in their hands and fingers. The remaining tests in both environmental scenarios were terminated due to the fact that the volunteer's T_{tip} had dropped to the safety criteria lower limit of 5°C. At least one volunteer was able to complete a full 4 hour exposure with every test glove during COLD-WET with the exception of prototype 3. Table 2 shows that the control glove had a significantly lower weight increase, as a result of water absorption, during the 1 hour immersion. None of the volunteers sensed moisture at the skin surface of the hand while wearing the four gloves utilizing a Gore-Tex membrane during COLD-WET. Gloves with moisture barriers other than Gore-Tex allowed moisture to penetrate the insulating material layer. Prototype 6 allowed moisture to penetrate to the skin surface of the hand during all eight COLD-WET tests. Overall, Flexor design gloves lined with a Gore-Tex membrane and insulated with Thermolite provided higher endurance time values. There were no significant differences in final T_{re} or final $\bar{T}_{sk}$ among the seven test gloves during either COLD-DRY or COLD-WET.

Table 2. Endurance times (ET) of volunteers (n=8) during COLD-DRY and COLD-WET conditions, weight increase of test glove-pairs at termination of COLD-WET tests (n=8 each glove type), and number of pairs sensed by volunteers to be wet. Values are mean±SD.

Glove	ET COLD-DRY (min)	ET COLD-WET (min)	Weight increase (g)	Sensed wet?
Control	79535	186±53	16±10	no
Prototype 1	82±18	161±54	112±38	no
Prototype 2	82±22	175±45	99±79	no
Prototype 3	72±34	151±44	161±8	no
Prototype 4	73±25	177±67	120±19	yes, 2 pair
Prototype 5	70±19	145±44	79±25	yes, 4 pair
Prototype 6	67526	137±64	120±64	yes, 8 pair

CONCLUSIONS

This study showed that the current U.S. Army ICWG provided superior thermal insulation, minimal weight gain as a result of water absorption and excellent thermal protection to the hands of human volunteers during sedentary cold and wet exposures when compared to a series of six prototype gloves employing advanced pattern designs, moisture barriers and insulating materials.

REFERENCES

1. McCaig, R.H. and Gooderson, C.Y.. 1986. Ergonomic and physiological aspects of military operations in a cold wet climate, *Ergonomics,* 29, 849-857.