# EFFECTS OF PROLONGED WATER CONTACT ON THE THERMAL INSULATION OF COLD WEATHER FOOTWEAR

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## INTRODUCTION

U.S. Navy personnel deployed to polar and sub-polar regions are exposed to a multitude of occupational and environmental hazards while both ashore and afloat. The standard-issue U.S. Navy boot utilizes wool felt insulation sealed within a rubber vapor-barrier to provide thermal protection in these extreme cold and cold-wet environments. Unfortunately, this boot is heavy, loses insulating ability if punctured, and causes excessive foot sweating. The latter requires a strict regimen of personal hygiene with frequent changes of clean and *dry* socks to prevent skin maceration and blister formation. Personnel are also at risk for severe foot injury due to the lack of an integrated steel safety toe. *An* extended exposure to cold-wet weather can result in non-freezing cold injury (NFCI) to the feet (i.e., trenchfoot) which *can* cause permanent physical impairment necessitating costly, long-term therapy. There was a high incidence of NFCI to the feet of UK ground combat personnel during the Falkland Islands conflict which was conducted in a typical cold-wet environment (1). Results from a post-combat survey of participants in this campaign showed the major clothing-related complaint was the poor performance of their footwear and the resulting physical condition of their feet *(2).* This present study was conducted to assist the U.S. Navy in their development of an improved Cold Weather Safety Boot (CWSB) that is lightweight, totally waterproof, more breathable and provides impact protection to the toes.

METHODS

The standard boot (CONTROL) and *six* commercially-made CWSB were evaluated for their thermal insulation properties using an automated, heated foot model (3). The following is a description of the test footwear:

CONTROL boot. Boot, Cold Weather, Insulated Rubber MIL-B-41816, Type I, Class 2 without an integrated safety toe and with multiple layers of wool-felt insulation.

1. Ranger Firewalker boot with steel safety toe, steel midsole, THINSULATE®[1] (microfibrous polyester) insulation, KEVLAR®[1] (aramid fiber) lining, and SYMPATEX®[1] (monolithic, hydrophilic polyester) membrane.

2. Modified Ranger Firewalker boot with fiberglass safety toe, THINSULATE insulation, and SYMPATEX membrane.

3. Chippewa boot no. 79371 with steel safety toe, THINSULATE insulation, and fleece lining.

4. Lehigh boot no. 1107 with steel safety toe, THINSULATE insulation, and SYMFATEX membrane.

5. LaCross Bison boot with steel safety toe and removable polypropylene felt innerboot.

6. Matterhorn boot no. 1949 with steel safety toe, THINSULATE insulation and GORE-TEX®[1] (micropomus polytetrafluoroethylene) membrane.

Data from the foot model was used to calculate a total insulation value, I, ($m^2 \cdot K \cdot W^{-1}$), of the complete boot system as well as a regional insulation value. $I_r$, for each of the 29 thermally isolated sections of the model. All footwear was tested in a *dry* condition (DRY) and then after 18 h of upright placement in 7 cm of water (WET). The water level was deep enough to completely submerge the entire welt and any adjacent stitching of the upper of each boot under water. The foot model was dressed with a 50% wool/50% nylon cushion sole

[1]THINSULATE (3M, St. Paul, MN, USA), KEVLAR (E.I. du Pont de Nemours, Wilmington DE, USA), SYMPATEX (ENKA America, Asheville, NC, USA), and GORE-TEX (W. L. Gore & Associates, Inc., Elkton, MD, USA) are registered trademarks.

**sock.** All footwear was weighed to the nearest gm pre and post-WET.

## RESULTS

*The* CONTROL boot provided a comparatively-high DRY $I_t$ value and showed the smallest overall thermal insulation loss as a result of WET. The three CWSB that did not utilize a hydrophilic polyester membrane had high DRY $I_t$ values (average = 0.304) but lost a substantial percentage of this insulation after WET (average loss 46%). Even greater losses were seen in that anatomical regions of the foot model where the potential for NFCI is the greatest (average loss at toes = 58%, sole = 58%, heel = 52%). These boots also had large increases in weight due to water absorption (average gain = 34.7%) and were wet internally post-WET. A recent study showed that leather boots employing integrated waterproof/breathable membranes could not prevent water ingression after a prolonged soak in shallow water. This fact contributed to several cases of friction blisters to the feet of subjects performing intermittent exercise while wearing this wet footwear **(3).** The three CWSB that were completely lined with the hydrophilic polyester membrane had smaller DRY $I_t$ values (average = 0.245) but reductions in $I_t$ as a result of WET were considerably smaller (average loss = 8.7%) than with the other three boots. $I_t$ losses at toes, sole, and heel (average loss = 20%, 21%, and 9%, respectively) indicate some degree of water penetration through the leather although these boots had comparatively small increases in *total* weight (average gain = 2.7%) and were observed to be totally *dry* internally post-WET. Table 1. shows $I_t$ values of all the test footwear as a result of DRY and WET as well as other pertinent data

Table 1.-Total insulation values ($I_t$, $m^2 \cdot K \cdot W^{-1}$) of all test footwear as a result of DRY and WET.

| BOOT | $I_t$ DRY | $I_t$ WET | INTERIOR WET? |
|---|---|---|---|
| CONTROL | 0.283 | 0.270 ***(-5%)*** | NO |
| 1 | 0.246 | 0.226 (-8%) | NO |
| 2 | 0.246 | 0.229 (-7%) | NO |
| 3 | 0.296 | 0.153 (-48%) | YES |
| 4 | 0.242 | 0.215 (-11%) | NO |
| 5 | 0.346 | 0.191 ***(-45%)*** | **YES** |
| 6 | 0268 | 0.147 ***(-45%)*** | YES |

## CONCLUSIONS

Cold injury to the feet *can* quickly immobilize an individual and usually requires immediate evacuation for emergency medical treatment. In this study, the standard-issue boot provided superior overall performance. Three of the footwear systems allowed a large quantity of water to ingress after prolonged water contact and would probably not provide adequate thermal protection for the feet of U.S. Navy personnel operating in a cold-wet environment. In these tests, three footwear systems completely lined with a hydrophilic polyester, waterproof/breathable membrane offered improved protection against water ingression and could possibly provide an increase in wearer comfort during operations conducted in cold-wet weather.

## REFERENCES

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