DETERMINATION OF IMMERSION SUIT THERMAL RESISTANCE: A COMPARISON BETWEEN HUMAN AND MANIKIN

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INTRODUCTION

The evaluation of immersion suits is being performed increasingly on thermal manikins. This practice encourages the development of standards and policies based on manikin testing but aimed at protecting humans against the hazards of cold water immersion. The shift from human to manikin testing was done primarily for logistic and economic reasons without much understanding of the differences between the two test mediums.

It is known that several factors such as posture, movement, wind and clothing fit (1), water leakage and leakage site (2) and wave motion (3) could affect the clothing insulation value. Any difference between the manikin test conditions and the "workplace" conditions has, therefore, a potential to cause a difference between the insulation value obtained from a manikin as compared with humans. Tipton and Balmi (4) showed that when every effort is made to ensure that the manikin and human test conditions correspond, the clothing insulation (in this case dry immersion suit) obtained from the manikin and human tests were in general agreement. The tests, however, were performed in a static water tank that does not represent the workplace conditions observed during accidental immersion where wave motion is often present.

The objective of the present study was to compare the thermal resistance (R) of immersion suits obtained from human and manikin testing in calm and turbulent water in open ocean.

MATERIALS AND METHODS

Subjects. Eight male subjects (mean ± SD; age: 29.8 ± 6.7 years; weight: 85.9 ± 7.5 kg; height: 181.4 ± 3.4 cm; % body fat: 13.3 ± 3.9%) were selected to participate in the study. All subjects were granted medical approval before being asked for their written consent. The protocol of the study was approved by the Institution's Human Ethics Committee.

Manikin. A thermally instrumented immersion manikin (TIM; the CORD Group Ltd.; Dartmouth, Nova Scotia, Canada) was used to compare the R values obtained from human subjects. The manikin comprises 13 independently temperature-controlled segments made of hollow aluminum and equipped with temperature sensors and electric heaters. The surface area of the manikin is 1.74 m^2 and its weight 94.5 kg. During the tests, the power consumption of each segment, in addition to the temperature difference between the surface of each segment and the environment, were continuously monitored.

The tests were carried at sea 8 km north east of Halifax, Nova Scotia in the CF minesweeper H.M.C.S. Anticosti and, as a control in still water, in the CORD Group Ltd. water tank, Dartmouth, Nova Scotia.

Procedures. The subjects and the manikin were exposed to four 1-h tests to evaluate the thermal insulation of two types of immersion suits: an insulated dry suit (CF constant Wear Dry Immersion Suit) and an insulated wet suit with moderate leakage (MAC 200 nearly dry suit; Mustang Survival Inc.; Richmond, BC, Canada). Both suits were used with a self-inflated twin lobe life vest with 15.4 kg of buoyancy (model MD 1141, Mustang Survival Inc.; Richmond, BC, Canada) and were tested in calm water and at sea with an average wave height of 1.7 ± 0.2 m. The water in the tank was maintained on average within 0.5°C of the 7.2 ± 0.4°C sea water temperature.

Before immersion in water, the subjects were instrumented with a rectal probe inserted 15 cm beyond the anal sphincter, ECG leads for continuous telemetric cardiac monitoring and 12 heat flow transducers with integrated temperature sensors taped on the skin, according to the Hardy & Dubois weighing system (5). An additional 12 temperature sensors were taped on the outside of the immersion suits corresponding to the same locations as on the skin of the subjects. The subjects were then dressed with polyester long underwear, a cotton one-piece undergarment, a MAC 200 wet immersion suit or the CF Constant Wear Dry suit with their proper winter liner, neoprene gloves, hood and boots, and a life vest. Once dressed, the subjects were immersed for 1 h in water while adopting a natural floatation position with about 40 to 50% of their body surface area above water. All data were recorded every 8 s and averaged over a 1-min period by small data loggers worn inside the immersion suit on a belt.

Simultaneously to these tests, the immersion suits were also tested using the thermal manikin immersed about 5 to 10 m away and in the same water conditions as for the subjects' immersion. Every effort was made to provide similar testing conditions between the human and the manikin: similar clothing, buoyancy, skin temperature distribution, location of probes on the skin, test duration

Table 1. Thermal insulation values (R) from human (n = 8) and manikin testing.

	Human testing R_h (clo)	Manikin testing R_m (clo)
Dry immersion suit		
Calm water	1.67 ± 0.14	1.48*
Turbulent water	1.31 ± 0.15	0.61*
Wet immersion suit		
Calm water	1.29 ± 0.19	1.09*
Turbulent water	0.99 ± 0.13	0.39*

*Differs significantly from human testing $P < 0.05$.

and ambient conditions. For each test, the skin temperature distribution used on the manikin was calculated from the average skin temperature distribution obtained from the 8 subjects for any particular test condition.

The total thermal resistance (including the boundary layer) of the immersion suits during the human testing (Rh) were calculated from the average heat flow and temperature data for the last 15 min of the 1-h immersion according to a method previously described (3). The total thermal resistance of the immersion suits during the manikin testing (Rm) was calculated from the power to the segments, the surface area of the segments and the temperature differences between the "skin" and the ambient condition for every segment of the manikin.

RESULTS

Table 1 shows that for all water conditions, a dry immersion suit with no water leakage provides a higher thermal resistance (R_h: 1.49 ± 0.15 clo; R_m: 1.05 ± 0.62 clo) than a wet immersion suit with moderate leakage (R_h: 1.14 ± 0.16 clo with an average of 0.82 ± 53 kg of water leakage; R_m: 0.74 ± 0.49 clo with 2.4 ± 0.5 kg leakage). On average, turbulent water decreased the R_h values by about 20% and the R_m values by about 60% as compared with calm water.

For all the immersion tests, the R_m values were significantly lower than the R_h values (Table 1). The results for the dry immersion suit show that in calm water, R_h was only 11% higher than R_m, while the difference increased to 53% in turbulent water. On the other hand, the results for the wet immersion suit show that in calm water, R_h was 16% higher than R_m, while the difference increased to 60% in turbulent water.

DISCUSSION

The present results support the conclusion of a previous study (2) suggesting that for similar testing conditions in calm water, the values for clothing insulation obtained from the manikin and human tests are similar (11% difference between R_h and R_m in the present study; 14% difference in Tipton and Balmi's study). In turbulent conditions, however, the difference between the R values obtained from humans and a manikin increased to 60%. The larger underestimation of R_m can be attributed to two main factors: a larger water leakage into the suits during the manikin tests and a greater inertia of the manikin, which makes it out of phase with the wave propagation, which induces a larger convective heat loss.

CONCLUSIONS

The results show that during ideal testing conditions (same procedures between manikin and human testing, calm water condition, comparable water leakage into the suit), manikin testing can provide R values similar to the values obtained from human testing. For testing in turbulent water, further study and development are required before a thermal manikin could be used with confidence for suit evaluation.

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