MEASUREMENT OF IMMERSION SUIT INSULATION: A COMPARISON BETWEEN HUMAN SUBJECTS AND A THERMAL MANIKIN

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INTRODUCTION

The use of human subjects for the evaluation of the thermal performance of immersion clothing has been previously criticized based on ethical, methodological and financial considerations. For these reasons, the use of thermal manikins is becoming an accepted alternative.

The objective of the present study was to investigate the differences in the thermal insulation of a dry immersion suit system when tested on human subjects and a thermal manikin during water immersion in calm or wavy conditions.

MATERIALS AND METHODS

Subjects. Six healthy male subjects participated in the study (see 1 for details). The protocol was approved by Institutional Ethics Committees and written informed consent was obtained from the subjects. The tests were carried out at the Institute for Marine Dynamics in St-John's, Newfoundland.

Thermal manikin. Parallel to the human tests, the immersion suit was also tested using a Thermal Instrumented Manikin (TIM, CORD Group Limited, Dartmouth, Nova Scotia) immersed in the same water conditions and at the same time without interfering with the subject or changing the wave pattern. The probe locations (except for the location of the HFTs that were fixed on the pile garment of the manikin instead of the skin as it was for the humans to avoid applying a large correction factor to the heat flow values; see 2) and the clothing were the same as for the human subjects (see 1 for details). The aluminum skin of the manikin was maintained constant and uniform at 25°C during the tests.

Measurements. The sensors arrangement allows the calculation of the thermal insulation for every suit layers (*Rpile*, *Rsuit*, *Rwater/air* boundary layer; see 1). The total suit system resistance for the whole body was measured for both the humans (*Rtotal_H*), and the manikin (*Rtotal_M*) as follows: *Rtotal* = *Rpile* + *Rsuit* + *Rwater/air*, where the three components of the suit system represents a resistance system in series (see 2 for details). A second estimation of total suit insulation was measured on the manikin by using the temperature gradient between the aluminum skin and the water, and the total power provided to all segment's heaters of the manikin as an index of heat loss (*Rtotal_Cord*).

Procedures. The wave heights were chosen randomly and varied between 0 and 70 cm (WH0 to WH70) by steps of 10 cm. A single wave height was used per day, only one subject was tested at any time, and each subject was tested at the same time of the day. Each subject's immersion last 60 minutes, while the thermal manikin stayed in water for the full day of testing. An additional immersion test was performed on calm water while the subjects and manikin were immersed up to the neck in a vertical posture (V0) and all the air was purged from the suit. During the wave tests, the manikin was placed in the standard manikin immersion frame and positioned into the water. Buoyancy was added to the immersion frame until an anticipated survivor floatation position was achieved.

RESULTS

All the data presented are averages from the last 15 minutes of the 1 hr immersion when thermal steady state was achieved. On average, the water temperature was 15.95 ± 0.02 °C and the air temperature 16.60 ± 0.31 °C during the trials with no differences between wave conditions.

Buoyancy of the human subjects and manikin. A significant portion of the subject and manikin body surface area was not immersed in water during the wave tests because of the buoyancy provided by the life vest in addition to the air trapped inside the immersion suit. It was estimated from video recordings that about 30-40% of the subjects' body surface area was exposed to air during the wave tests, while only 10-20% of the manikin surface area was exposed to air.

Insulation of the dry immersion suits. The results showed that wave motion decreased *Rtotal_H* by 14% (1.35 ± 0.34 Clo at 0 cm to 1.16 ± 0.53 Clo at 70 cm), *Rtotal_M* by 17% (0.78 ± 0.01 Clo at 0 cm to 0.65

± 0.01 Clo at 70 cm), and *Rtotal_CORD* by 36% (0.70 ± 0.01 Clo at 0 cm to 0.45 ± 0.01 Clo at 70 cm). In the vertical position test, *Rtotal_M* (0.60 ± 0.01 Clo) was not different from *Rtotal_CORD* (0.58 ± 0.01 Clo), but both were lower than *Rtotal_H* (0.85 ± 0.02 Clo). From 0 to 70 cm wave conditions, *Rtotal_H* were on average 45% higher than *Rtotal_M* and 57% higher than *Rtotal_CORD* (see Fig.1).

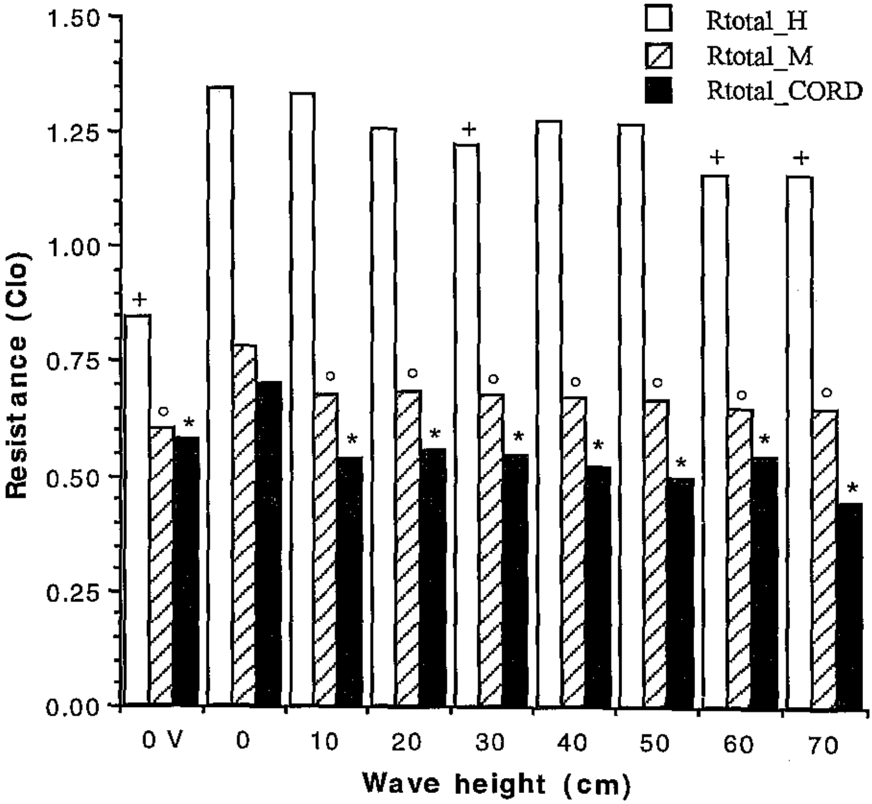

*Figure 1. Effect of wave height and vertical immersion posture on the total thermal resistance (Rtotal) of the suit system worn by the human subjects and the thermal manikin during immersion in 16°C water. *, °, +: significantly different ($p < 0.05$) from the 0 cm wave height condition.*

DISCUSSION

Despite a similar effect of wave motion on suit system insulation between human subjects and manikin (14 and 17% decrement, respectively), the *Rtotal* were on average 51% lower when measured on the manikin compared to human subjects for the same water conditions and suit system. The discrepancy can largely be explained by the difference in buoyancy and amount of trapped air into the suit between the manikin and human subjects. The larger portion of the human's body surface area exposed to air during the immersion trials (30 to 40%) probably contributed in providing a larger overall suit system insulation when compared to the 10 to 20% surface area in contact with air in the case of the manikin. This is supported by closer *Rtotal* values between humans and manikin during the V0 condition.

The decrement of *Rtotal_CORD* by 36% from WH0 to WH70 contrasts with the 14 and 17% decrement observed for *Rtotal_H* and *Rtotal_M*, respectively. Furthermore *Rtotal_CORD* were on average 21% lower than the *Rtotal_M* values. Two factors might have contributed to this discrepancy: the use of the extremities in the calculation of the suit insulation, and the use of *Twater* for the calculation of *Rtotal* for every sites on the manikin. It was observed that the heat loss from the extremities of the manikin were more affected by the wave motions when compared to the rest of the body. This effect was not present in humans since the extremities were vasoconstricted during cold water immersion. This will exaggerate the effect of wave motion on suit insulation for the manikin in addition to decrease the overall *Rtotal*.

It was concluded that to improve the correlation between human and manikin, the manikin should reflect more closely the thermal physiology of humans and its flotation characteristics.

REFERENCES

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