# THE EFFECT OF STANDARD WAVE CONDITIONS ON DRY SUIT INSULATION WHEN MEASURED ON HUMANS

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## INTRODUCTION

Testing of immersion suits is commonly conducted in calm or circulatory water. Several investigators have argued that this is an unrealistic test for a suit that is designed to protect a human from hypothermia in open ocean conditions. In support of this argument, Steinman et al. (1) and Romet et al.(2) reported a significant reduction of suit insulation in turbulent water when compared to still water by an average of about 30% when measured on humans. Such differences were found for loose-fitting wet suits but were not investigated for dry suits. Recently, Sowood et al. (3) reported a reduction of dry suit insulation by about 30% in turbulent water (wave height of 60 cm) compared to still water when tested on a thermal manikin.

The objectives of the study were 1) to investigate the effect of standard wave conditions on dry immersion suit insulation when tested on humans, 2) to define which components of the suit system were affected by the waves and 3) which body parts were the most and least affected.

## MATERIALS AND METHODS

*Subjects.* Six healthy male subjects with an average age of 25.0 ± 1.7 years (mean ± SEM), height of 179 ± 1 cm, weight of 76.5 ± 1.6 kg and body fat of 15.9 ± 1.9 % participated in the study. 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.

*Measurements.* Rectal temperature (*Tre*) was measured by using a thermistor inserted 15 cm into the rectum, heart rate (*HR*) was recorded from a three point leads system, skin temperature (*Tsk*) and skin heat flux (*Hsk*) were measured by using recalibrated heat flux transducers fixed on 12 sites based on the Hardy and Dubois modified 12 points system (4). Two other set of 12 thermistors were fixed on the surface of the pile garment and on the outside surface of the immersion suit for the same sites on the body. The thermistor arrangement creates a system of three layers (components of the suit system) capable of measuring the insulation of the pile garment (*Rpile* in Clo), the suit (*Rsuit* in Clo), and the water/air layer (*Rwater/air* in Clo) for every sites as follows: $Rpile = (\Delta T_1/Hsk) / 0.155$, $Rsuit = (\Delta T_2/Hsk) / 0.155$, and $Rwater/air = (\Delta T_3/Hsk) / 0.155$ where $\Delta T_1(°C) = Tsk - Tpile$, $\Delta T_2$ (°C) $= Tpile - Tsuit$, $\Delta T_3$ (°C) $= Tsuit - Twater/air$, *Hsk* is the heat flow in $W \cdot m^{-2}$ measured by the HFTs, and 0.155 is the conversion factor from $°C \cdot m^2 \cdot W^{-1}$ to Clo. The 12 body sites represents a resistance system in parallel (see 5 for details). The total suit system resistance for the whole body was measured by $Rtotal = Rpile + Rsuit + Rwater/air$, where the three component represents a resistance system in series.

*Procedures.* Before the immersion, the subject was instrumented with the sensors and then dressed with a one-piece Helly Hansen pile undergarment, a set of Helly Hansen pile socks, an uninsulated nylon/butyl Typhon Ranger dry immersion suit, neoprene mitts and hood, and an inflatable twin lobe life vest. The subject entered the water and its feet were hooked with flexible positioning cable to ensure a constant positioning relative to the wave propagation while maintaining freedom of movement. 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 immersion last 60 minutes.

## 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.

*Physiological parameters.* On average *HR* did not change significantly ($p > 0.05$) with the wave conditions, although it increased to 59 ± 4 beats $\cdot$ $min^{-1}$ for WH70 as compared to 55 ± 3 beats $\cdot$ $min^{-1}$ for WH0. *Tre* decreased significantly during the hour of immersion by 0.24 ± 0.02°C, but was not affected by the wave condition, averaging 37.16 ± 0.04°C and 37.15 ± 0.04°C for the WH0 and WH70 conditions respectively. Although mean *Tsk* decreased on average by 0.82 ± 0.26°C during the hour of immersion, it was not affected by the wave conditions, being on average 29.83 ± 0.11°C. Mean *Hsk* was not different between WH20 and WH50 inclusively (average of 78.48 ± 2.53 W • $m^{-2}$), but was significantly higher than WH0 and WH10 (average of 73.15 ± 1.92 W • $m^{-2}$), and lower than WH60 and WH70 (average of 84.93 ± 1.93 W • $m^{-2}$). From WH0 to WH70, the skin heat loss increased significantly for the head, trunk and proximal limbs by 71.1 ± 8.0, 14.5 ± 6.8 and 9.2 ± 4.2 W • $m^{-2}$ respectively, while it did not changed for the distal limbs.

*Insulation of the system components.* No difference was found for conditions between WH0 and WH70 inclusively for *Rpile* (average of 0.81 ± 0.03 Clo) and *Rsuit* (average of 0.32 ± 0.01 Clo). *Rwater/air* was significantly higher for WH0 (0.24 ± 0.03 Clo) and WH10 (0.17 ± 0.02 Clo) and significantly lower for WH70 (0.06 ± 0.01 Clo) compared to the other wave conditions. No difference was observed for conditions between WH20 and WH60 inclusively (average of 0.09 ± 0.01 Clo). *Rtotal* did not change significantly for conditions between WH0 and WH50 inclusively (average of 1.28 ± 0.04 Clo), except between WH0 (1.35 ± 0.03 Clo) and WH30 (1.22 ± 0.03 Clo). Values of *Rtotal* were not different between WH60 (1.16 ± 0.02 Clo) and WH70 (1.16 ± 0.02 Clo) conditions but these values were about 14% lower than *Rtotal* at WH0 (1.35 ± 0.03 Clo) and WH10 (1.33 ± 0.04 Clo). The total insulation of the suit system was most affected by the wave conditions for the head segment where *Rtotal* decreased by an average of 0.86 ± 0.06 Clo (57.8 ± 6.4% decrease in insulation) from WH0 to WH70 compared to the trunk and proximal limb segments where the decrease in *Rtotal* was respectively 0.54 ± 0.13 (32.0 ± 6.8% decrease in insulation) and 0.21 ± 0.09 Clo (16.0 ± 5.8% decrease in insulation). No change was observed in *Rtotal* between WH0 and WH70 for the distal limb segments.

## DISCUSSION

The physiological results from the present study are in agreement with those of Steinman et al. (1). The present study shows that the total thermal resistance of the dry suit system decreased by 14% from still water condition to 70 cm wave height when tested on humans. This effect is smaller than the reported 25-36% decrement when the same suit system is tested on a thermal manikin (5; 6). Sowood et al. (3) suggested that part of the decrement observed in suit thermal resistance could be attributed to the effect of the water movement over the manikin surface. Our study shows that *Rwater/air* was the only suit system component that was significantly affected by the wave motion.

Vasoconstriction minimized the increase of the skin heat loss for the proximal limbs and abolished it for the distal limbs during the wave motion. On the other hand, because of the weak vasoconstriction capacity of the skin of the head, head heat loss doubled from WH0 to WH70 condition, mainly due to water splashing occurring during wave breaks at WH70. These vasomotor changes were mainly responsible for the large decrement in suit thermal resistance at the head and trunk, while suit thermal resistance decreased by only 16% for the proximal limbs and did not changed significantly for the distal limbs. These results suggest that to optimize the survival time during immersion in turbulent water, further development of dry immersion suit should focus on improving the thermal protection at the head and trunk, and not at the limbs.

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