

HUMAN THERMAL RESPONSES IN WIND AND WAVES

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INTRODUCTION

A large number of people work or travel over the cold ocean waters of Canada's coastline every day. Due to the risk of becoming accidentally immersed in water, an immersion suit is often required by federal regulations to be readily available to people to help improve their chances of survival. Current Transport Canada (TC) regulations require immersion suits to be carried on board all small capacity vessels in a sufficient quantity so that every person has one. Offshore oil installations follow a similar policy. The immersion suits are usually a one-piece suit system that provides thermal protection and may provide buoyancy to the wearer (7).

There currently exists a knowledge gap on how wind and waves affect an immersed human, compared to the calm water pool that is often used for testing (7). Previous work carried out by Hayes et al (1985) found that wave motion did not significantly increase the rate of body cooling when compared to calm conditions (3). Later work conducted by Steinman et al (1987) examined the effects of rough seas on the thermal performance of anti-exposure garments, and found that mean rectal temperature and back skin temperature decreased significantly with loose fitting wet suit garments in rough water, compared to calm (5). The authors concluded that immersions in rough seas may be associated with much lower survival times than those expected in calm water (5).

Tipton et al (1995) also examined the effect of deteriorating weather conditions on survival time (6). Participants who wore a well fitting, uninsulated dry suit experienced a 30% reduction in predicted survival time in relatively mild weather conditions compared to calm water; with estimated survival time dropping to 4.8 hours from 6.8 (6).

Ducharme and Brooks examined the effects of varying wave heights on dry suit insulation (1). The participants wore uninsulated dry immersion suits with a one piece undergarment. Wave conditions did not affect mean rectal temperature, and mean skin temperature was only affected when participants performed immersions up to their neck in a vertical position (1). However, skin heat flow did show a significant increase with increasing wave height (1).

Our own previous work examined the effects of wind and waves on human thermal responses during one hour immersions (4). The environmental condition consisting of wind and waves caused a significant increase in mean heat flow, and significant decrease in mean body temperature, compared to calm water conditions (4). Based on the results from this work, in the present study we investigated the effects of varying wind and wave conditions, compared to

calm, on human thermoregulatory responses during the course of three hour immersions. Our null hypothesis was that wind and waves would not cause a significantly greater drop in deep body temperature compared to that seen in calm conditions.

METHODS

The study received full ethical approval from the National Research Council’s Research Ethics Board (REB). Each participant provided written, informed consent before participating.

Twelve healthy males volunteered for the experiment. Body fat percentage was estimated through two methods: using a bio-electrical impedance and skin fold thickness using the method of Durnin & Womersly (2). All participants were asked to refrain from consuming alcohol the night before an experimental trial, and caffeine at least 3 hours before the start of an experiment. All experiment trials were conducted in the Offshore Engineering Basin (OEB) at the National Research Council of Canada’s Institute for Ocean Technology (NRC-IOT), located in St. John’s, Newfoundland, Canada.

Participants performed three, 3-hour immersions in the following environmental conditions: Calm water, Weather 1, and Weather 2. The environmental characteristics of each immersion condition are given in Table 1. The waves used in each environmental condition consisted of irregular, 20-minute Joint North Sea Wave Analysis Project (JONSWAP) spectrums generated from data collected from a wave buoy deployed off the south west coast of Newfoundland, Canada. The wave spectrum was truncated to a maximum height of 0.67m due to mechanical limitations in the OEB.

Table 1. Environmental characteristics of the three immersion conditions.

	Calm	Weather 1	Weather 2
Maximum wave height (m)	0	0.34	0.67
Wind speed ($\text{m}\cdot\text{s}^{-1}$)	0	3.5	4.6
Mean Water Temperature (SD) ($^{\circ}\text{C}$)	11.14 (0.24)	10.93 (0.41)	10.85 (0.32)
Mean Air Temperature (SD) ($^{\circ}\text{C}$)	17.17 (0.51)	17.36 (0.40)	17.34 (0.42)

Upon arriving at NRC-IOT, participants were instrumented and changed into the standardized test clothing assembly of: wool socks, cotton pants, cotton undershirt, and cotton over shirt; a White’s Marine Abandonment Suit. This clothing ensemble was based on the CGSB testing standards (7).

Skin temperature and heat flow were measured at 12 different sites on the body using heat flow sensors (Concept Engineering, Old Saybrook, Connecticut, USA). The sensors were connected to self-contained data loggers (ACR Data Systems, Surrey, British Columbia, Canada) that measured and recorded all 12 sensors, once every 8 seconds. Deep temperature was measured once every 20 seconds using gastro-intestinal pills (HQ Inc., Palmetto, Florida, USA). Heart rate was measured once every 20 seconds using a polar heart rate monitor (Polar, Lake Success, New

York, USA), with the values recorded by the CorTemp data recorder. Oxygen consumption and carbon dioxide production was measured once every 15 seconds using the Cardio Coach CO₂ (KORR Medical Technologies, Salt Lake City, UT, USA).

Participants entered the water carefully via steps and were loosely tethered in place by the ankle. They were told to relax during the immersions and were able to watch videos.

Analysis of variance (ANOVA) was performed on all collected results. Tamahrene T2 post hoc tests were performed to determine significance. Alpha was set at 0.05.

RESULTS

All of the participants completed their immersions. Change in deep body temperature over the last 30 minutes of the each immersion was examined and is presented in Figure 1.

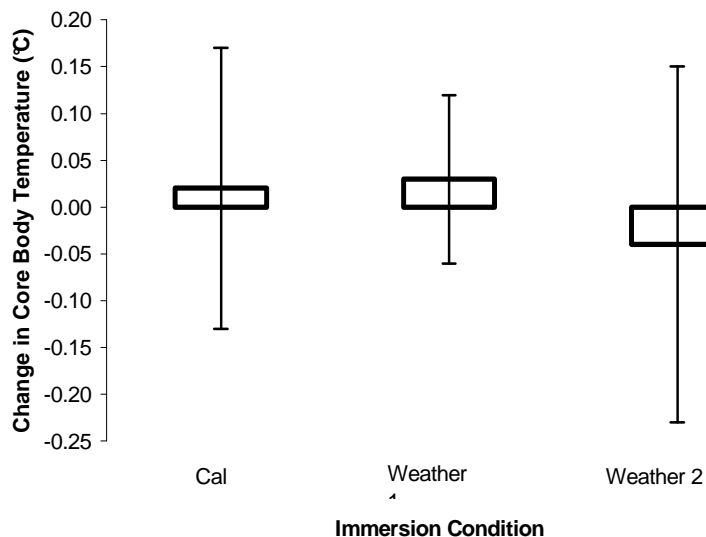


Figure 1. Mean (*SD*) Change in deep body temperature (°C) over the last 30 minutes of immersion ($n = 12$).

Across all immersion conditions, there were no significant changes in deep body temperature. Participant's deep body temperature rose 0.02°C during the final 30 minutes in the calm immersion, 0.03°C in Weather 1, and dropped 0.04°C in Weather 2.

Mean oxygen consumption over the last 30 minutes of the immersion is presented in Table 2.

Table 2. Mean VO_2 and SD during the last 30 minutes of immersion ($n = 12$).

	Mean (SD) VO_2 ($\text{mL}\cdot\text{min}^{-1}$)
Calm	325.41 (54)
Weather 1	332.74 (108)
Weather 2	365.83 (80)

There were no significant differences in oxygen consumption during the final 30 minutes of the immersion.

Mean heat flow during the final 30 minutes of the immersion, measured from all sites sampled except the forehead is presented in Figure 2.

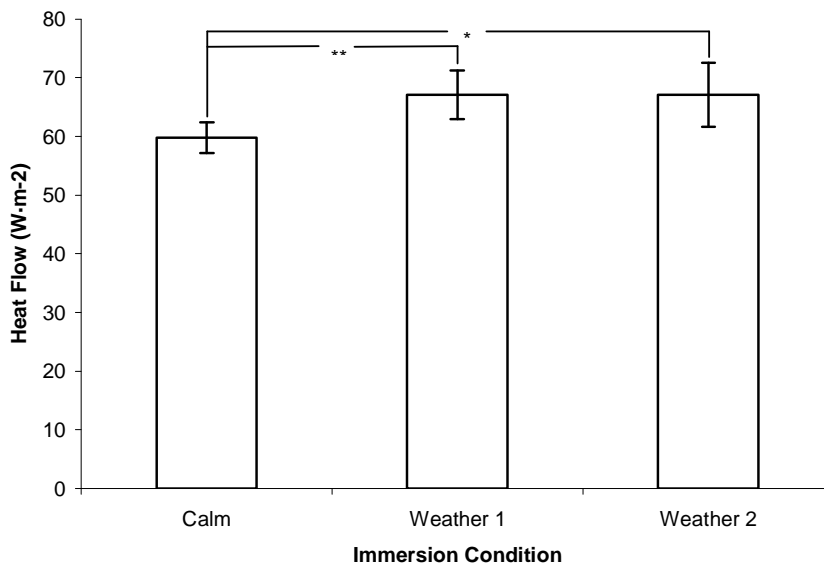


Figure 2. Mean (SD) heat flow over the last 30 minutes of the immersion (* = $P < 0.05$. ** = $P < 0.001$, $n = 12$).

A significant difference was observed in heat flow during the last 30 minutes of the immersions.

CONCLUSIONS

The present study examined the influence of wind and waves on the thermal responses of clothed individuals immersed in cold water. Initial analysis of the results confirm the findings of Hayes et al. (1985) and Ducharme & Brooks (1998), and suggest that the quality of the protective clothing provided may have been sufficient to make the immersions a fairly innocuous challenge: metabolic rate, heat flux and change in deep body temperature all remained relatively low. Heat flow did increase significantly from Calm conditions to the Weather immersions, but only by a small amount ($\sim 7 \text{ W}\cdot\text{m}^{-2}$). This result is in agreement with our previous work (4), but the heat flow measured here in Weather 2 ($67 \text{ W}\cdot\text{m}^{-2}$) during the last 30 minutes of a three hour immersion is, as might be expected, lower (approximately 27% less) than that observed at the

end of the one hour immersion in our previous work ($92 \text{ W}\cdot\text{m}^{-2}$) in the same environmental conditions.

In these circumstances it is unsurprising that differences were not seen between conditions; the level of stress imposed was insufficient to reveal such differences. It is possible that the provision of good quality immersion protective clothing moved participants back into the “prescriptive (thermoregulatory) zone” and they were able to thermoregulate by small changes in cutaneous blood flow; it is unlikely that heat flux transducers will have detected these small regional alterations.

We support our null hypothesis that an immersion condition consisting of wind and waves will not cause a greater drop in deep body temperature compared to a calm one. Whilst it is clear that the addition of wind and waves will increase the cooling capability of the environment; in situations such as those that pertained in the present study, where individuals are well protected, the increase in cooling capability of the environment may not translate into lower deep body temperatures. Hence, the importance of considering the *physiological* as well as the *physical* in situations where a thermoregulatory system is active.

It is concluded that in situations similar to those of the present study, the prediction of survival time may not need to be adjusted for the presence of wind and waves.

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