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Testing a New Concept of Immersion Suit at Sea

Dr. Michel B. Ducharme
Human Protection and Performance Group, Defence and Civil Institute of Environmental Medicine
1133 Sheppard Ave. W., Toronto, Ontario, M3M 3B9, Canada

Summary

A new concept of immersion suit, the nearly dry suit, was recently developed to overcome the main limitations of the wet and dry suits. The main new feature of the suit is the adjustable seals that can be closed before or upon entry in water. The purpose of the present study was to test the new suit at sea against a standard dry suit. Seven male subjects were immersed for over one hour in 3°C water in the Atlantic ocean. Three conditions were tested during which the subjects were wearing a dry suit (DRY), a nearly dry suit with the seals closed (NEAR-DRY-C) or a nearly dry suit with the seals opened upon entry in water (NEAR-DRY-O). The thermal resistances of the suit, measured from the skin heat loss data and the temperature difference between the skin and the outside surface of the suits, were 0.95 ± 0.14, 0.69 ± 0.13 and 0.58 ± 0.09 Clo for DRY, NEAR-DRY-C and NEAR-DRY-O conditions, respectively, with the thermal resistance being significantly lower ($p \leq 0.05$) for the NEAR-DRY conditions. The decrease in insulation for the NEAR-DRY-O condition was attributed to a significantly larger water leakage through the seals (1.37 ± 0.29 L) as compared to the other conditions (DRY: 0.41 ± 0.20 L; NEAR-DRY-C: 0.35 ± 0.28 L). It was concluded that the nearly dry suit concept, while maintaining a greater comfort when the seals were opened before immersion, successfully limited the water leakage into the suit to a level observed with a dry suit when the seals were closed upon entry in water. The thermal insulation provided by the nearly dry suit when closed is not inferior to 0.75 Clo, the recommended insulation to obtain adequate thermal protection in cold water. During immersion in the open mode, the nearly dry suit can decrease the survival time by a factor a two.

Introduction

Two types of immersion suits are available today to protect aircrew against the risks associated with accidental cold water immersion, namely the wet and the dry immersion suits. The main limitation of the wet suit is its limited thermal protection during cold water immersion because of the constant leakage of water into the suit. The principal limitations of the dry suit are seal leakage, and neck and wrist seal discomfort.

A new concept of immersion suit called the nearly dry suit, was recently developed by the Canadian company Mustang Survival to overcome the main limitations of both the wet and dry suits. The main new feature of the suit is the adjustable seals that can be closed before or upon entry in water. This new feature, in addition to improve comfort, could help the aircrew to manage heat stress inside the aircraft during flight operations in temperate conditions without the assistance of an active air conditioning or cooling system. However, such a feature could also be a source of water leakage that may cause a major deterioration of the thermal properties of the immersion suit during water immersion. The consequence could be fatal to aircrew crashing in cold water because of the rapid cooling of the body and the risk of dying from hypothermia before being rescued from the water.

Purpose

The purpose of the present study was to compare the physiological responses, leakage rate, and thermal properties of the new suit concept to a standard dry immersion suit currently in use by the Canadian Forces during a simulated accidental cold water immersion in the open sea. The open sea environment was used in the present study to simulate a realistic cold water accidental immersion of aircrew at sea

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where self-rescue activities and the sea state can both influence the thermal insulation of an immersion suit.

Methods

Subjects

Seven healthy, non-smoking male volunteers with the following characteristics were recruited (mean ± S.D.): age 36.0±4.3 years, height 178.0 ± 10.0 cm, weight 80.3 ± 14.1 kg, body surface area 1.98 ± 0.20 m^2 and percentage body fat 17.6 ± 6.4%. Body surface area was calculated using the formula of Dubois and Dubois (1). Percent body fat was estimated from the skinfold from 5 body sites according to Katch et al. (2). All subjects were medically screened by a physician before being asked for their written consent. This study was approved by the Human Ethics Committee at the Defence and Civil Institute of Environmental Medicine (DCIEM).

Ambient Condition and Clothing Worn

The study was performed in the Atlantic Ocean on the Defence R&D Canada Research Ship Quest, 20 to 50 km off the coasts of Nova Scotia, Canada. The average air and water temperatures, and the average peak wave height during the study were (mean ± SD) 7.3 ± 1.0°C, 3.6 ± 0.2°C, and 2.5 ± 0.5m, respectively.

Three conditions were tested on each of the seven male subjects. In the first condition called DRY, the subjects wore a dry suit currently used by the Canadian Forces. The suit tested was the MSF750 Immersion Dry Suit by Mustang Survival that has 0.85 immersed Clo of thermal insulation as measured in stirred water on a thermal manikin (TIM; The CORD Group, NS, Canada). In the second and third conditions, the subjects wore the nearly dry suit MAC 200 also by Mustang Survival with 0.91 immersed Clo of thermal insulation as measured in stirred water on the thermal manikin. The neck and wrist seals of the MAC 200 immersion suit were closed for the second condition called NEAR-DRY-C, and opened for the third condition called NEAR-DRY-O upon entry in the water. All seals were closed after resurfacing during the NEAR-DRY-O condition. Both types of suits were made of a Nomex shell, an inner Goretex membrane and a thermally insulative liner. In addition to the immersion suits, all subjects wore the following clothing: long polyester underwear (top and bottom), one-piece cotton flying suit, neoprene boots and hood, and inflatable mitts.

Procedures

Before each immersion, the subjects were dressed with sensors and the appropriate clothing and then weighed on an electronic scale. Each immersion consisted of a series of 4 events that were completed within a period of about 1.5 hr. The purpose of the immersion was to simulate the series of evens experienced by an aircrew during a helicopter crash at sea. The first event, simulating the crash, was a helicopter simulator egress into the sea. The egress consists of moving the subject from the ship deck to the sea water while harnessed inside the simulator. Once touching the water, the simulator was inverted under water and the subject counted to 5 before releasing himself from the chair, exiting the simulator and resurfacing.
After resurfacing, the subject inflated his life vest, put his mitts and started swimming to a one-man life raft positioned 20 m away from the main ship. After reaching the life raft, the subject boarded it and then immediately exited it to return to the water. Finally, the subject was immersed for 1-hr, un-tethered and using a natural floating position. The subjects were used in pair during the immersions and were closely monitored by a rescue crew on board of a fast-craft. The main ship was following the subjects to a distance of about 500 m in order to be within a 5 min rescue time.

Following the immersion, the subject boarded the fast-craft and returned to the main ship where they were sprayed with fresh water (to consistently saturate the outside of the suit) and weighed following a 2-min waiting period.

Physical and Physiological Variables Measured

During all immersions, the following physical parameters were continuously monitored from the main ship: air temperature, water temperature about 50 cm under the water surface, and wave height.
Water leakage into the suit was estimated by weighing the fully dressed subject before and after each immersion test on an electronic scale accurate to ± 5g. To minimize the effect of the mass fluctuation caused by the movement of the ship on the water leakage estimation, the mass of the subject was recorded every second for a period of 30 sec while seating still on a chair fixed on the scale platform, and an average mass was calculated. In addition, the average mass of the subject was compared to the average mass of a manikin of a similar and known weight measured simultaneously. The post-immersion weight was corrected for the water saturation of the outer layer of the suits.

During each test, skin temperature and heat flow (HFTs; Concept Engineering, Old Saybrook, CT, USA) from 12 sites according to the Hardy and Dubois formula (3) were continuously monitored, in addition to the outside surface temperatures on the suits at those 12 sites, the rectal temperature (Pharmaseal 400 series, Baxter, Valentia, CA, USA) and the heart rate (Polar heart rate monitor; Polar Electro, Stamford, CT, USA). All the temperature and heat flow data were recorded and saved on small data loggers.

The thermal resistances of the suit were measured according to a method previously described (4). Briefly, the thermal resistances were measured from the skin heat loss data and the temperature difference between the skin and the outside surface of the suits.

Statistical Analyses

A one-way ANOVA for repeated measures was used to compare conditions DRY, NEAR-DRY-C and NEAR-DRY-O. These analyses were done for the dependent variables mean skin temperature, mean heat flow, rectal temperature, heart rate, water leakage and thermal insulation of the suits. Results were considered statistically significant at $p \leq 0.05$ (using the Greenhouse-Geisser adjustment for repeated measures). A Newman Keuls post-hoc test was used to determine where was the significance. All values are presented as mean ± SE.

Results

During the last 10 min of the immersions, the rectal temperature was not different between the three conditions averaging 37.3 ± 0.1°C for DRY, 37.3 ± 0.1°C for NEAR-DRY-C and 36.7 ± 0.3°C for NEAR-DRY-O, although the data from the last condition tends to be lower.

The average skin temperature and skin heat loss from 12 sites on the body were significantly lower for the MAC 200 suit than for the dry suit (26.4 ± 1.1°C, 147 ± 8W/m^2) and lower for the NEAR-DRY-O (21.4 ± 1.2°C, 188 ± 5 W/m^2) than the NEAR-DRY-C condition (23.5 ± 0.9°C, 174 ± 5 W/m^2) (Fig. 1, 2).

The heart rate was significantly higher for the NEAR-DRY-O (96.2 ± 1.6 beats/min) as compared to the two other conditions (91.6 ± 1.6 beats/min for DRY; 90.4 ± 2.3 beats/min for NEAR-DRY-C).

The thermal resistances of the suit were 0.95 ± 0.14, 0.69 ± 0.13 and 0.58 ± 0.09 Clo for DRY, NEAR-DRY-C and NEAR-DRY-O conditions, respectively, with the thermal resistance being significantly lower ($p \leq 0.05$) for the NEAR-DRY conditions (Fig. 3). The decrease in insulation for the NEAR-DRY-O condition was attributed to a significantly larger water leakage through the seals (1.37 ± 0.10 L) as compared to the other conditions (DRY: 0.41 ± 0.11 L; NEAR-DRY-C: 0.35 ± 0.11 L) (Fig. 4).

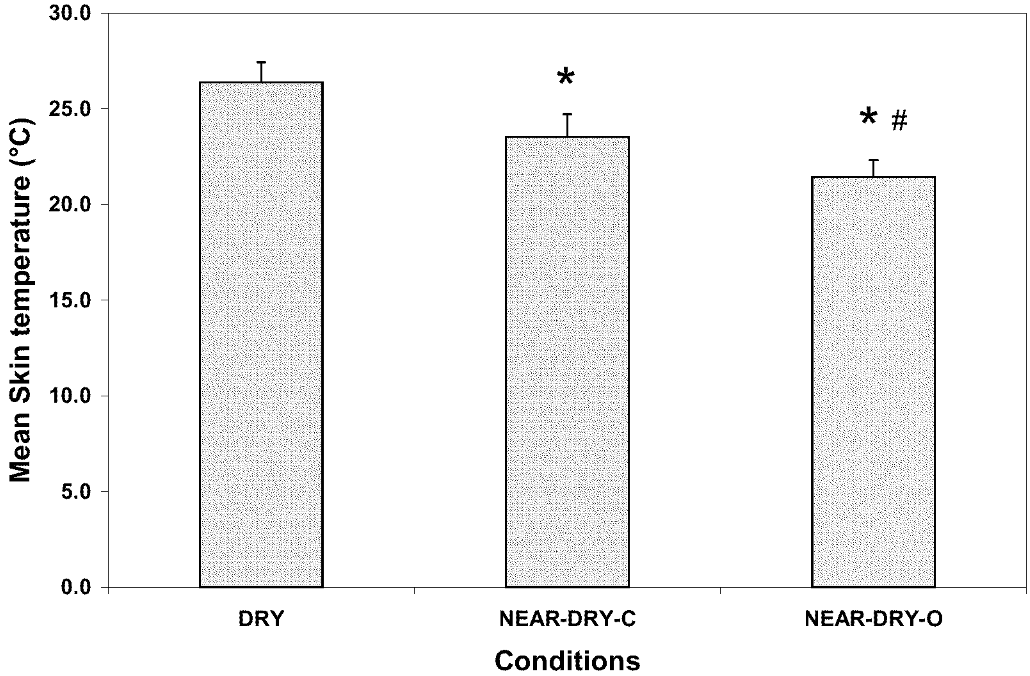

Figure 1. Mean skin temperature (±SE) during the last 10 min period of the 1-hr immersion in 3°C water for all conditions tested at sea. n = 7. *: significantly different from the DRY condition; #: significantly different from the NEAR-DRY-C condition.

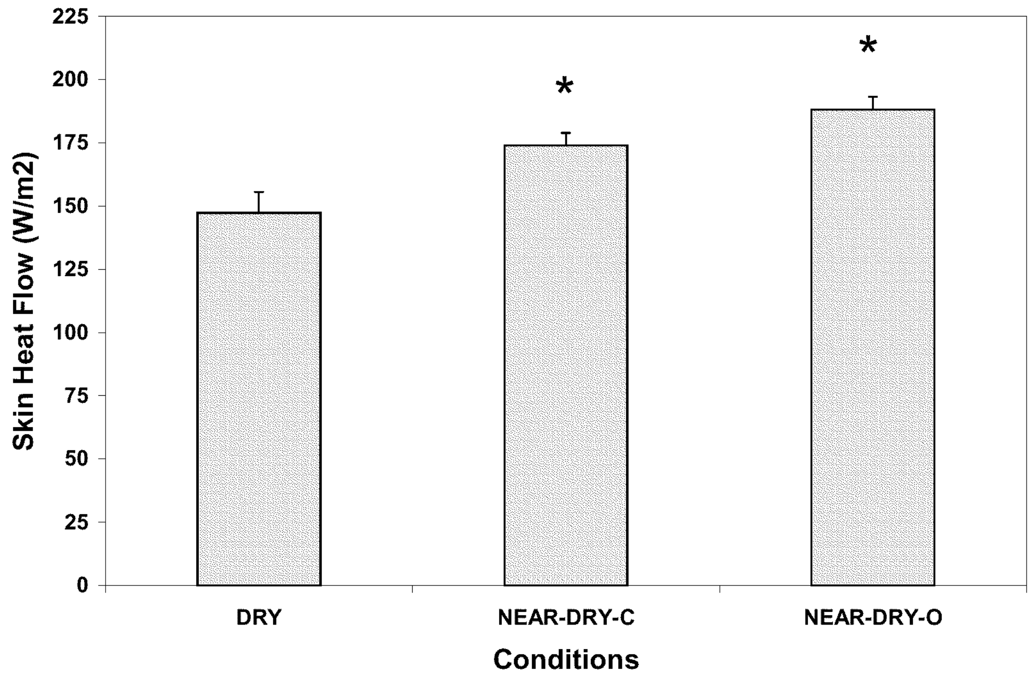

Figure 2. Mean skin heat flow (±SE) during the last 10 min period of the 1-hr immersion in 3°C water for all conditions tested at sea. n = 7. *: significantly different from the DRY condition.

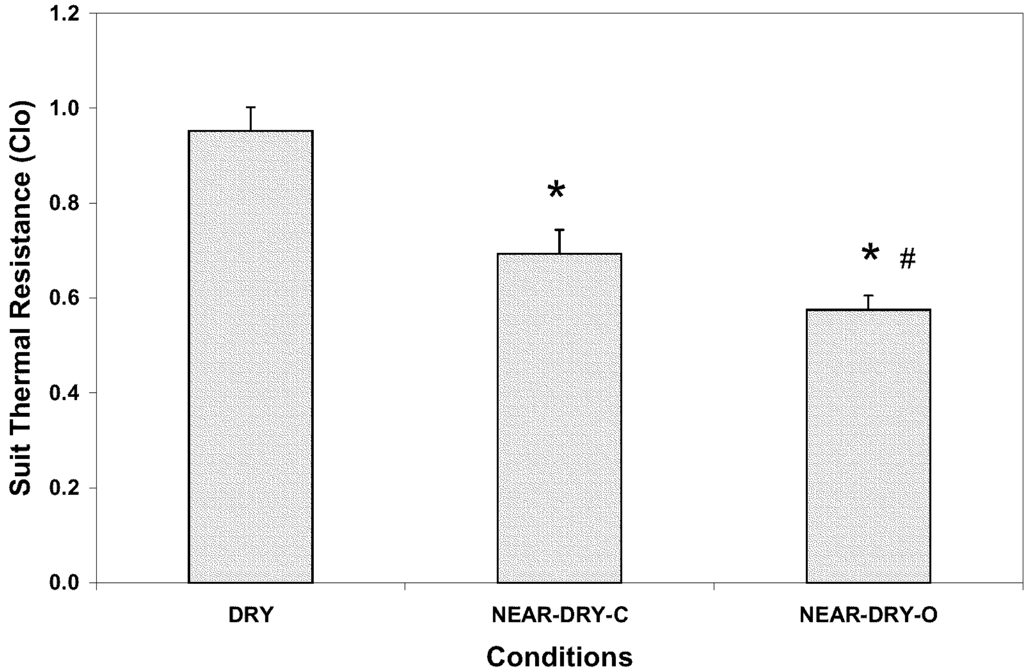

Figure 3. Suit thermal resistance (±SE) during the last 10 min period of the 1-hr immersion in 3°C water for all conditions tested at sea. n = 7. *: significantly different from the DRY condition; #: significantly different from the NEAR-DRY-C condition.

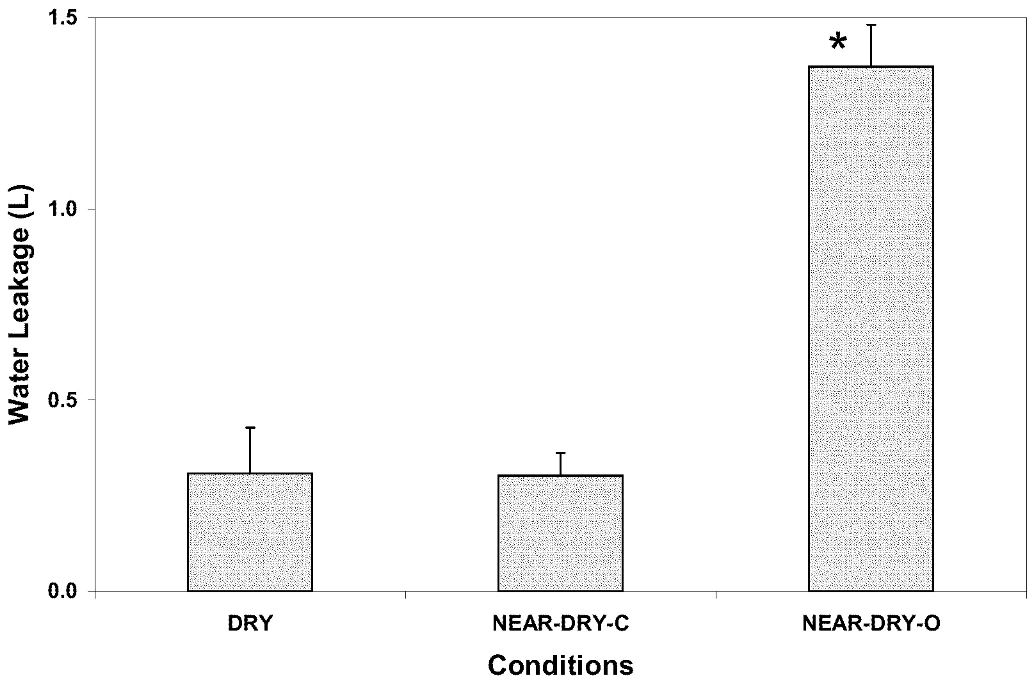

Figure 4. Water leakage into the suits (±SE) estimated from the difference between the pre and post immersion weight of the subjects. n = 7. *: significantly different from the DRY condition.

Discussion and Conclusion

The results from the present study show that when tested at sea during a simulated accidental cold water immersion, the nearly dry suit used in the closed mode did not promote more water egress into the suit as compared to a dry suit. The water leakage observed for the dry suit during this study may seems excessive (0.41 ± 0.11 L), but one has to keep in mind that the suits were tested in a very realistic scenario with a number of self-rescue exercises that promoted water egress. In addition, the dry suits used were not new, but were considered serviceable and had been used by aircrew for a minimum period of three months prior to the study. The same applies to the MAC 200 immersion suits tested. This was intentionally done to further underline the practice dimension of this study. When the neck and wrist seals were open upon entry in the water and closed upon resurfacing, the water leakage was multiplied by a factor of nearly 4. This scenario simulated a situation where the aircrew may have been unconscious or did not have the time to close his seals upon the entry in water.

Despite a similar water leakage, the MAC 200 caused a greater cold stress as compared to the DRY suit condition as reflected by the various physiological parameters (see Fig. 1 and 2). This could be explained by a lower thermal resistance of the MAC 200 immersion suit as compared to the dry suit (see Fig 3). The greater water leakage into the MAC 200 immersion suit during the NEAR-DRY-O condition would explain the further decrease in thermal resistance during that condition.

It was concluded that the nearly dry suit concept, while maintaining a greater comfort when the seals were opened before immersion, successfully limited the water leakage into the suit to a level observed with a dry suit when the seals were closed upon entry in water. The thermal insulation provided by the nearly dry suit is lower than the insulation provided by the dry suit, but not inferior to 0.75 Clo, the recommended insulation to obtain adequate thermal protection in cold water. When the seals of the nearly dry suit were opened before entry in water, the resulting water leakage could significantly decrease the survival time by a factor of two, based on the results from a prediction model (5).

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