DIVER THERMAL PROTECTION USING REGIONAL HEATING AND COOLING IN COLD AND HOT WATER

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ABSTRACT

Introduction: Diver thermal protection in cold water is challenging (hands/feet), however, warm water exposure can be more problematic (core). Previous studies have shown that a total body diver thermal protection system (DTPS) protected divers in warm and cold water.

Purpose: This study investigated thermal protection using only regional heating or cooling (hands/feet/chest in cold and chest in warm water) with a tube suit connected by umbilical to the remotely located DTPS.

Methods: Four divers in 50°F and 98°F water (3 hrs rest or exercise) and 8 divers simulating a swimmer deliver vehicle mission in 95°F (3 hr rest, 1hr exercise, 2 hr rest) participated. Eight skin temperatures (Ts) and core (Tc) were measured and mean skin and body T calculated.

Results: In both 98°F and 95°F, the unprotected divers Tc increased 0.42°F during rest and 0.92 °F during exercise, and it remained elevated during recovery (0.72 °F). Divers cooled by the DTPS had significantly less increase in Tc (0.17, 0.53 and 0.48 °F, for rest, exercise and recovery, respectively). Mean body T was 133% , 54 % and 25 % higher and mean skin T 126%, 90%, and 241% higher unprotected than when cooled, for rest, exercise and recovery, respectively. In 50°F water neither hands/feet or core were protected when only they were thermally protected, with Ts and Tc approaching 68 and 96°F, respectively, while with total body coverage the divers were thermally protected and comfortable. Power to cool/heat the diver was 134 W at rest and 158 W during exercise (45-50% less than total body cooling) and 306 W in the cold (50% less than for total protection).

Conclusion: Divers were protected thermally with a cooling vest under a wet suit in warm water at rest and during exercise, while total body coverage is needed in cold water.

Funding: ONR, NAVSEA, CRESE, NEDU

INTRODUCTION

- Most of the waters that divers are exposed to are either below or above their thermal neutral temperature (30-35°C), thus exposing them to thermal stress. Their thermal stress is determined both by water temperature and exposure time, and can seriously limit both cognitive and physical performance. A previous investigation at the Naval medical Research Institute (NMRI) verified the inadequacy of the diver thermal protection employed by combat swimmers in long-duration, cold water missions (4).
- The Program Executive Office, Naval Special Warfare (PMS NSW) has identified a need to develop a system or systems to mitigate the effects of thermal stress associated with both cold and warm water immersion during SEAL Delivery Vehicle (SDV) operations.
- Over the past years a diver thermal protection system (DTPS) has been developed at CRESE under funding form ONR and currently from NAVSEA. The CRESE DTPS is an active heating and cooling system that can be worn with any diver insulation. The system is comprised of a multi-zone tube suit worn under the insulation in contact with the diver. There is an active heating/cooling unit worn by the diver that conditions water and circulates it through the 6 zones of the tube suit at an optimal flow of 500 ml/min and temperature of 30°C. This system provides (in cold water) or takes away (in warm water) heat to maintain the diver in thermal balance and comfort, thus preventing thermal stress. This system also acts as a total body and regional calorimeter.

METHODS

- **SPECIFIC AIMS:**

1. Re-engineer the existing DTPS for application to cooling of SDV divers in cold and hot water, with specific reference to regional regulation; i.e. hands/feet in cold and torso in hot.
2. Test this re-configured system with divers at CRESE to prove the concept.
3. Test the DTPS for SDV use at the Navy Experimental Diving Unit in a simulated SDV mission scenario.

- **PROTOCOL:**

a. Preliminary testing was performed at CRESE on 4 recreational divers during rest or exercise to determine the feasibility of heating hands/feet only in the cold, and cooling only the torso in hot water.

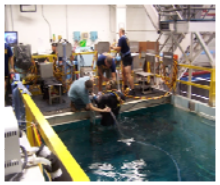
b. The second phase of this study was conducted at NEDU in a simulated SDV mission scenario with 8 Navy divers: 3 hrs rest, 1 hr intermittent exercise and 2 hrs rest.

- **PROCEDURES:**

Diver were instrumented with multiple skin and core thermal sensors. Divers at CRESE swam and at NEDU cycled at a moderate rate. Divers wore a full wet suit (6.5 mm) in cold and a "shortie" in the warm water.

EXPERIMENTAL SETUP AT NEDU

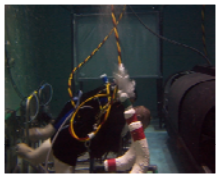
Diver with umbilical



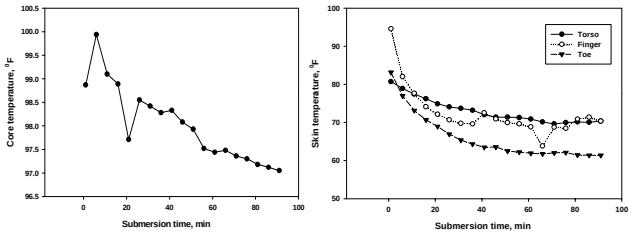
Divers in SDV at rest (3 & 2 hrs)

DTPS Mounted on pool wall

Divers exercising (1 hr)

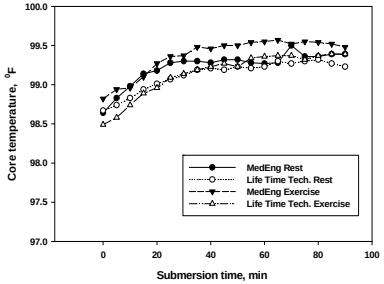


RESULTS: CRESE TESTING IN COLD



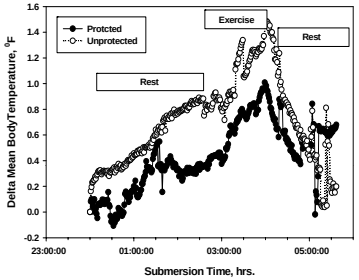
- Four divers in 50°F water wearing tube suit "vest", "gloves" and "socks".
- Although finger/toe temperatures were above water temperature, core temperature was not protected. Thus, the diver was not protected.
- It is concluded that total body protection is needed in the cold.

RESULTS: VEST TESTING IN HOT



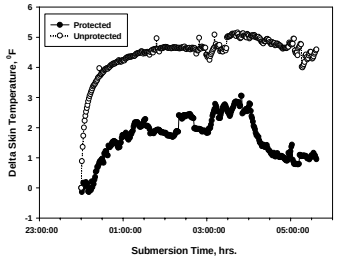
- Four vests tested in 39°C water. Data are average of four subjects.
- The divers were thermally protected in all conditions
- There was no significant difference among conditions or vests. Based on subject comfort the MedEng vest was selected

RESULTS: NEDU TESTING IN HOT



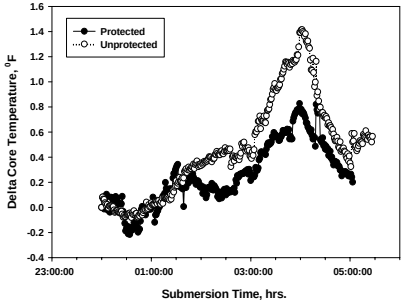
- Eight Navy divers in 95°F water, rest, ex and rest.
- Mean body T, increased significantly more when unprotected than protected in all conditions (95-133%).

RESULTS: NEDU TESTING IN HOT



- Data for the increase in skin temperatures for 8 Navy divers unprotected or protected with the DTPS.
- The unprotected divers were not in thermal balance, where as the protected divers were kept with in the Ts criteria, MST was 90-241% higher unprotected.

RESULTS: NEDU TESTING IN HOT



- Data for the increase in core temperature of 8 Navy divers in 95°F water, unprotected or protected with the DTPS.
- The unprotected divers were not in thermal balance, where as the protected divers were kept with in the Tc criteria.
- Tc was 48 to 147% higher unprotected than protected.

CONCLUSIONS

- **The present experiments at both CRESE and NEDU demonstrate that SDV divers can be protected in water temperatures between 95°F and 98°F with the DTPS combined with a tube suit vest during rest and exercise for up to 5-6 hrs. Actually as the divers were in a steady state during both rest and exercise the time of exposure could be extended up to the 12 hrs.**
- **The comfort was not significantly improved when the entire diver was cooled by the multiple zone tube suit, and the power requirement was significantly greater, thus using vest only is optimal for warm water.**
- **Importantly, the power required to cool the diver was 130-150W. This translates into about 300-500 W of electrical power using the CRESE DTPS in water as warm as 38°C, as the thermal electric coolers have a cooling efficiency of about 40-45%.**
- **Another important observation based on previous studies and these data is the importance of insulation in warm water, as it reduced uptake of heat from the warm water, even when the body temperature is increased by exercise.**
- **Another important advantage of thermal protection with the DTPS, is that the skin temperatures under the insulation were maintained at approximately 30°C, which minimizes sweating and therefore dehydration.**
- **While torso only protection proved sufficient in hot water, protecting the hands and feet and torso did not protect the divers in cold water (10°C), further coverage is necessary.**

ACKNOWLEDGEMENTS

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- Navy Experimental Diving Unit