Effect of Hand and Foot Heating an Diver Thermal Balance

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INTRODUCTION

Divers at rest immersed in cold water for long durations wearing passive thermal protection garments are limited by painful and numb fingers and toes due to low digit temperatures which occur well before rectal temperatures fall to unsafe levels. Increasing passive insulation is detrimental, as doing so results in decreased manual dexterity. It was reasoned that low levels of hand and foot active heating might improve diver comfort without decreasing manual dexterity. Supplemental heating to maintain digit temperatures at either 12 *or* 18° C was chosen to minimize potentially counter-productive increases in local skin conductivity (1).

METHODS

A total of 32 divers participated in 3 series of immersions for periods of up to 8 h in 3 C water. Divers wore a dry suit with Thinsulate undergarments. In the first series, divers wore warm water perfused gloves and socks. The gloves and socks were heated to maintain finger and toe temperatures of 12° *C or* 18" C. *The* diver was questioned as to his comfort, and tested for grip strength and ability to do fine tasks of manual dexterity every 2 h. In the second series, divers wore electrically heated socks and gloves, which continually delivered 21 W of heat to each extremity to establish whether sufficient power was available to achieve the desired digit temperature. A third series was conducted with intermittent energizing of the gloves and socks to determine the average power required to maintain 18° C finger and toe temperatures.

RESULTS

During the first series the divers reported that 12 ° C fmger and toe temperatures were uncomfortably cold, with ***50%*** reporting numbness by the end of an 8 hour-immersion. Divers without supplemental heating were unable to complete the immersion due to pain and numbness occurring between 2-4 hours. Heating fingers and toes to 18° C resulted in greater perceived comfort, with divers reporting some cold sensation but no discomfort or numbness. Hand grip strength was not different between the heated and unheated groups, as forearm muscle groups that provide grip strength were presumably not affected by hand heating. There was no increase in forearm skin temperature or heat flux. Manual dexterity was not different between groups heated to 12 or 18° C, but was improved over the unheated group, whose fingers became painfully cold or numb between 2 and 4 hours of immersion.

The second series of continuous electrical heating produced finger temperatures of 25 ± 3° C and toe temperatures of 29 ± 2° C when 84 W was applied to the hands and feet. In the third series, ON/OFF control was used to maintain digit temperatures of 18 ± 0.5° C. The duty cycle (ON time/ON t OFF time) was 62 ± 5% for hands and ***49*** ± 3% for feet during the last *2* h of immersion. Average heating power for each hand was

13.4 ± 3.4 W, and each foot 9.8 ± 2.4 W. The rate of fall in mean skin or rectal temperature in heated divers was not different from those of unheated divers during the course of the immersion. Metabolic rate rose in response to falling body temperatures, and was sufficient to offset the rate of heat loss, resulting in a rectal temperature plateau at 36 °C. Whole body heat fluxes were similar to those reported by Thalmann (2) for resting divers immersed in 2-4 °C water wearing comparable amounts of dry suit insulation.

CONCLUSIONS

The energy required for extremity supplemental heating to 18 °C in this study (50 W for electrical, 211 W for warm water) is in the range of only 10-25% of the energy cost of whole body heating in 0-5 °C water estimated by Lippitt (3). However, Lippitt's calculations assumed no change in core temperature, while in this study core temperature decreased 1.2 ± 0.3 °C in 8 h. This is similar to that reported for similarly insulated, unheated resting divers (2). The major advantage of extremity supplemental heating is the improvement in perceived comfort and manual dexterity, as there was no demonstrable effect on diver core temperature change during immersion in cold water.

This study has demonstrated that electrical resistance heating at the hands and feet has a lower power requirement than the hot water perfused system that was tested. The entire electrical resistance system was assembled from off-the-shelf components that are readily available. It is a thin glove or sock with electrical resistance wire woven in the fabric, permitting overlying passive insulation to reduce energy requirements and still providing good diver manual dexterity while affording some passive thermal protection in the event of a heating power failure.

Supplemental heating of the hands and feet does provide increased comfort to the diver wearing passive insulation at low energy cost. However, it does not affect the loss of body heat during cold water immersion. The rate of body cooling remains a function of diver activity level garment insulation, and water temperature. The duration of exposure determines the amount of total body heat loss, and how much of a decrement in performance will occur.

REFERENCES

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