

INDIVIDUAL THERMAL PROFILES FOR HUMAN COMFORT MANAGEMENT IN EXTREME ENVIRONMENTS

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INTRODUCTION

Long-duration space flights pose unique problems, not only because of the monotony of the onboard environment, but also because of different thermal comfort levels due to factors such as age, gender, race, adaptation to climatic extremes and subjective perception of temperature conditions. There are substantial differences in the functioning of human physiological systems, particularly the cardiovascular and nervous systems and in processes of mineral exchange, in earth conditions and the space environment (1). Discomfort due to thermal conditions onboard and during extra-vehicular activity (EVA) have occurred a number of times on both U.S. and Russian flights (2).

The creation of individual thermal profiles is a potentially important methodology for ensuring a rapid adjustment to the spaceship environment and the continued comfort of each crewmember over long-duration flights. Through the identification of individual differences in the heat flux range of different areas of the body, it will be possible to establish zones of thermal comfort for each person. This information can be applied to the better design of onboard and EVA garments and other equipment to enhance work performance and protection against overcooling/overheating in usual and emergency situations. A more effective human-machine system will be produced.

Several years ago, the current investigators developed a new methodological paradigm using non-uniform temperatures on the body surface to measure heat flux under different environmental circumstances and physical activity levels (3,4). Through this method, it is also possible to measure simultaneously the intensity of heat flux from individual body parts. The focus of this paper is on the determination of how heat flux from different parts of the body is modified by thermal conditions on the body surface. Examples of several profiles of body areas are given, from which individual thermal profiles can be constructed.

METHODS

The suit consists of a hood, shirt, gloves, pants and socks, which is sagittally divided into ten areas and was designed with plastic tubing through which temperature controlled water circulates (Figure 1). The water inlet and outlet temperatures were controlled for each area. It was possible to combine a variety of regimes on the body surface by switching the water flow from region to region or using several zones collectively. In our study, the evaluation of maximal heat

release by cooling different parts of the body (head, torso, total hands, 1 or 3 fingers, feet and legs) was investigated through separate experiments. The rest of the body surface was comforted or overheated by the suit. The temperature cooling zones were 8°C, and the warmed zones were 33°C or 45°C.

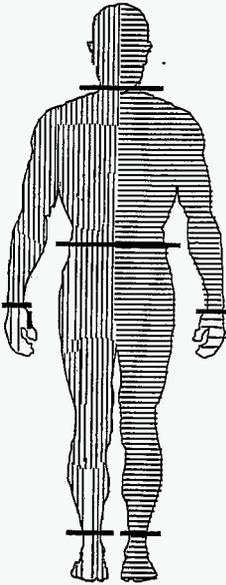


Figure 1.
Experimental
Segmented Tubing
Suit

2 cooled gloves and the calorimeter on 1 finger and 3 fingers, respectively. Each peak appeared after initiation of water circulation in the gloves or finger calorimeter, indicating extremely rapid heat removal from the skin surface due to the cooled circulated water. After several minutes, the process stabilized, and a dynamic curve was evident. The greatest heat absorption occurred when 2 gloves were worn. One glove absorbed relatively less heat but not in an amount proportional to that of gloves on both hands.

A separate finger calorimeter (for 2nd, 3rd and 4th digits) with embedded tubing was also used for measuring heat flux of the individual finger or 3 fingers.

Heat outflow from each body segment was measured continuously as a result of the difference in inlet/outlet water temperatures and water flow rate. The water flow rate on the different suit segments was measured by a flowmeter. It provided a measure of physiological effectiveness of selected areas to protect the body against heat dissipation.

Local skin temperature was measured by thermistors applied on 24 various sites of the skin surface. Rectal and tympanic temperature were also measured.

Heat production, heat balance, temperature redistribution in the core and on the body surface and heat flux were the main parameters assessed.

RESULTS

Thermal profile of the hands. Figure 2 presents the dynamic of heat absorption by 1 cooled glove,

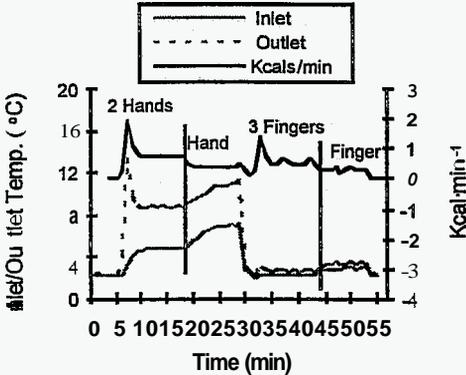


Figure 2. Suit Temperature Inlet/Outlet and Heat Absorption Profile (kcal·min⁻¹) by Gloves and Fingers Calorimeter (Female, age 32).

The finger heat **flux** data indicated only a small amount of heat outflow, likely because the fingers have a highly effective protective countermeasure against environmental cold. The cold finger coverall caused the vessels in the finger to constrict immediately.

The dorsal part of the hand lost a considerable amount of heat. However, it is not comparable to the fingers (despite their relatively larger surface area)

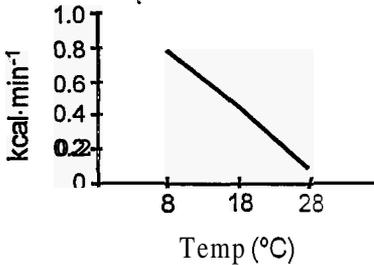


Figure 3. Heat Absorption by Gloves (kcal/min) with Different Circulating Water Temperatures (Male, age 30)

because the physiological mechanism and reflex reaction in this area is highly active. Under certain conditions, it is possible to increase heat flux from the fingers when the circulating water temperature is mild; therefore, more compromise between the body and glove surface or finger coverall takes place for heat release.

Figure 3 presents heat **flux** dependence from different circulating water temperatures in the gloves. A clear relationship

was exhibited between heat outflow and glove temperature: the lower the temperature, the greater the heat **flux**.

Thermal profile of other parts of the body. Figure 4 presents the dynamic of heat **flux** from different parts of the body. It is evident that the greater the body surface covered by the tubing suit, the greater the heat outflow. The greatest amount of heat loss occurred from the legs and torso. However, if one calculates the heat outflow from these parts of the body per 10 meter length of tubing, opposite findings emerge (Figure 5). The hands are the primary area for heat outflow with the best vessel network and the greatest ability to transfer heat.

Heat loss from the trunk and lower part of the body per equal unit of cooled tubes was considerably less than from the hands and head. The lesser amount of heat dissipation by the feet illustrates the strong protective reaction existing in this area. The quantity of heat loss for this

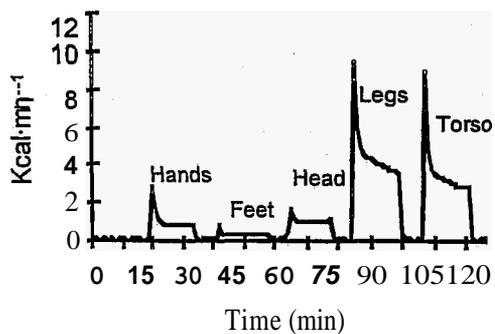


Figure 4. Maximal Heat Flux from Different Parts of the Body Under Cooling Suit at 8°C (Female, age 40).

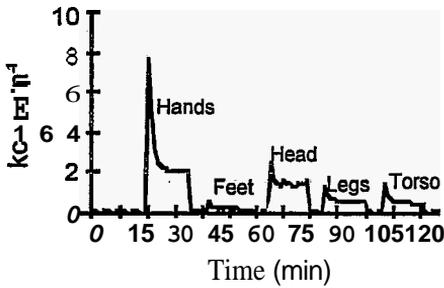


Figure 5. Maximal Heat Flux from Different Body Sites Calculated per 10 Meter Length of Tubing (female, age 40)

individual ranging from highest to lowest amount was as follows: hands, head, torso, legs and feet,

CONCLUSIONS

Through the use of individual local and total body thermal profiles, it may be possible to make significant progress in comfort management and protection in different environmental conditions. The thermal profile must function not only as a reference

point for individual comfort, but also as a primary protective countermeasure: heat exchange stabilization through absorption/dissipation of heat from different body sites. These profiles have significant potential as highly effective tools for forced and directed heat exchange, and for the redesign of the space suit system in a more energy efficient manner. Information from individual thermal profiles can be extremely helpful during extended duration EVA in terms of decreasing energy expenditure and enhancing safety in a range of circumstances.

This developed methodology of individual human profile design allows the comparison of different individuals and selection of the most resistant for heat release during future exploration of extreme environments.

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