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Person to Person Biological Heat Bypass During EVA Emergencies

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ABSTRACT

During EVA and other extreme environments, mutual human support is sometimes the last way to survive when there is a failure of the life support equipment. The possibility to transfer a warming fluid from one individual to another to increase heat and support the thermal balance of the individual with system failure was assessed. The following analog scenarios were considered: 1. one subject has a cooling system that is not working well and already has a body heat deficit equal to 100-120 kcal and a finger temperature decline to 26-27°C, the other subject is at comfort level; 2. one subject is overcooled due to system failure and the other is mildly overheated. Preliminary findings showed promise in using such thermal sharing tactics to extend the time duration of survival in extreme situations when there is an increased metabolic rate in the donor.

INTRODUCTION

In considering the protection of astronauts during planetary exploration, a situation could arise in which there is a failure of an astronaut's life support system. Rapid support is crucial, particularly if the astronaut is at some distance from the habitat or space ship. Mutual support may be the only option for survival; there is a precedent for this procedure, for example, when mountain climbers share the same oxygen breathing mask to survive in the combination of hypoxia and a cold environment, or divers share a breathing apparatus. The aim of this pilot analog study was to evaluate whether a specially designed file interconnecting two space suits could extend the thermal balance of the astronaut experiencing system failure, potentially prolonging survival time until help arrives. In order to evaluate whether such system design is feasible, the possibility to transfer a warming fluid from one individual to a second chilled person to increase heat in the latter was examined. The strategy of sharing only metabolic heat was also assessed, in which one participant is at comfort level, and the other in a chilled thermal state.

Thus, a physiological approach was used to explore a method for optimizing human survival in extreme cold conditions through sharing heat between body areas. There are few data in the literature that serve as a foundation/background for this particular paradigm. Previous studies by the present research group demonstrated that finger comfort in cold conditions can be supported by the delivery of heat from the head to the hands through water circulating within a tubing bypass in a liquid cooling/warming garment (Koscheyev, Leon, Coca, & Treviño, 2005). Carrying this notion a step further, this pilot study/probe evaluated whether body heat can be shared from one person to another when one individual has a body heat deficit and the other is in either thermal comfort or mild overheating. Two scenarios were considered: 1. one subject's cooling/warming system is not working properly and the individual is in heat deficit while the other subject is at a thermal comfort level; 2. one subject is at the same level of heat deficit as in Scenario 1, and the other subject is in a state of mild overheating after moderate exercise.

METHODS

Subjects

Two females participated in this study. Subject characteristics are shown in Table 1. Both were nonsmokers and free of medications. Subject A was the Recipient, and Subject B the Donor.

Table 1. Anthropometric characteristics of subjects

Subject	Age (yr)	Height (m)	Weight (kg)	BSA (m^2)[a)]	BMI	Body fat(%)[b)]
A	24	1.70	60.1	1.70	20.8	19.5

B	23	1.79	70.8	1.89	22.1	22.9

[a] BSA(m^2)= ($Weight^{0.425}$ ×$Height^{0.725}$) × 0.007184;
[b] %BF = [(4.95/Body Density)-4.5]/100.

Experimental equipment

A plastic tubing shortened liquid cooling/warming garment (the MACS-Delphi) through which water circulated was used in this research and worn over briefs and bra. The garment covered the total body surface except for the face, the hands, the calves and feet. The garment was composed of cotton/polyester spandex fabric; the tubing system was sewn onto the fabric. The tubing diameter was ID 2.8mm and OD 4.5mm (TYGON R TUBING AAC02641-CP, Cole-Parmer, IL). The garment characteristics are shown in Table 2.

Table 2. Characteristics of MACS-Delphi liquid cooling/warming garment

	Subject A (Size S)	Subject B (Size M)
Total length of tubing	47.12m	75.27m
Surface area covered by tubing and % of BSA	$0.333m^2$ 20%	$0.532m^2$ 28%
Flow rate during Stage 2	Average 556(ml/min)	

A small water bath (model No. MRC150DH2-HT-DV, Melcor Corporation, NJ) controlled the temperature of the water and provided stability of the flow rate at 1.9 liter/min. Temperature sensors inserted in the tubing inlet/outlets of the garment controlled the designated temperature of the circulating water. The water temperature regimes imposed had an accuracy of ±0.2°C. Water temperature was also monitored by means of a data acquisition program displayed on the computer screen.

Measurements

Heat exchange was controlled by monitoring skin and core temperature. For Subject A (Recipient), thermal sensors (model 409A; YSI, Yellow Springs, OH) were placed on the body surface, symmetrically distributed on sites on the left and right sides of the body as follows: forehead, cheek, earlobe, neck, chest, finger, axilla, thigh, femoralis, calf, and toe. Finger (T_{fing}) and toe (T_{to}) temperature sensors were placed, on the mid-lateral distal phalanx of the fourth finger of each hand, and on the mid-lateral proximal phalanx of the third toe of each foot. Core temperature (T_c) was estimated by measurement of rectal temperature (T_{re}) using a temperature probe (model 401; YSI) inserted 13 cm into the rectum. For subject B (Donor), rectal, earlobe, finger and toe temperatures were monitored. A customized Labview data acquisition system summarized temperature data at 44 sec intervals. Overall body thermal sensation and thermal comfort were assessed by ratings on individual point-scales.

Calculation

Based on [Eq. 1], heat flow was calculated. Weighted mean of skin temperature based on Hardy and DuBois 7-point equation (1938a) and heat storage (Eq. 3 and 4; 1938b) were calculated according to [Eq. 2] ~ [Eq. 4].

$$\text{Heat flow (kcal/min)} = m_w C_w (T_{in}-T_{out}) \text{ ---------- [Eq. 1]}$$

Where, m_w : Water flow rate ($l \cdot min^{-1}$);
C_w : The specific heat of water, $1 kcal \cdot kg^{-1} \cdot ℃^{-1}$;
T_{in} : The inlet temperature (℃); T_{out} : The outlet temperature (℃).

$$\text{Mean skin temperature } (\bar{T}_{sk}) = 0.07\times T_{head}+0.35\times T_{trunk}+0.14\times T_{arm}+0.05\times T_{hand}+0.19\times T_{thigh}+0.13\times T_{calf}+0.07\times T_{foot} \text{ ---------- [Eq. 2-1]}$$

$$\text{Mean } T_{sk\ corrected}= 0.07\times[(Cheek_{L,R}+Carotid_{L}+Forehead_{L,R}+Earlobe_{L,R})/7] + 0.35\times[(Chest_{L,R})/2] + 0.14\times[(Armpit_{L,R})/2] + 0.05\times[(Finger_{LR})/2] + 0.19\times [(Thigh_{L,R}+Femoralis_{L,R})/4] + 0.13\times[(Calf_{L,R})/2] + 0.07\times[(Toe_{L,R})/2] \text{ ----- [Eq. 2-2]}$$

$$\text{Mean body temperature } (\bar{T}_b) = 0.8T_{re}+0.2\bar{T}_{sk} \text{ --------- [Eq. 3]}$$

$$\text{Heat storage (kcal/hr)} = \Delta\bar{T}_b \times \text{Body weight (kg)} \times \text{Specific heat of human body } (0.83 kcal/kg.^{o}C) \text{ ---------- [Eq. 4]}$$

Procedure

The study consists of two conditions: *No Exercise* and *Moderate exercise*.

Condition 1: No exercise

Both subjects were studied in an environmental chamber (24°C, humidity 22%) at rest, seated in an arm chair, and donned in the MACS-Delphi. During Stage 1, Subject A Recipient was chilled by inlet water temperature at 15°C while Subject B Donor was warmed by inlet water temperature at 33°C circulating through the garment. When the Recipient reached a finger temperature (T_{fing}) of 26~27°C, Stage 2 was initiated: the tubing from the Donor's garment was connected to the Recipient's garment through a water bath, as shown in Fig. 1. When the water temperature in the water bath began to decrease after showing a plateau, Stage 2 was terminated.

Condition 2: Moderate exercise

The Comfort and Exercise conditions were evaluated on separate days in the same environmental chamber as in Condition 1. In Stage 1, chilling of the Recipient was the same as in Condition 1 (inlet water temperature at 15°C); the Donor ran on a treadmill at a work rate of approximately 50% of Target Heart Rate (THR). When either the Recipient reached a criterion of T_{fing} 26~27°C or the Donor's T_{re} reached approximately 38°C, the Donor terminated running. At this point, Stage 2 was initiated: the garment tubing from the Donor was connected to the garment tubing of Recipient as shown in Fig. 1, and then both subjects were seated.

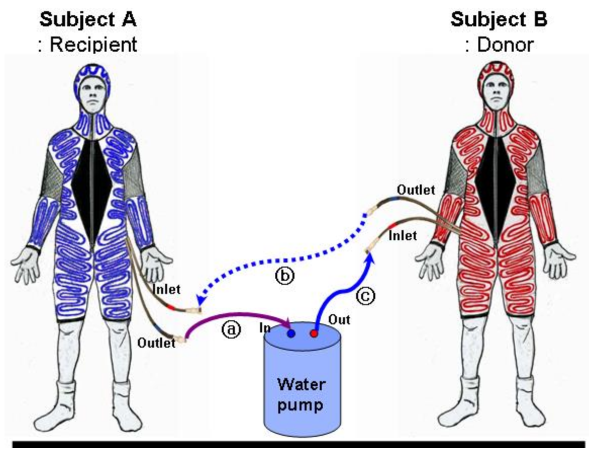

Fig. 1. Thermal bypass and the direction of the tubing between two persons, Donor- Recipient.
Note: a,b,c refer to parts of the inlet/outlet file connections; arrows indicate direction of water flow.

RESULTS

Table 3 presents a summary of the heat transfer between the Donor and the Recipient in Conditions 1 and 2.

Table 3. Body heat exchange between Donor (D) and Recipient (R)

	Condition 1 (56 min)				Condition 2 (33 min)			
	Stage 1 (R-cooling; D-comfort)		Stage 2 (Heat Sharing)		Stage 1 (R-cooling; D-Exercise)		Stage 2 (Heat Sharing)	
	45min	Per min	11 min	Per min	24 min	Per min	9min	Per min
R	-52	-1.2			-106	-4.4	-12.0	-1.3
D	11	0.2			28	1.2	-9.0	-1.0
R_D			-59.6	-5.4			-21.0	-2.3

Units are: kcal.

Condition 1: No exercise

Heat flow

Fig. 2 demonstrates the quantity of heat transfer from the Donor to the Recipient through Stages 1-2.

Core temperature

The T_{re} dynamic of the Recipient shows a lack of stabilization in the period of heat sharing (Fig. 3). The temperature dynamic continues to decrease 0.0045°C/min (Stage 2) as compared to a decrease of 0.0018°C/min in Stage 1. The Donor T_{re} exhibits relative stability across stages.

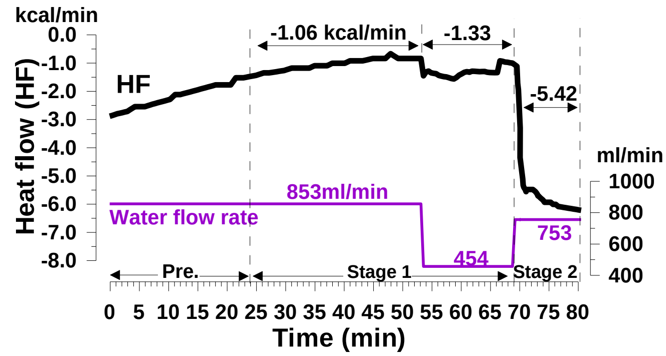

Fig. 2. Heat flow and water flow rate of Recipient garment.

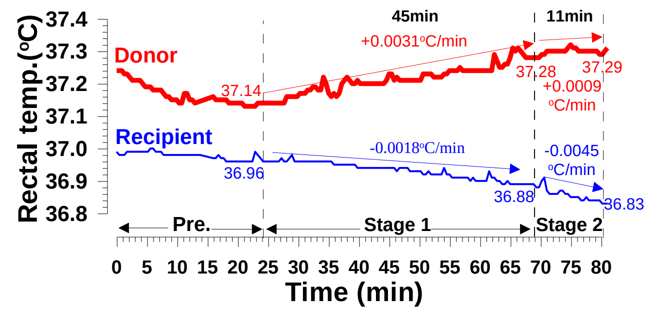

Fig. 3. Rectal temperature (T_{re}) dynamic of Recipient and Donor across stages.

Finger temperature

As with T_{re}, a similar dynamic is evident with T_{fing}; in Stage 2 both subjects show a decrease in T_{fing} when they are attached to a common water file.

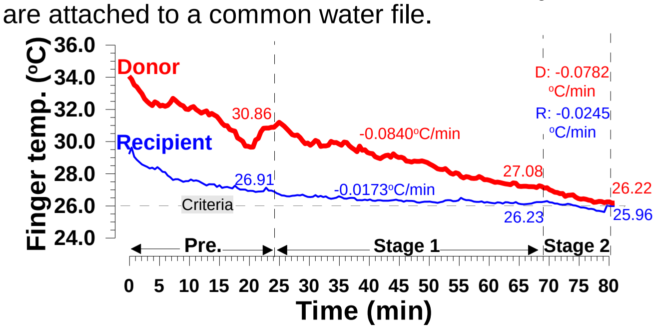

Fig. 4. Finger temperature T_{fing} of Donor and Recipient across stages.

Skin temperatures

Simultaneously, the dynamic of local skin temperature of the Recipient exhibits obvious restoration (improvement) under the influence of the circulating water of the resting Donor. For example, the temperature indices for the earlobe and carotid areas increased by 0.2-0.9°C (Fig. 5).

Subjective sensations

Subject ratings of Overall Thermal Sensation and Overall Thermal Comfort indicated that both the Recipient and the Donor showed a decrease in perception of cold from Stage 1 to Stage 2, and a lesser perception of discomfort. These ratings show that the sharing of heat had a salutary effect on the chilled Recipient (Fig. 6).

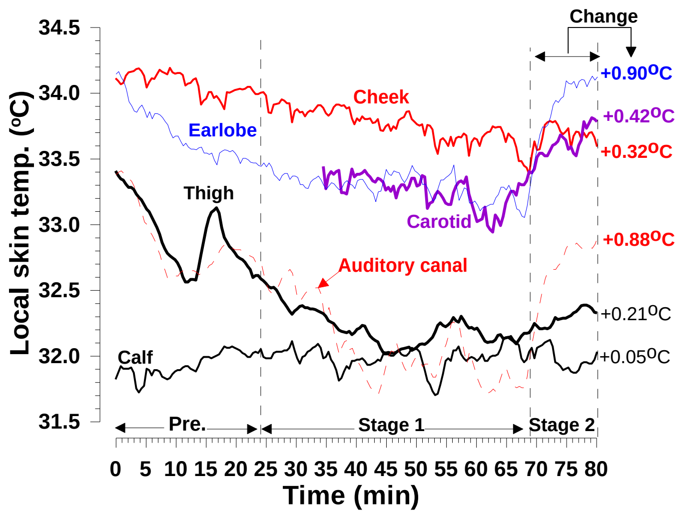

Fig. 5. Local skin temperatures of the Recipient across stages.

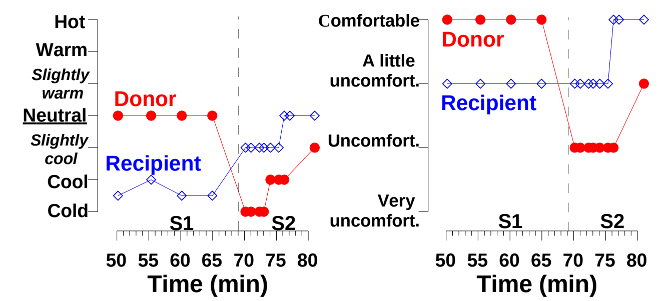

Fig. 6. Overall thermal sensations and comfort of the Recipient and the Donor.

<u>Condition 2.</u> Donor moderate exercise and Recipient cooling at rest

Heat flow

The water temperature in the outlet file between the Donor and Recipient in the Stage 2 period of heat exchange increased from 18.6°C to 24.2°C on the Recipient's surface (Fig. 7). It can be noted that this change initiates a chain of temperature changes in the core and on skin surfaces (Figs. 8 and 9).

Core temperature

There was little change in T_{re} of the Recipient through the entire period of Stages 1-2 (0.07°C); simultaneously, T_{re} of the Donor, under exercise conditions, increased by 0.5°C in Stage 1 and decreased in Stage 2 by 0.2 °C due to the sharing of heat with the Recipient (Fig. 8).

Skin temperatures

Skin temperature dynamics of the Recipient changed significantly during the period of heat transfer from one person to the other, especially on the lower extremities and the earlobe (Fig. 9). Other skin temperatures were relatively stable, showing a small tendency to increase.

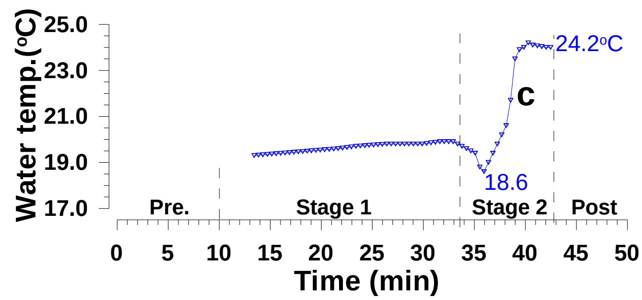

Fig. 7. Change in water temperature in the water file (point C) between the garments of the Recipient and Donor. Stage 1 – donor temperature; Stage 2 – file temperature.

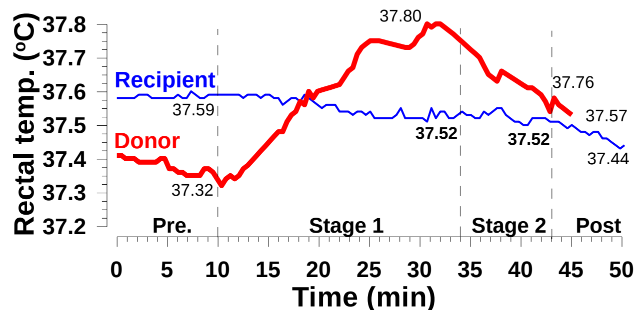

Fig. 8. T_{re} of Recipient and Donor across stages. Stage 1 – Donor exercise, Recipient rest; Stage 2 – heat exchange.

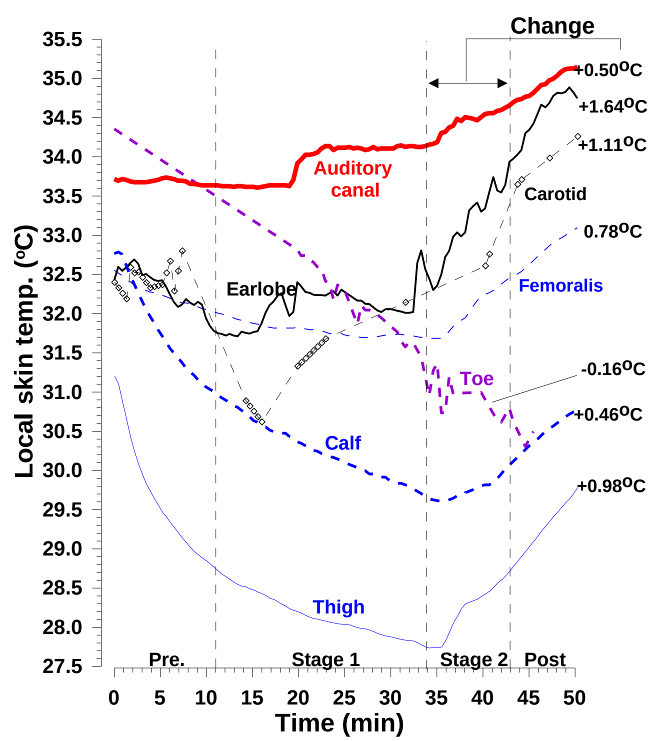

Fig. 9. Skin temperatures of the Recipient across Stages 1 and 2. Stage 1 – Donor exercise, Recipient rest; Stage 2 – heat exchange.

CONCLUSIONS

These pilot evaluations suggest that it is possible to share heat between two persons through files of circulating water in the liquid cooling/warming garments. Potentially, this procedure has practical application not only for planetary exploration, but on Earth as well in extreme environments. The findings showed that the capability of heat sharing in the donor comfort condition is not great because the donor has only basal metabolic heat which in normal conditions does not exceed 100 kcal. Therefore, the heat of the donor passing to the recipient's body surface is capable of changing only skin temperature in certain body areas, and does not affect the thermal status of the core and periphery of the limbs. In the situation in which the donor's metabolic rate was increased under the Condition 2 exercise protocol, there was an increase in the temperature of the water circulating in the cooling/warming garment which was transferred through the file to the recipient. This transfer of heat helps to stabilize the temperature of the body surface of the recipient and provides support to stabilize the temperature of the lower extremities. It is possible that with an increase in the intensity of physical exertion by the donor and increasing the duration of heat exchange between the two participants, thermoregulation and stabilization of thermal balance of the recipient would be enhanced. Further more comprehensive studies are necessary to follow through with the concepts and findings of this pilot/probe exploration.

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