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PERSONAL COOLING WITH PHASE CHANGE MATERIALS IN A VERY HOT ENVIRONMENT

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INTRODUCTION

Hot environments are a threat for daily life, sports and exercises, work, military drills and operations. Ambient air cooling has been approved to be ineffective when air temperature reaches 40 °C or higher, particularly when relative humidity is also high. In a hot and dry environment (45 °C and 10% relative humidity), the study of ventilated vest with ambient air alleviated heat strain when subjects worn military clothing (Barwood et al., 2009). However, a recent study showed that continuous cooling of the torso by use of fan-driven ambient air at 45 °C and 20% relative humidity is not efficient (Ciuha et al., 2011).The study of the rectal temperature drop during resting recovery with a battery driven ambient air fan based cooling vest at 40 °C and 40% relative humidity heat exposure showed no cooling effect (Hadid et al. 2008). Cooling capacity for body ventilation system with ambient air cooling decreased as ambient temperature increased. The cooling capacity decreased to about zero when ambient temperature was higher than 40 °C (Xu and Gonzalez, 2011). Therefore to explore alternative personal cooling methods in very hot environments is necessary. Our previous studies on cooling effects of phase change materials (PCMs) when wearing fire fighting clothes in an extremely hot environment showed that PCMs alleviated heat strain (Gao et al., 2010 and 2011). The objective of this study was to investigate if personal cooling with PCM could mitigate heat strain of subjects with military clothing in a very hot environment at 40 °C and 45% relative humidity.

METHODS

PCM cooling vest and military clothing

The cooling vest is made of polyester with separate pockets containing 21 PCM packs. The main ingredients of the PCMs are salt mixtures including sodium sulphate, water, and additives. The melting temperature of the PCMs was 21 °C. Before and after the tests in the hot environment, the vest was kept at 15 °C overnight to solidify and prepare for reuse. The total weight of the vest was 2224 g. The weight of the PCM was 1785 g.

Other military clothing used in the study was the same as in our previous studies (Wang et al., 2011). The clothing included Swedish military jacket, long trousers, net t-shirt, briefs, socks, sports shoes (total insulation:1.65 clo, evaporative resistance: 0.0421 kPa m^2 W^{-1}).

Subjects

Eight male subjects, age 27.0±2.3 (mean±SD) years, height 1.73±0.03 m and weight 71.4±10.0 kg participated in the study with the cooling vest. Written information about the study was given to the subjects. An introduction session to the study, protocol, and equipment was held in the laboratory. Written consent was obtained before they participated in the study. During preparation, all clothes, equipment, and subjects were weighed separately. The rectal temperature (T_{rec}) sensor (YSI-401) was inserted by the subjects at a depth of 10 cm above the anal sphincter. Skin temperature (T_{sk}) sensors (thermistors ACC-001) were taped on the left side of the body on the upper arm, chest, thigh and calf. After preparation and weighing, the subject entered the climatic chamber (air temperature T_a=40 °C, relative humidity RH=45%, and air velocity V_a=0.4 m/s), and were asked to walk on a treadmill at a speed of 4.5 km/h. The heart rate, rectal (T_{re}) and skin (T_{sk}) temperatures were recorded continuously over the whole test period. The termination of walking and exposure was based on one of the following three criteria: (i) subjects felt the conditions were intolerable and were unable to continue, (ii) the rectal temperature T_{re} reached 38.5 ◦C or (iii) the planned time limit of 70 min reached, even if none of the above two criteria had been met.

T_{rec} and T_{sk} were recorded by a LabView program (National Instruments, USA) at 15-second intervals. Oxygen uptake (VO_2) was measured for five minutes between the 5th to 10th minute with MetaMax® I (CORTEX Biophysik GmbH, Germany).

RESULTS

Results showed that the increase of the chest skin temperature with the PCM cooling vest was alleviated about 1-3 °C during the heat exposure and stayed at 35 °C at the end of 70 minutes exercise in the heat. The increase of the rectal temperature ($T_{rec\_end} - T_{rec\_initial}$) was alleviated 0.2 °C (see figure below). Although the alleviation of the rectal temperature increase was not as effective as for the chest skin temperature, a lower chest skin temperature facilitates heat transfer from the core to peripheral areas of the body. Upper arm, thigh and calf skin temperatures with and without the cooling vest reached about 37 °C at the end, which were not much affected by the PCM cooling.

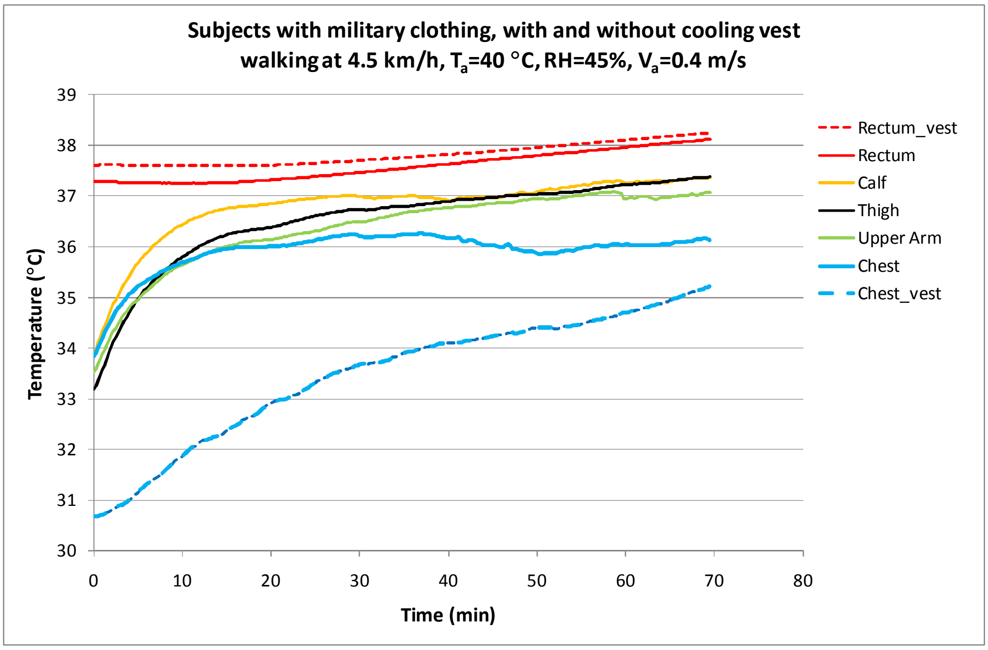

Fig. Skin and rectal temperature changes with and without the PCM cooling vest when the subjects with military clothing walked at 4.5 km/h in the climatic chamber.

CONCLUSIONS

The main cooling effect of the PCM vest is on local torso skin. The findings indicate that the personal cooling with the phase change material can be used as an alternative to alleviate heat strain in very hot environments.

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