Phase Change Material in Hiking Boots Does Not Minimise the Risk of Cold Injury

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ABSTRACT

The present study compared the thermal insulation properties of identical hiking boots, incorporating a layer of either Sympatex® or a layer of Outlast® Phase Change Material (PCM). PCM contains paraffin filled microcapsules, which change their state of aggregation with temperature. During heating, PCM liquefies and absorbs a certain amount of energy. Conversely, during cooling PCM changes from a liquid to a solid state and releases thermal energy. Specifically, we evaluated whether PCM offers any significant protection against peripheral cooling and subsequent cold injury to the feet. Subjects (20 males and 20 females) participated in three trials. In two of these trials they immersed their booted feet, wrapped in a thin plastic bag, in 30°C for 15 min, followed by 3 hrs in 15 °C water. On one occasion they wore boots with a PCM layer (PCM), and on the other, identical boots, but without a PCM layer (Control). At regular intervals we monitored tympanic temperature (Tty), average skin temperature of the arm, chest, thigh and calf (Tsk), foot temperature (6 sites), and heat flux from the skin of the foot (6 sites). Thermal insulation of the boots was determined separately with a thermal foot manikin. There was no change in Tty and Tsk during the three trials. There were no differences in any of the foot skin temperatures or heat flux measurements between the Outlast® and Sympatex® boots. The thermal insulation of the boots was 0.167 m^2K/W for the Sympatex® and 0.163 m^2K/W for the Outlast® boot. Phase change material does not offer any significant improvement in thermal protection, and thus does not minimise the risk of cold injury.

1.0 INTRODUCTION

The present study compared the thermal insulation properties of hiking boots (Alpina d.d., Slovenia) containing a layer of either Sympatex® or Outlast® Phase Change Material (PCM). PCM contains paraffin filled microcapsules, which change their state of aggregation with changing temperature. In the process of being heated from a solid state, PCM liquefies and absorbs a certain amount of thermal energy. Conversely, during cooling, PCM changes from a liquid to a solid state and releases thermal energy. We therefore tested the hypothesis that the exothermal reaction of the phase change material during exposure to cold may provide better thermal insulation and thus offer greater protection against adverse cooling and cold injury of the feet.

2.0 METHODS

Twenty subjects (10 males and 10 females) participated in the study. The protocol of the study was approved by the National Ethics Review Committee (Republic of Slovenia).

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Subjects participated in two trials separated by a minimum of 5 days. During each trial they wore the same clothing, with the exception of the hiking boots (Alpina d.d., Ziri, Slovenia). In one trial, the boots incorporated Outlast® as the thermal insulative layer and in the other Sympatex®. The study was a double blind study; namely both the experimenters and subjects were naïve regarding the boots tested. The external appearance of the boots was identical. Approximately 30 minutes prior to each experiment, the boots were wrapped in a polyurethane bag and immersed in a bath of water maintained at 30°C. Prior to donning the boots, the subjects left foot was instrumented with temperature and heat flux transducers. Once instrumented, both booted feet were then placed in the separate thin polyurethane bags and immersed to within 1 cm of the top of the boot in 30°C water for 20 minutes. Thereafter, the feet were immersed in a similar manner in bath of water maintained at 15°C.

During the immersion we monitored skin temperature of the upper arm (lateral aspect), chest (mid-clavicular line, at the level of the 3rd intercostal), mid-thigh (anterior aspect), and mid-calf (lateral aspect) with YSI 401 thermistors (Yellow Springs Instruments, Yellow Springs, Ohio, USA). Heat flux and skin temperature (T_{sk} °C) was monitored with Concept Engineering Heat Flux transducers at six sites on the left foot: toe (bottom), arch, heel, top of toes, instep, lateral. All measurements were recorded at 1-minute intervals. Skin temperature from the torso was recorded with a Biopac data acquisition system controlled by Acknowldege Software on a Macintosh computer. Foot skin temperatures were recorded with an Almemo data acquisition system (Ahlborn Mess-und Reglungstechnik GmbH, Holzkirchen, Germany). Tympanic temperature (T_{ty} °C) was recorded every 30 minutes with an infrared thermometer (ThermoScan IRT 3020, Braun, Kronberg, Germany).

The differences between the average regional skin temperatures and heat fluxes observed with the two prototype hiking boots were compared with a one way repeated measures ANOVA over the time interval of 21 to 200 min.

3.0 RESULTS

Average unweighed T_{sk} (33.79 ± 1.39°C versus 33.81 ± 1.16°C) and T_{ty} (36.73 ± 0.17°C versus 36.75 ± 0.13°C) were identical during the Sympatex® or Outlast® trials respectively. There were no statistically significant differences in any of the foot T_{sk} (Fig. 1 and 2) or heat fluxes between the two boots containing Sympatex® or Outlast®. Overall thermal insulations of the boots determined with a Thermal Foot Manikin were 0.167 m^2K/W and 0.163 m^2K/W for the Sympatex® and Outlast® boots, respectively. The difference was not significant.

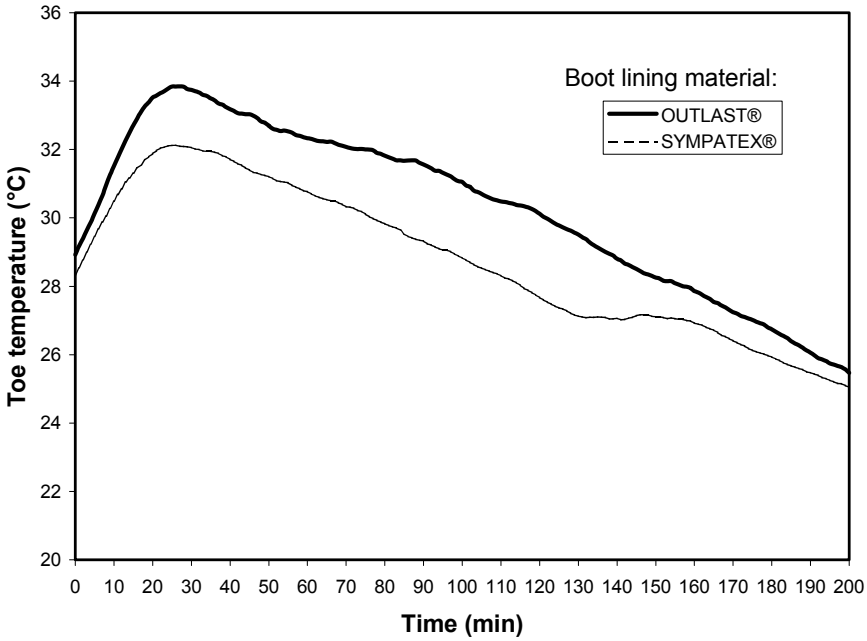

Figure 1: Average toe temperature during 30 minutes immersion in 30°C water, followed by 3 hr immersion in 15°C water. Subjects wore hiking boots containing a layer of either Outlast® Phase Change Material (thick line) or Sympatex® (thin line).

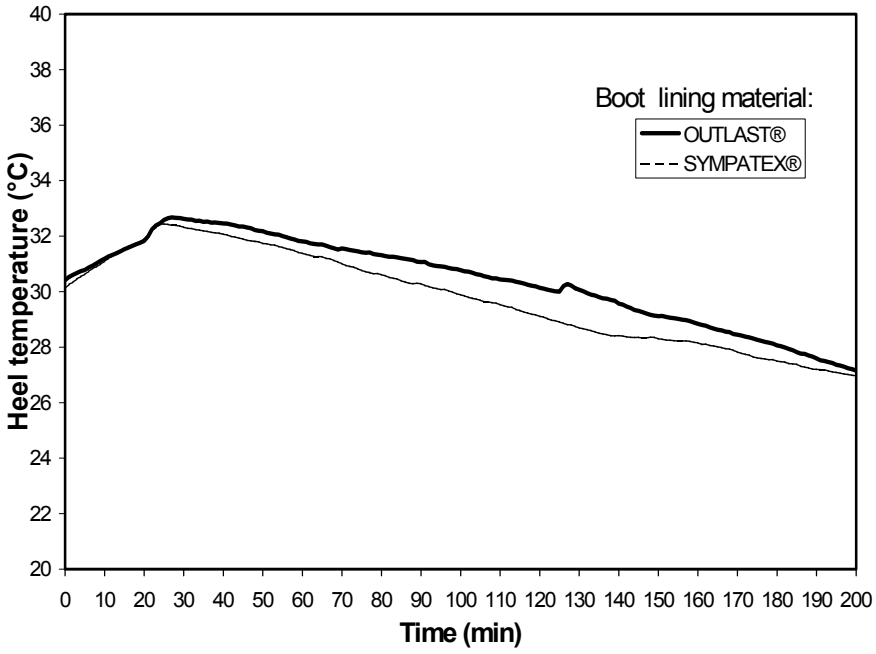

Figure 2: Average heel temperature during 30 minutes immersion in 30°C water, followed by 3 hr immersion in 15°C water. Subjects wore hiking boots containing a layer of either Outlast® Phase Change Material (thick line) or Sympatex® (thin line).

4.0 CONCLUSION

In contrast to the reported benefits of incorporating PCM in cold protective clothing (Pause, 1998), our findings concur with those of Endrusick et al. (2000), namely that Outlast® Phase Change Material does not improve the thermal insulation properties of hiking boots.

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