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Heat loss and moisture retention variations of boot membranes and sock fabrics

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Introduction

Friction blisters on the foot are among the most frequent injuries for hikers and infantry soldiers (Knapik et al., 1997; Gardner and Hill, 2002; Van Tiggelen et al., 2009). Shear forces are the friction between the skin and sock and responsible for the cause of friction blisters (Naylor, 1955). These shear forces increase with increased skin hydration as well as increased moisture content of the textile in contact with the skin (Gwosdow et al., 1986; Gerhardt et al., 2008). Ideally, all sweat produced by the feet is transported away from the skin-sock-boot system as vapor in an instance, reducing the likelihood for blisters and increasing the ability for the foot to regulate temperature. Under realistic conditions it is unlikely that these ideal conditions are reached. However, the current literature does now report on variations in heat loss and moisture retention among boot membranes and sock fabrics under neutral or warm conditions. For sub-zero conditions, Kuklane et al. has carried out several studies (e.g., Kuklane, 1999). Therefore, the aim of the present study was to investigate these variations using a thermal manikin foot.

Methods

Foot manikin

A commercially-available walking, sweating, thermal foot manikin (UCS, Vrhnika, Slovenia) was used for the present measurements and described elsewhere (Babič et al., 2008). The foot manikin simulates walking via counter-clockwise rotation of the disk on which it is mounted. A plane mounted on rods exerts a damped upward force and simulated the walking surface. Air temperature and relative humidity were maintained at 21.2 ± 0.2 °C, and 42.6 ± 0.9%, respectively.

Boots

Four army boots with variations in water-proofing were assessed. All membrane-variations were based on the same model, and detailed in Table 1.

Socks

Four sock types were assessed. All socks had similar weights and their characteristics are given in Table 2. The heels and toes of the socks contained polypropylene, and contributed with approximately 22% to the total weight of the sock. For these experiments, a boot similar to the one described above, but with no membrane or port, was employed.

Table 1. Variations among the measured boots.

Label	**Membrane**	**IQ TEX**
G+PORT	GORE TEX	Yes
½O	½ OUTDRY†	-
O	OUTDRY	-
O+PORT	OUTDRY	Yes

Table 2. Variations among the measured socks

Label	**Main Area**
$PP_{100\%}$	100% Polypropylene
PP_{blend}	66% Polypropylene and 33% polyamide
W_{pa}	50% Merino-wool, and 50% polyamide
W_{pp}	50% Merino-wool, 33% polypropylene, and 17% polyamide

Protocol and statistics

A measuring session containing five different phases: (i) weighting, (ii) heat loss measurements with no walking and without sweating, (iii) heat loss measurements with walking and without sweating, (iv) heat loss measurements with walking and sweating, and (v) weighting. The phases during which heat loss was measured were preceded by an acclimation phase which goal was to reduce the time during which steady state was reached in the measuring phase. Walking was simulated with 15 step/min. The sweat rate was 9 g/h during for membrane variation and 12 g/h for the sock fabric variations. A measuring session was carried out four times for each sample, after a fresh placement. Finally, an ANOVA was used for statistical analysis and a Bonferroni corrected t-test was performed as post-hoc analysis.

Results

No differences were found for heat loss during the absence of sweating between standstill and walking for both the membrane and fabric variations. However, heat loss was 1.5 ± 0.1 times greater for the sweating condition compared to the non-sweating condition ($p < 0.001$). Compared to all other membranes the sock in G+PORT stored 1.6 ± 0.4 g more moisture ($p < 0.001$) (Figure 1). Finally, regarding the moisture retention in the socks, W_{pa} retained 3.7 ± 0.5 g more moisture compared to PP_{blend} ($p = 0.036$), yielding 6.0 ± 0.5 g and 2.3 ± 0.2 g, respectively.

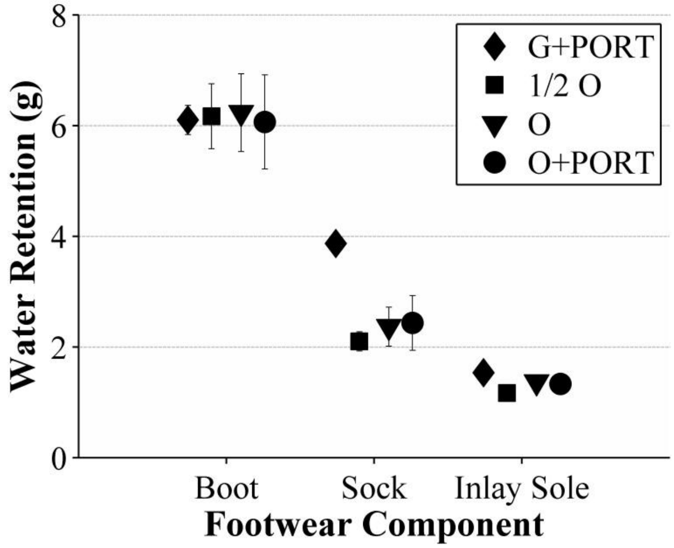

Figure 1. Moisture retention of the different components of the footwear. Results are presented as mean ± SD. The abbreviations given in the legend are explained in Table 1.

Discussion

No pumping effect was observed contrary to typical heat transfer measurement of a clothing walking manikin. The absence of a pumping effect for footwear is likely caused by a lack of movement between foot and boot, facilitated by the tight fit of the footwear around the foot. Since the foot manikin allows for some internal movement, does this not providing an explanation for the lack of a pumping effect. However, footwear with a less tight fit might facilitate a pumping effect.

The results allow for the calculation of the maximum moisture vapor transmission rate (MVTR), resulting in 61.2 ± 6.6 g/m/h. Previously, perspiration rates of the foot during exercise in a warm environments have been reported to range between of 447 g/m/h and 391 g/m/h (Taylor et al., 2006; Fogarty et al., 2007); whereas perspiration rates of 88 ± 112 g/m/h have been reported after 60 min of moderate intensity walking in a neutral environment(Bogerd et al., 2011). Therefore, a MVTR of 61.2 ± 6.6 g/m/h is much less than these perspiration rates. A potentially large improvement in the parameters measured in this study can be gained by improving (i) the vapor transmission rate and/or (ii) increasing the moisture retention capacity within the footwear.

Conclusions

The present results indicate few differences in heat loss and moisture retention among different boot membranes and sock fabrics, under the measurement conditions. It is suggested that under these conditions, a pumping effect is not present. Finally, maximum moisture vapor transmission rates (MVTR) of the order of 61.2 ± 6.6 g/m/h are measured, which is far below typical sweat rates of the foot.

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