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INFLUENCE OF SOCK AND SHOE CONSTRUCTION ON TEMPERATURE AND HUMIDITY IN WORKING BOOTS

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ABSTRACT

Climatic comfort is an important factor on comfort of working boots worn for long durations. Although, climatic comfort is influenced by the boot, the sock and their interaction, there are just few studies on the interaction of wearer/foot, sock and shoe. This study characterises heat and moisture management of 25 sock-boot combinations by means of a sweating foot manikin. Furthermore, results are discussed in regards to beneficial combinations providing high thermal comfort.

KEYWORDS

socks; working boots; heat and moisture management; manikin

1. INTRODUCTION

Climatic comfort is an important parameter on shoe comfort, especially for shoes worn for long durations like working boots (Auber et al., 1983). Climatic comfort when wearing working boots is influenced by the boot itself, but also by the sock worn as well as by the interaction of foot-sock-shoe. It is defined by temperature, humidity, dampness and ventilation through the shoes as well as by the sensation of these parameters.

Knowledge on running shoes (Reinschmidt, Nigg, 2000) can be adapted into the field of working boots (Auer et al., 2008; Table 1). Working boots should not just protect from external threats, but should prevent blisters and runner's feet by dry foot climate. Furthermore, there are studies showing that thermal discomfort leads to lower mental and physiological performance (DeGroot et al., 2013, Livingstone et al., 1995) as well as to a higher injury/accident risk. Climatic comfort is part of long-term comfort and a good one leads to lower distraction (Auber et al., 1983), better performance and accident prevention during working.

Table 1: Requirements on running shoes (left; Reinschmidt, Nigg, 2000) as well as their interpretation in regards to working boots (middle) and foot climate (right) (Auer et al., 2008, Harnisch et al., 2009)

running shoe	working boot	foot climate
injury prevention	protection from external threats	damp feet lead to blisters and runner's feet (Steigleder, 1977)
performance	working performance and concentration	hints for better performance (Livingstone et al., 1995)
comfort	comfort	climatic comfort is part of

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		long term comfort(Auber et al., 1983)

Despite this importance of heat and moisture management of socks and working boots there are just few studies on the interaction of wearer/foot, sock and shoe (Reinschmidt, Nigg, 2000; Taylor et al., 2006). Actual studies focus just on one of the three parameters – foot e.g. Taylor et al. (2006), shoe e.g. Diebschlag (1971) and Schultheis et al. (2006), socks e.g. Rossi et al., (2011).

2. MATERIALS AND METHODS

Five different socks and working boots each were chosen to represent standard constructions. Socks could be divided by fibre chemistry (**Error! Not a valid bookmark self-reference.**). Working boots have been constructed with different upper materials and linings resulting in different shoe weights (**Error! Reference source not found.**). To guarantee same fit, all boots were manufactured on the same last. Overall, 25 sock-shoe combinations were characterised in regards to their heat and moisture management.

Table2: Fibre composition of socks and metatarsal thickness at metatarsus $d_{metatarsal}$

sock	S1	S2	S3	S4	S5
fibre content	PA 54%, PES 23%, CO 20%, EL 3%	PP 40%, CO 23%, PA 23% PAN 12%, EL 2%	WO 100%	WO 70%, PA 30%	CO 65%, PES 22%, PA 13%
$d_{metatarsal}$ [mm]	6.55	4.93	6.17	5.29	4.71
					

Table 2: Description of working boots

boot	B1	B2	B3	B4	B5
upper	leather	leather nubuck	woven PA	leather	leather
lining	leather	knit PES	stitch bonded PES	artificial fur WO (80%), PES (20%)	stitch bonded fabrics PES
weight [g]	669	625	607	658	653
					

Thermal insulation R_c and water vapour resistance R_e were measured using a sweating foot model by UCS, Slovenia (Babič et al., 2008). It consists of 13 segments, which can be heated separately. Data analysis was performed just for segments covered by the boots. Sweating can be simulated by 32 evenly distributed sweat glands and by peristaltic pumps. Non-covered sweat glands were inactivated.

Measurements were performed in a climatic chamber (T_a=23°C, RH_a=65% rh) and samples were acclimatized in this conditions for 8 hours. Results are shown as average and standard deviation of three measurements. Each measurement consisted of three phases. First hour was in dry state to calculate thermal insulation R_c (phase 1 – PI). Second hour was performed with 5% of pump power resulting in 24 g/h of sweat and was used to calculate water vapour resistance R_e (phase 2 – PII). Afterwards drying on the foot was simulated for another 60 minutes after stopping sweating (phase 3 – PIII). By weighing socks and boots, sweat uptake and evaporation were calculated. Weighing was performed with a lab scale (Vibra AJH 4200).

Standard formulas were used to calculate thermal resistance $R_{c,i}$ (ISO 11092) and water vapour resistance $R_{e,I}$ (ASTM 2370, non-isothermal conditions) of single segments of the foot manikin. Resistances for the whole model were calculated using the parallel model (ISO 15381). In addition, change of heating power ΔHS(PIII-PII) was calculated by subtracting heating power at the end of the sweating phase (PII) from that at the end of the test (PIII) to characterise drying of the sock-boot-system (1).

$$\Delta HS(PIII\text{-}PII)=HS(t=150\text{-}160\ min)-HS(t=110\text{-}120\ min) \quad (1)$$

ΔHS(PIII-PII) change of heating power

HS(t=110-120 min) heating power at the end of the sweating phase PII

HS(t=150-160 min) heating power at the end of the drying phase/end of the test PIII

3. Results

The following figures show the results of the R_c, R_e and the drying of the different investigated sock and boot combinations. There are small differences in regards to thermal resistance R_c (Figure 1). Comparing socks for one boot each thermal resistance differs just within measurement accuracy (Figure 1). When comparing boots with same sock each differences between combinations are bigger than measurement accuracy (Figure 1). Highest values of R_c are measured for boot B3 (textile upper, textile liner), lowest R_c for boot B1 (leather upper, leather liner).

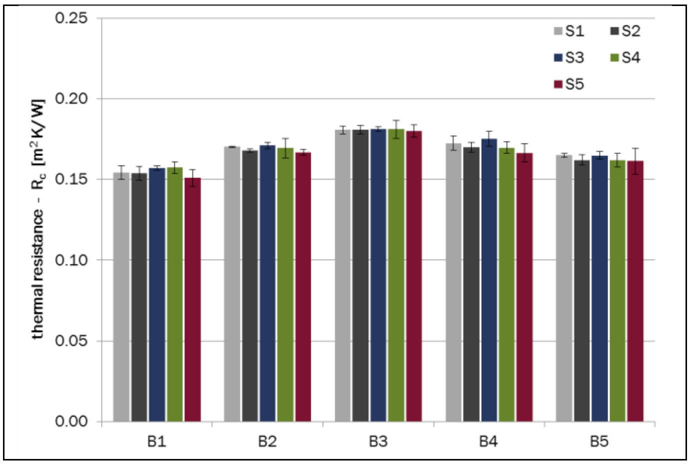


Figure 1: Thermal resistance R_c of sock and boot combinations

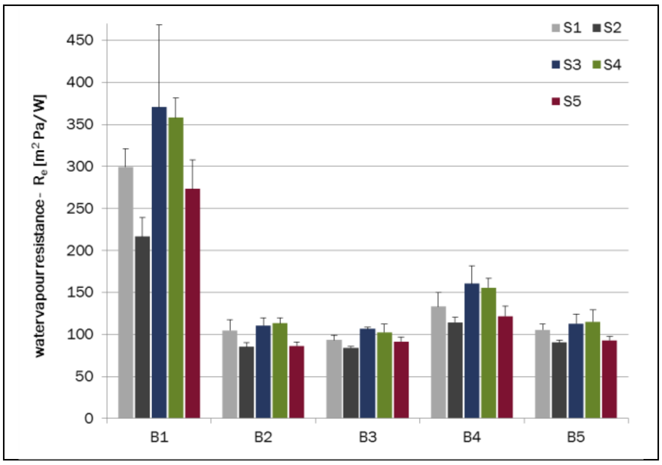


Figure 2: Water vapour resistance R_e of sock and boot combinations

In regards to water vapour resistance R_e socks and boots can be differentiated (Figure 2). Comparing socks for one boot each best/lowest values are measured for S2, highest/worst values are measured for S3 or S4 (Figure 2). Furthermore, ranking of socks is similar when socks are combined with boots. In combination with different socks low water vapour resistance R_e is measured for boots B2, B3 and B4, highest/worst values are measured for boot B1 (Figure 2).

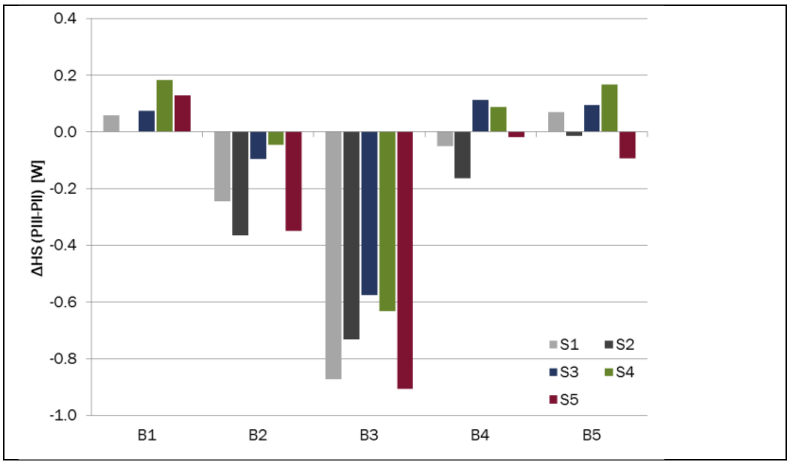
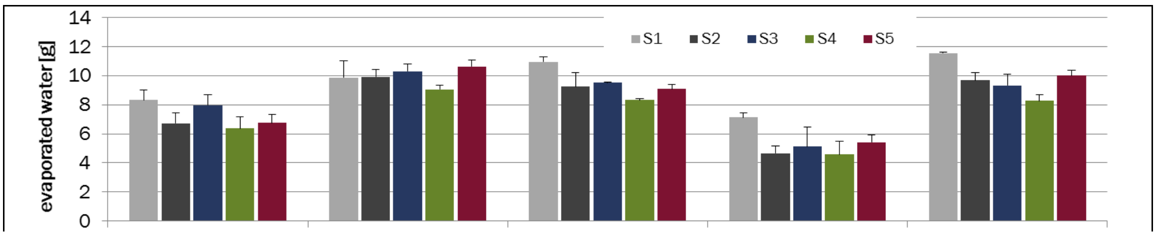


Figure 3: Change of heating power ΔHS(PIII-PII) during drying of sock and boot combinations

Drying behaviour is characterised by change of heating power (Figure 3) and sweat uptake or evaporation respectively (Figure 4Figure 4: Sweat management represented by evaporated sweat (top) as well as by water uptake of sock (middle) and boots (bottom) for different combinations). A decrease in heating power after stop of sweating means less water is evaporating due to drying. In regards to this, boot B3 and sock S2 and S5 perform best (Figure 3). On the other hand, no combination including B1 shows any decrease of heating power or drying, respectively.



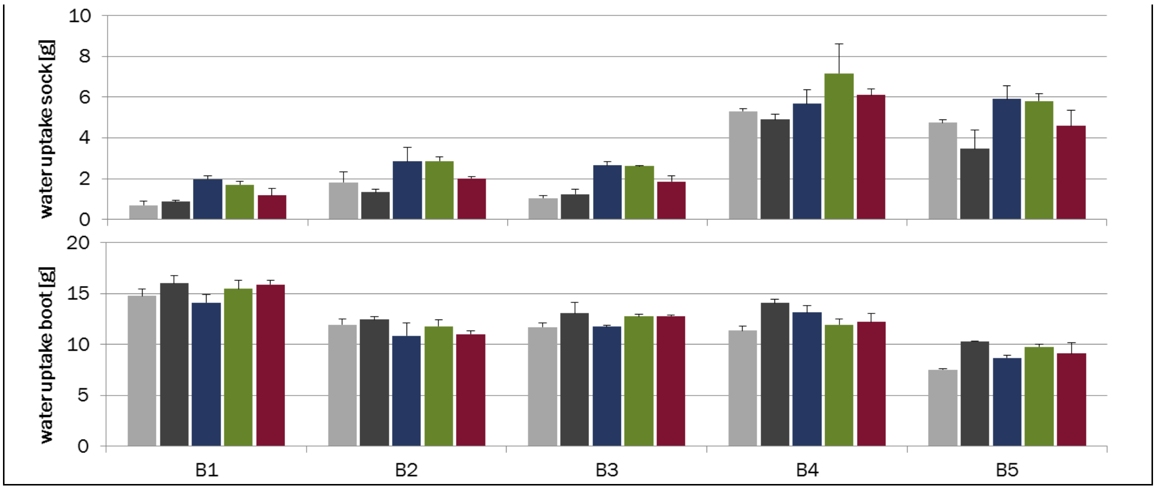


Figure 4: Sweat management represented by evaporated sweat (top) as well as by water uptake of sock (middle) and boots (bottom) for different combinations

This is proven by results of water uptake of socks and boots, too (Figure 4).

4. Discussion

The sweating foot is a suitable tool to differentiate sock-boot combinations in regards their heat and moisture management. Standard deviation of thermal resistance does not exceed 5% within all measured combinations. The more complex measurement of water vapour resistance by means of a multimode manikin is more likely to higher standard deviation, but is also not exceed 10%. Such cases with high standard deviation can be explained by a change of sample properties due to the measurement. Especially with boot B1 (leather lining) and B4 (artificial fur lining) an optical change of lining with visible.

In regards to thermal resistance, differences between boots are much bigger than between socks. Even woollen socks S3 and S4 do not provide higher thermal insulation then other socks. It can be concluded that in boots, socks are compressed due to lacing in a way, that insulating air layers in socks become minimal. Furthermore, sample B4 with an artificial fur does not provide higher thermal insulation than other boots do. Like with socks insulating air layers are compressed due to lacing.

Moisture management of sock-boot combinations is influenced by socks and boots. One could see differences between socks and boots in regards to water vapour resistance and drying. Socks containing mixtures of synthetic fibres and cotton (S1, S2, S5) show better results than those containing wool (S3, S4). Wool is absorbing sweat and prevents it from evaporation, resulting in high water vapour resistance and slow drying. With boots, lining plays an important role. Leather lining (B1) and artificial fur (WO; B4) show high water absorption, high water vapour resistance and slow drying. On the other hand boots with PES containing liner (B2, B3) or membrane (B5) show better properties. Best performance is by B3, especially due to fast drying. This is important for working boots, because the will be worn again the next day.

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REFERENCES

ASTM F2370-10 (2010). *Standard test method for measuring the evaporative resistance of clothing using a sweating manikin*.

Auber, J., Lòrànt, I. Murlasits (1983). Die Beziehung zwischen Traghygiene und Schuhwerkstruktur. *Schuh-Technik abc,* No. 8, pp. 527-531.

Auer, M., Michel, F. I., Harnisch, M., Leimer, R. (2008). Schuhklima in Sportschuhen. *Orthopädieschuhtechnik*, No. 9, pp. 18-23.

Babič, M. Lenarčič, J. Žlajpah, L., Taylor, N. A. S., Mekjavic, I. B. (2008). A Device for Simulating the Thermoregulatory Responses of the Foot: Estimation of Footwear Insulation and Evaporative Resistance. *Journal of Mechanical Engineering,* Vol. 54, No. 9, pp. 628-638.

Bogerd, C. P., Brühwiler, P. A., Rossi, R. M. (2012). Heat loss and moisture retention variations of boot membranes and sock fabrics: A foot manikin study. *International Journal of Industrial Ergonomics,* , Vol. 42, No. 2, pp. 212-218.

DeGroot, D. W., Gallimore, R. P., Thompson, S. M., Kenefick, R. W. (2013). Extremity cooling for heat stress mitigation in military and occupational settings. *Journal of Thermal Biology*, Vol. 38, No. 6, pp. 305-310.

Diebschlag, W. (1971). Klimatechnische Untersuchungen der physiologischen Zusammenhänge im Funktionssystem Fuß- Schuh unter Verwendung verschiedener Schuhschaftmaterialien. Phd-Thesis, TU – Muenchen.

Harnisch, M., Michel, F. I., Witte, K., Nguyen, T. V. A., Leimer, R. (2009). Comparison of microclimate between breathable and non-breathable shoes. *European Conference on Personal Protective Clothing*, Arnhem, The Netherlands.

ISO 11092 (2014). *Textiles - Physiological effects - Measurement of thermal and water vapour resistance under steady-state conditions (sweating guarded-hotplate test).*

ISO 15831 (2004). *Clothing – Physiological effects - Measurement of thermal insulation by means of a thermal manikin*.

Livingstone, S. D., Nolan, R. W,. Keefe, A. A. (1995). Heat loss caused by cooling the feet. *Aviation, space & environmental medicine,* Vol. 66, No. 3, pp. 232-237.

Reinschmidt, C., Nigg, B. M. (2000). Current issues in the design of running and court shoes. *Sportverletzungen und Sportschäden*, Vol. 14, No. 3, pp. 71-81.

Richter, M., Schäfer, K., Mahr-Erhardt, A., Harnisch, M., Schenk, A. (2016). *Optimierung der Feuchte- und Wärmeregulation im komplexen System Fuß-Strumpf-Schuh am Beispiel von Arbeitsschuhen*, Final Report No. IGF 17908 N, Prüf- und Forschungsinstitut Pirmasens e.V. & Hohenstein Institut für Textilinnovation gGmbH, Pirmasens.

Rossi, R. M., Stämpfli, R., Psikuta, A., Rechsteiner, I., Brühwiler, P. A. (2011). Transplanar and in-plane wicking effects in sock materials under pressure. *Textile Research Journal*, Vol. 81, No. 15, pp. 1549-1558.

Schultheis, P., Gündel, J., Bartels, V. T., Blinn, J., Picard, A. (2006). Verbesserung der tragehygienischen Eigenschaften von Arbeitsschuhen durch klimaregulatorische, materialtechnische und konstruktive Maßnahmen. Final Report No. IGF 123 Z, Prüf- und Forschungsinstitut Pirmasens e.V., Pirmasens.

Steigleder, G. K. (1977): *Therapie der Hautkrankheiten*, Thieme Verlag Stuttgart

Taylor, N. A. S., Caldwell, J. N., Mekjavic, I. B. (2006). The Sweating Foot: Local Differences in Sweat Secretion During Exercise-Induced Hyperthermia. *Aviation, Space, and Environmental Medicine*, Vol. 77, No. 10, pp. 1020-1027.