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Microclimate in ski boots – Temperature, relative humidity, and water absorption

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ABSTRACT

Ski boot quality is determined by mechanical properties and comfort. Comfort is strongly affected by cold feet. The purpose of this study was to determine the microclimate in ski boots. Climate chamber tests with five male subjects and field tests with two male subjects were conducted. Temperature and relative humidity were measured using four sensors placed on the foot and one on the liner. Absorbed water in liners and socks was measured with a precision balance. The subjects gave subjective ratings for comfort. The toe sensor temperature dropped below 20 °C at an ambient temperature of 0 °C, −10 °C, and −20 °C. Relative humidity values at the foot were as high as 78% in the climate chamber and 93% in the field. Water absorption in socks and liners ranged from 4 to 10 g in the climate chamber and 19 to 45.5 g in the field. The results reveal the importance of keeping the feet and in particular the toes warm during skiing. One possible improvement may be to construct the liner so that sweat and melted snow are kept as far away as possible from the foot. Liner material with high water absorption capacity and hydrophobic socks were suggested to prevent wet feet.

1. Introduction

Winter sports are popular. Skiing is enjoyed by approximately 200 million people in the world (Hunter, 1999). Important factors to enjoy the sport are performance and comfort of the ski boots, which act as an interface between skier and skis. Several studies focused on the mechanical properties of ski boots with respect to performance (Corazza and Cobelli, 2005; Schaff and Hauser, 1993; Schaff et al., 1997). Besides mechanical properties the quality of ski boots is determined by their comfort characteristics. Comfort of ski boots is related to the correct fit of the boot and to the microclimate in the boot. Temperature is the most critical factor for assessing thermal wear comfort (Senthilkumar and Dasaradan, 2007). Foot temperature is determined by ambient temperature, duration of the exposure to cold, level of physical activity, and moisture in the ski boot (Gavin, 2003; Rissanen and Rintamäki, 2009). Ski boots possess quite good thermal insulation properties. But moisture vapour transmission through the ski boot liner is in general hindered by laminated liner materials. Foot sweating and lack of moisture vapour transmission through the liner lead to moisture saturation inside the ski boot. The presence of condensate facilitates the conductive heat loss. Hence sweat or melted snow in the liner increase the thermal conductance and leads to insulation break downs (Fauland et al., 2011; Heus et al., 2005; Kuklane, 2009; Kuklane et al., 1999). Despite the importance of the temperature management for feeling comfortable there are no published data about the climate in ski boots during skiing. So the purpose of this study was to determine the microclimate in ski boots assessed by temperature, relative humidity, and water absorption.

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2. Method

The microclimate in the ski boot was assessed during imitated skiing in a climate chamber and during field tests.

Five male subjects (Mean ± SD: age 32.0 ± 5.3 years, body height 181.6 ± 3.6 cm, body mass 79.4 ± 9.7 kg) were exposed in the climate chamber for 1.5 h to ambient temperatures of +10 °C, 0 °C, −10 °C, and −20 °C. All subjects were in good health and were experienced skiers. Relative humidity was set to 65%. The climate chamber (Kältepol Inc., AT) allows adjusting ambient temperature (−30 to +60 °C) and relative humidity (10–90%). All tests were performed in the morning hours with intervals of at least 1 day between two measurements. Preparations for the tests took about 20 min in an ante-chamber at room temperature. Skiing respectively lift transportation was imitated by repeated 1 min 90° box squats with a loaded barbell followed by a 10 min break sitting on a chair. A metronome gave the rhythm of 40 beats per minute for the squats. Barbell and discs (Eleiko Sport Inc., SE) were loaded with 20% of body weight. The measurement started with a 10 min rest period.

Temperature and relative humidity were measured in the liner between skin and sock using four SHT15 sensors (Sensirion Inc., CH). These sensors have a thickness of 2.5 mm and a surface area of 0.37 cm^2. The four sensors were placed with FIXOMULL (BSN medical Inc., DE) at the lateral side of the metatarsophalangeal joint of the first toe (toe sensor), in the arch of the foot sole (sole sensor), on the dorsum of the foot above os cuneiforme II (dorsum sensor), and between liner and shell above the medial ankle (shell sensor). The signals were stored using a 122 g data logger fixed at the lower leg. To determine the amount of water in liner and sock a precision balance (Kern 500, Kern & Sohn Inc., DE) was used. Immediately after the test liners and socks were weighed separately. In order to prevent evaporation before weighing liner and sock were placed in a pre-weighed airtight plastic bag. The weight of liner and sock respectively was recorded before and after testing as well as after drying. From the relative humidity and temperature the absolute humidity was calculated.

The subjects were asked for subjective ratings every 20 min and at the end of the test. The subjective responses on thermal sensation (scale from +4 = very hot to −4 = very cold) and pain sensation (scale from 0 = no pain to 4 = intolerable pain) were recorded in an observation sheet (ISO 10551, 1995).

The subjects used their own skiing clothes. The clothes were chosen individual based on the ambient temperature. For the same ambient temperature the same clothes were worn. Long-legged and long-sleeved underwear, socks, ski jacket and trousers, knitted cap, gloves, and scarf were used. The subjects wore socks of the same type (Speedmachine, Nordica Inc., IT) of the following composition: 18% wool, 40% acrylic, 40% polyamide, and 2% elastane. Prior to the test the ski boots were cooled in the climate chamber at the test temperature for 45 min. The subjects put on the ski boots in the climate chamber. During the test the buckles of the ski boots stayed locked. Each subject had to perform the test twice with different ski boots (Edge+8.5 and Vector 120, Head Inc., AT).

Field tests were carried out with two male subjects (age 31 and 41 years, body height 188 and 180 cm, body mass 83 and 65 kg) on five skiing days. The subjects performed recreational skiing on all terrain without rests between 1.6 and 5.4 h per day. The sensor setup and skiing clothing ensemble were the same as during the climate chamber tests. Additionally, ambient temperature and ambient relative humidity were recorded in the middle part of the slope with a meteorological station.

Prior approval for the testing was given by the Institutional Review Board. The subjects were informed of any risks associated with participation in the tests and gave written informed consent before the testing. Testing was carried out according to the Declaration of Helsinki.

3. Results

Fig. 1 shows the mean decrease of the sensor temperature during the climate chamber tests at −20 °C ambient temperature. At the beginning of the test the temperature of the foot sensors (sole, dorsum and toe) was around 25 °C. Especially the temperature of the toe sensor dropped remarkably. After 29 min the temperature was below 20 °C. The temperature of the shell sensor decreased from 3.1 to −3.3 °C. Table A.1 summarizes the measured sensor temperature during the climate chamber tests.

Fig. 2 shows the mean relative humidity in the ski boots during the climate chamber tests at −20 °C ambient temperature corresponding to the temperature values in Fig. 1. The relative humidity increased after each box squat set. The curves show an increase of all sensors. Notable are the low dorsum sensor values in comparison to the other sensors. Table A.2 summarizes the relative and absolute humidity during the climate chamber tests.

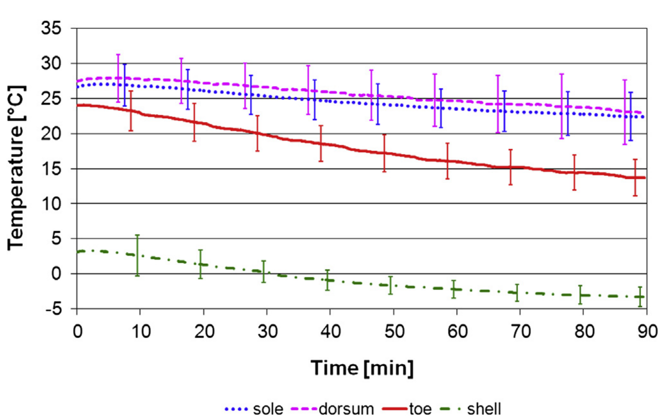

Fig. 1. Mean (±SD) foot temperature of the subjects during exposure to −20 °C in the climate chamber (for clarity SD are given at 7, 8, 9, 10 min).

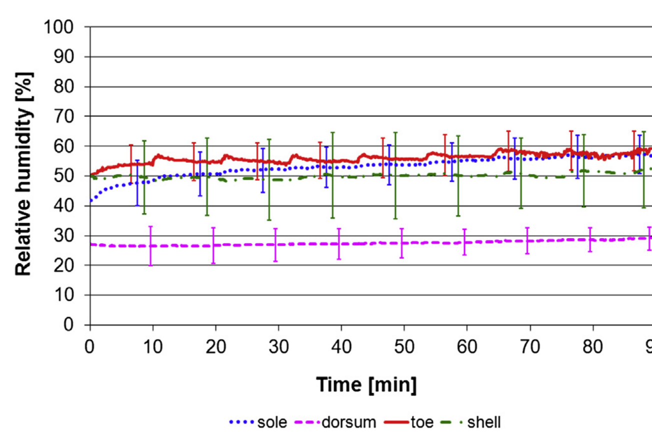

Fig. 2. Mean (±SD) relative humidity of the subjects during exposure to −20 °C in the climate chamber (for clarity SD are given at 7, 8, 9, 10 min).