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THE INFLUENCE OF SHAFT STIFFNESS ON ANKLE JOINT KINEMATICS AND KINETICS DURING WALKING IN HIKING BOOTS

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Most hiking boots are characterized by a firm construction and typically a higher shaft to protect the ankle against direct contact with the environment and ankle sprains. Little is known how variant shaft stiffness influences walking mechanics. The purpose of this study was to assess the effect of different commercially available hiking boots on ankle joint loading. Fourteen subjects were walking with and one low-shaft and four different high-shaft shoes in a gait laboratory. Ground reaction forces and lower extremity kinematics were collected to extract ankle joint angles and joint power using an inverse dynamics model. Results showed significant differences between low and high shaft all high-shaft boots with some of the latter also being different. Results indicate that the shaft construction may have substantial effects on walking economy in hiking boots.

KEY WORDS: footwear, shaft height, joint power, range of movement, tramping.

INTRODUCTION: Hiking is a popular recreational activity with health benefits while exposing hikers to injury risks (Lam et al. 2011). Ankle injuries are common in hiking, with a prevalence ranging from 5.8% (Fong et al. 2008) to 9.2% (Lam et al. 2011). Mostly lateral sprains have been reported occurring during walking on scree ground or downhill (Lam et al. 2011). A common belief is that shoes limiting ankle inversion protects against lateral ankle sprains (Böhm & Hösl 2010). High shaft shoes have been shown to limit ankle inversion (Lam et al. 2015), however epidemiological studies have failed to show a clear relationship between shaft height and ankle injury risk (Barrett et al. 1995; Lam et al. 2011). Other studies have investigated kinetics (Böhm & Hösl 2010; Cikajlo & Matjacić 2007) and lower leg muscle activity (Fu et al. 2014; Dobson et al. 2015) in shoes with different shaft height and stiffness. Fu et al. (2014) showed a difference in pre-landing muscle activity between high and low shaft shoes with lower leg muscles being activated later and to a lesser extent in high shaft shoes and interpreted this as a lack of landing preparation. Further, Böhm and Hösl (2010) showed an increased knee muscle activity, increased knee and decreased ankle joint loading in high shaft boots with a stiffer shaft. Cikajlo and Matjacić (2007) found that a softer high-shaft boot enabled more ankle joint movement and showed an increased ability of the ankle to generate power in the push-off phase while Robinson et al. (1986) found performance deterioration with increased shaft stiffness. These studies indicate that finding the optimum compromise between protection and movement restriction is yet to be found.
The aim of present study was to compare the effect of shaft height during normal and perturbed walking. It was hypothesized that high-shaft shoes would 1) decrease ankle plantar/dorsiflexion and inversion/eversion and increase knee flexion-extension 2) increase knee and decrease ankle joint power.

METHODS: Fourteen healthy male subjects (age: 23.9±1.6 years, mass: 76.0±9.1 kg, height: 178.9±7.0 cm) received information about the study and signed informed consent prior to participating. All subjects had no history of musculoskeletal injuries within the last six months and refrained from strenuous physical exercise 24 hours before the experiment.
A randomized crossover study design was employed. One low-shaft (SHOE 1: Professional GTX, ECCO) and four pairs of high-shaft shoes (SHOE 2: Biom Terrain Mid GTX, ECCO; SHOE 3: Mountain Trainer GTX, Salewa; SHOE 4: Renegade GTX, Lowa; SHOE 5: Tatra GTX, Hanwag) were compared. Walking was performed on a 10-m walkway with a robotic platform (van Doornik & Sinkjaer 2007) embedded halfway. Subjects practiced walking at a self-selected cadence to ensure consistency in trials prior to testing. During testing, a

metronome paced the self-selected walking cadence detected during familiarization. For each shoe a total of 20 trials were performed. The first five trials were baseline trials, as no perturbations occurred. Within the next 15 trials, three perturbed trials were randomly interspersed (anterolateral tilt by 12° at 100°/s). Subjects were asked to continue walking whether perturbations occurred or not. No instructions were given regarding upper body movement. Perturbations were triggered when Fz exceeded ~30 N.
An eight-camera three-dimensional motion capture system (Oqus 300, Qualisys, Gothenburg, Sweden) recorded lower extremity kinematics at 250 Hz using total of 26 retroreflective markers were used. Bilaterally, four external markers were placed on tip of the shoe, first and fifth metatarsal and on the heel 6 cm above the ground. Two external markers were attached to the high shaft shoes to represent the medial and lateral malleolus while for the low shaft shoe skin markers were placed on the medial and lateral malleolus. Three skin markers were placed on the shank, one on the tibial tuberosity, one on the fibula head and one at 50% of the midline between the fibula head and lateral malleolus. Skin markers were placed on the medial and lateral femoral epicondyle, and anterior-superior and posterior-superior iliac spine to represent the knee and hip, respectively.
Kinematic and kinetic data were low-pass filtered (15 Hz) using a 4th order zero-lag Butterworth filter. Kinematic data were analysed from the contact of the right foot on the force plate and the following left step. Dependent kinematic variables were ankle and knee range of motion (ROM), step length and width and right foot stance time during unperturbed and perturbed gait. For kinetic analysis, peak ankle and knee joint power during baseline trials were calculated using Visual 3D software (version 5.02.26, C-Motion Inc., USA).
All kinematic variables were tested for normal distribution and compared by a 2×5 repeated measures ANOVA with conditions (unperturbed/perturbed) × shoes as factors was performed. A Tukey post hoc test was performed when appropriate. Only kinetic data for baseline trials were included in this paper and were assessed for statistical significance by a Friedman test between shoes. Statistics were performed in Statistica (version 10, StatSoft Inc. Tulsa, OK). Results were significant if $P<0.05$ and are presented as mean ± standard deviation (SD) unless stated otherwise.

RESULTS: Ankle plantar-dorsiflexion ROM showed a main effect of shoes ($F(4,52)=7.93$, $P<0.01$) with a higher ROM in SHOE 1-4 compared to SHOE 5 while an interaction effect of conditions and shoes showed increased ROM for SHOE 1 and 2 compared to SHOE 5

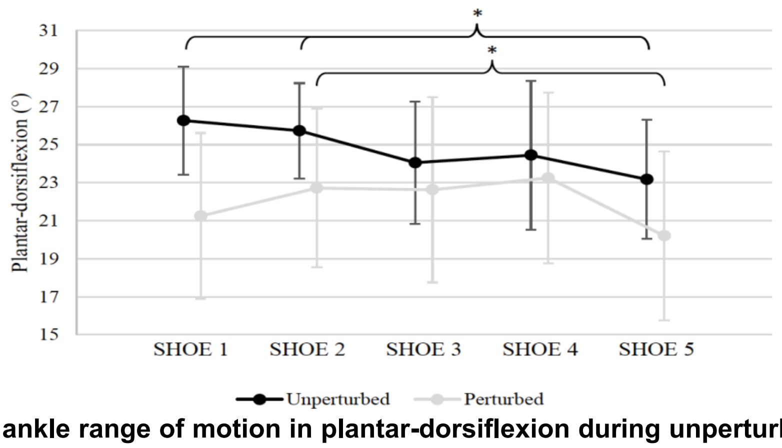

Figure 1: Mean ankle range of motion in plantar-dorsiflexion during unperturbed and perturbed walking. * denotes significant difference between shoes.

during unperturbed walking. Interestingly, ankle inversion-eversion did not differ between high and low cut shoes ($F(4,52)=2.39$, $P>0.06$) Knee joint extension-flexion ROM angle showed a main effect of shoes ($F(4, 52)=4.60$, $P<0.01$) with lower knee flexion-extension ROM for SHOE 5 compared with SHOE 1. Further, a main effect between conditions was found ($F(1, 13)=123.41$, $P<0.01$) with a smaller knee flexion-extension ROM for perturbations compared to unperturbed trials.

A main effect of peak concentric ankle joint power was found (Chi Sqr: N=14, df=4; 18.74, $P<0.01$) with lower joint power for SHOE 3-5 compared to SHOE 1 ($P<.05$). Furthermore, a main effect of peak eccentric ankle joint power was found (Chi Sqr: N=14, df=4; 12,97, $P<0.01$) with a higher eccentric joint power for SHOE 1 compared with SHOE 3. No difference in eccentric or concentric peak knee joint power was found between shoes.

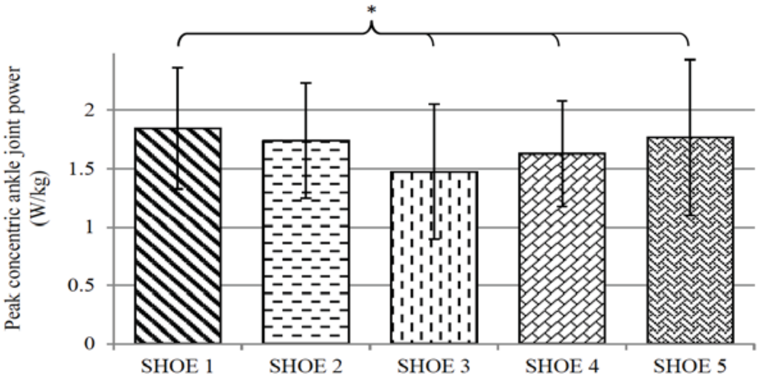

Figure 2: Peak concentric ankle joint power during unperturbed gait. * denotes significant difference between shoes.

DISCUSSION: In regard to plantar-dorsiflexion ROM, similar findings have been reported previously comparing soft and stiff-shaft boots (Böhm & Hösl 2010), similarly no differences were found in this study for inversion-eversion range of motion. It may therefore be asked if the perturbations were large enough to create a situation where the shaft becomes important. Our results in regard to ankle joint power demonstrate significant differences between the low shaft shoe and the remaining four models (Figure 2). Most importantly, the effect seems not related to general shoe hardness (results not shown) as it was not the hardest shoe which created the largest difference. Currently, our lab is designing a boot shaft flexibility test to assess the directional stiffness of hiking boots. As the presented powers are based on net joint moments it is required to include the specific boot stiffness to estimate muscle power as it may well be that the effective joint power is increased due to stiffer shaft which would affect the energy consumption during hiking.
The preliminary results from the perturbation experiments indicate that inversion and flexion joint range of motion can be varied selectively (Figure 1). This needs to be followed up by an analysis of the joint moments in the perturbed situation which is currently under way.

CONCLUSION: This study showed that different hiking boots allow for specific changes to walking biomechanics with a large potential for design optimization in regard to stability and flexibility, i.e., to improve both walking safety and economy.

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