THE EFFECT OF SHOE TYPE ON VARIOUS KINETIC AND KINEMATIC VARIABLES DURING STEP-UP AND STEP-DOWN MOTIONS

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The purpose of this study was to examine the effect of shoe type on the biomechanical responses to a stepping task. Participants (n = 8) performed six two minute stepping trials at a stepping rate of 72 bpm; 3 trials in hiking boots and 3 trials in hiking shoes. Lower limb joint angles and moments were calculated using Visual 3D. No significant differences were found in step down peak ground reaction forces (GRF), ankle, knee, and hip range of motion (ROM), joint moments, joint flexion at step down contact, or toe clearance height between footwear conditions. Due to the lack of differences found between footwear conditions, the use of either a hiking shoe or boot may not result in an increased risk of injury, therefore leaving the choice of footwear to the hiker's personal preference.

KEYWORDS: hiking, footwear, stepping.

INTRODUCTION: Hiking is a popular recreational activity that provides multiple health benefits, such as improved cardiorespiratory fitness, reduced blood pressure, and a lowered risk of heart disease (Mitten, Overholt, Haynes, D'Amore, & Ady, 2016). However, due to the physically demanding nature of the task, hiking may also increase the risk of injury among participants, with strains, sprains, and other soft tissue injuries to the knees, ankles, and feet account for about 75% of all hiking-related injuries (Lobb, 2004). Previous literature has shown that footwear choice may play a role in these lower extremity injuries (Park, Trejo, Miles, Bauer, Kim, & Stull, 2015).

Previous literature has investigated the effects of footwear on several kinematic and kinetic variables, including functional gait (Chiou, Turner, Zwiener, Weaver, & Haskell, 2012; Park et al., 2015) and joint moments of the knee and ankle (Keenan, Franz, Dicharry, Croce, & Kerrigan, 2011). Several studies have shown that wearing personal protection equipment (PPE), which includes wearing tall-shaft boots, significantly decreases firefighters' lower body range of motion (Park et al., 2015), as well as significantly reduces trailing toe clearance when stepping over an object (Chiou et al., 2012), both of which may lead to higher incidences of tripping. Literature has also shown the impact of footwear on joint moments of the lower extremities. A study by Park et al. (2015) reported that restricted lower body mobility may lead a person to apply greater ground reaction forces when walking, resulting in increased moments at the knee and hips. Additionally, Theodorakos, Rueterbories, Lung, Andersen, de Zee, and Kerstring (2016) investigated the effect of semi-rigid ankle braces on lower extremity joints during drop landings and found that when landing with braced ankles, knee and hip joint moments were not increased compared to the unbraced condition. However, it remains unclear how the load was distributed to other structures, such as ligaments and menisci.

The change in various biomechanical variables (joint angles, joint moments, joint reaction forces, ground reaction forces) as a result of footwear choice (i.e., hiking boots versus hiking shoes) has not been extensively investigated in the hiking community. However, as previously mentioned, these changes due to footwear have been extensively investigated in firefighters and military personnel and has been linked to increased injury risk, due to tripping and falling. Therefore, the purpose of this study was to examine the effect of various hiking footwear on kinetic and kinematic responses to a stepping task.

METHODS: For this study, 5 females and 3 males (n = 8; mean ± SD: age = 26 ± 5 yrs; body mass = 81.8 ± 13.1 kg; height = 175.1 ± 9.4 cm) volunteered. Inclusion criteria required the participant be between the ages of 18-39, have an absence of lower extremity pain or injury in the 6 months prior to involvement in the study, and to have previously participated in recreational outdoor hiking activities (i.e., day hiking, backpacking, thru-hiking) for at least one year. Permission to complete the study was obtained from Northern Michigan University's Institutional Review Board (Approval Number: HS18-960).

Prior to beginning testing, participants selected the shoes (hiking boot: Adidas Outdoor Terrex AX2R Mid GTX; hiking shoe: Adidas Outdoor Terrex AX2R GTX; Herzogenaurach, Germany) they wore for testing by trying on several sizes of each and choosing the best fit. Footwear weights were standardized across shoe sizes via high density lead golf tape. Participants were also issued a standard daypack (Osprey DayLite; Cortez, CO, USA), weighing 5 kg to mimic a day hiking pack. Participants completed a standardized warmup of walking on a TrackMaster treadmill (TMX428CP, Full Vision Inc., Newton, KS, USA) at a rate of 1.3 m/s and 0% grade for 5 minutes.

Following the warm-up, participants had 39 retroreflective markers placed on their pelvis and lower extremities following a modified version of the Helen Hayes marker set, consisting of a combination of clusters and single markers. Motion capture was recorded with a 10-camera Motion Analysis Corporation (MAC) system (Santa Rosa, CA, USA). Following marker placement, participants were instructed to step up and step down on a handmade wooden step (18 cm) containing 3 AMTI force platforms (Watertown, MA, USA) at a rate of 72 steps per minute for a total of two minutes, equating to one trial. A metronome (Model XB-700, Haven, CT, USA) was used for participants to maintain the step rate, with a step-up motion occurring on one beat and a step-down motion occurring on the following beat. Each participant completed 3 step-up/step-down trials, lasting 2 minutes each, in hiking shoes and hiking boots, for a total of 6 trials, with 5 minutes of rest between each trial.

The last 10 steps of the third trial in hiking shoes and hiking boots were used for analysis. Kinematic and kinetic data were filtered using a low pass, Butterworth filter with a cut-off frequency of 5.5 Hz (Winter, 1987). Lower limb kinematic and kinetic variables were calculated using a conventional gait model with a CODA pelvis in Visual 3D (v. 4.0, C-Motion, Inc., Germantown, MD, USA), with standard gait events identified. The swing and stance phases of each stepping cycle were defined as the stance phase occurring when the lead leg maintained contact with the step and the swing phase occurring when the trail leg was brought over the step. The lowering phase of the step was defined as the swing leg passed the stance leg on the step until contact with the bottom force plate. Supplemental schematics further explaining these phases can be found here. Peak joint moments during the lowering phase of the step, peak ground reaction forces (GRF) after contact on the step down, and toe clearance height of the stance (lead) and swing (trail) leg were measured and analysed. Additionally, ankle, knee, and hip flexion at contact on the step down and ankle, knee, and hip range of motion (ROM) during swing and stance phases were analysed. All variables were analysed separately using MATLAB (v. R2018a, MathWorks, Natick, MA, USA). Peak GRF were normalized to percentage of participant body weight (BW) plus weight of the day pack. Differences between footwear were analysed through IBM© SPSS (v. 25, IBM, NY, USA) using paired t-tests. Significance level was set at $p < 0.05$. Cohen's d_z effect sizes were used to determine magnitude of differences between conditions. Hopkins' (2000) scale for effect size classification was used to interpret effect size: trivial = < 0.04, small = 0.041-0.249, medium = 0.25-0.549, large = 0.55-0.799, and very large = > 0.8.

RESULTS: Tables 1-3 report various biomechanical variables measured during the stepping task in hiking shoes and hiking boots. No significant differences were found in peak GRF, joint ROM in swing or stance phase, joint moments, joint flexion at contact, or toe clearance height of the lead and trail leg. Data are presented as mean ± standard deviation. Variables that tended to decrease between conditions are bolded.

Table 1: Kinematic variables of the swing leg in hiking shoes and hiking boots (n = 8).

Measured Variable	Hiking Shoes	Hiking Boots	P-value	Cohen's d_z
Ankle ROM (deg)	38.88 ± 6.39	36.84 ± 7.62	0.10	0.29
Knee ROM (deg)	74.89 ± 4.52	75.32 ± 3.81	0.76	0.10
Hip ROM (deg)	44.83 ± 4.44	45.42 ± 4.18	0.58	0.14
Ankle Flexion at Contact (deg)	-6.20 ± 5.46	-5.91 ± 4.80	0.81	0.06

Knee Flexion at Contact (deg)	16.05 ± 7.92	14.73 ± 9.36	0.41	0.15
Hip Flexion at Contact (deg)	-16.69 ± 12.78	-15.61 ± 16.18	0.59	0.07

Table 2: Kinematic variables of the stance leg and lead and trail toe clearance in hiking shoes and hiking boots (n = 8).

Measured Variable	Hiking Shoes	Hiking Boots	P-value	Cohen's d_z
Ankle ROM (deg)	**31.28 ± 8.14**	**28.53 ± 8.08**	**0.08**	**0.34**
Knee ROM (deg)	61.53 ± 5.96	60.13 ± 5.73	0.30	0.24
Hip ROM (deg)	9.42 ± 2.97	9.10 ± 2.14	0.60	0.13
Ankle Flexion at Contact (deg)	-26.04 ± 10.07	-23.76 ± 9.03	0.10	0.24
Knee Flexion at Contact (deg)	75.54 ± 3.96	75.00 ± 4.02	0.71	0.14
Hip Flexion at Contact (deg)	-14.91 ± 10.06	-14.81 ± 13.01	0.96	0.01
Toe Clearance - Lead (cm)	12.45 ± 2.96	13.02 ± 3.21	0.27	0.18
Toe Clearance - Trail (cm)	12.73 ± 1.66	12.69 ± 1.78	0.91	0.02

Table 3: Kinetic variables measured in hiking shoes and hiking boots (n = 8).

Measured Variable	Hiking Shoes	Hiking Boots	P-value	Cohen's d_z
Peak GRF (%BW + pack weight)	**137.89 ± 7.71**	**133.88 ± 9.10**	**0.06**	**0.48**
Ankle Plantarflexion Moment Lowering - Stance (Nm•kg^{-1})	-0.08 ± 0.12	-0.18 ± 0.41	0.45	0.38
Ankle Dorsiflexion Moment Lowering - Stance (Nm•kg^{-1})	**1.47 ± 0.40**	**1.28 ± 0.56**	**0.08**	**0.40**
Knee Flexion Moment Lowering - Stance (Nm•kg^{-1})	4.62 ± 0.52	4.44 ± 0.57	0.27	0.33
Ankle Dorsiflexion Moment Lowering - Swing (Nm•kg^{-1})	-1.15 ± 0.20	-1.08 ± 0.20	0.50	0.35
Knee Extension Moment Lowering - Swing (Nm•kg^{-1})	-0.28 ± 0.18	-0.25 ± 0.11	0.63	-0.21
Knee Flexion Moment Lowering - Swing (Nm•kg^{-1})	0.52 ± 0.40	0.47 ± 0.37	0.54	0.13

DISCUSSION: The aim of the current study was to examine the effects of hiking footwear on the biomechanical responses to a stepping task. No significant differences were found between hiking shoes and hiking boots in joint ROM, joint flexion at contact, toe clearance height, peak GRF, or ankle and knee moments (Tables 1-3). The boot shaft height used in the current study was smaller than used in previous studies (mid-shaft vs. tall-shaft), which may explain the similarity in kinetic and kinematic variables between hiking boots and hiking shoes. Peak GRF tended to decrease with hiking boots compared to hiking shoes, though no significant differences were found ($p = 0.06$, $d = 0.48$; Table 1). This finding is consistent with previous research that has examined the effects of ankle bracing on GRF and during jump landing tasks. Theodorakos et al. (2016) investigated the effects of a braced ankle on knee and hip mechanics during landing on inclined surfaces and reported that no significant differences were observed in peak GRF between braced and unbraced conditions. Additionally, the authors found no significant differences in knee moments between braced and unbraced conditions, attributing the findings to high inter-individual variability and load distribution during landing (Theodorakos et al., 2016). These findings are similar to the current study, where no significant differences in ankle and knee moments were found between footwear and may be a result of high inter-individual variability during the lowering phase of the step down, as evident by the relatively large standard deviations of joint flexion at contact in the swing and stance leg and joint moments of the lowering phase. DiStefano, Padua, Brown, and Guskiewicz (2008) reported similar results in regards to GRF, with peak GRF not affected by ankle bracing during a jump landing. The authors of both studies attributed these findings to the compensatory mechanism of the lower extremities at contact to account for lack of ankle ROM (i.e., increased knee flexion), as well as the characteristics of the ankle brace (DiStefano et al., 2008, Theodorakos et al., 2016). In the current study, the mechanism behind differences in peak GRF is unclear due to the lack of change in knee and hip flexion at initial contact at the step down.

Ankle ROM during both the swing and stance phase tended to decrease in hiking boots compared to hiking shoes ($P = 0.10, 0.08$, $d = 0.29, 0.34$, respectively; Tables 1 and 2). The ankle ROM observed in the current study during the hiking shoe and hiking boot conditions were similar to those found during the running shoe condition by Park et al. (2015). Park et al. (2015) reported significant differences in ankle ROM between the running shoe and rubber boot conditions, noting that this reduction in ankle ROM may also be attributed to material of the shaft the boot. The shaft of the boots used in the current study were a mesh material with synthetic overlays, however, had a different boot type been used (i.e., rubber), significant reductions in ankle ROM may have been seen (Park et al., 2015). However, as previously mentioned, significant reductions may not have been seen due to the height of the shaft of the footwear used in the current study, which was a smaller height than used in past research (Park et al., 2015).

Additionally, a reduction in ankle ROM could potentially lead to an increased risk of stumbling due to the limited dorsi- and plantar-flexion necessary to step over obstacles (Park et al., 2015), with the magnitude of the restriction dependent upon shaft height. Chiou et al. (2012) investigated the effects of various types of footwear on lead and trail toe clearance height and found no differences between lead toe clearance height during the low obstacle condition (15 cm). However, significant differences were found during the high obstacle condition (30 cm), with trailing toe clearance decreasing as boot weight increased (Chiou et al., 2012). The lack of change in toe clearance height of both the lead and trail leg in the current study may be a result of similarities in ankle ROM in the stance and swing leg. In the current study, differences in ankle ROM and toe clearance height may have been observed if a taller boot shaft height or a step height been used, respectively.

Ankle bracing has been hypothesized to cause detrimental effects to ankle musculature when used over an extended period of time (DiStefano et al., 2008). However, due to the similarities found in kinetics and kinematics between hiking boots and hiking shoes in the current study, it can be proposed that use of mid-shaft hiking boots may not affect the integrity of the ankle joint during outdoor activities that may involve stepping. Additionally, use of either shoe or boot may not result in an increased risk of injury, therefore leaving the choice of footwear up to the hiker’s personal preference. Differences in biomechanical variables may have been seen with a taller boot shaft height or a higher step height.

CONCLUSION: In conclusion, no significant differences were found between hiking shoes and hiking boots in peak GRF, ankle, knee, and hip ROM, ankle and knee moments, and toe clearance during a stepping task. Use of either a hiking shoe or a hiking boot may not result in an increased risk of injury during these tasks, therefore leaving the choice of footwear up to the hiker’s personal preference.

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