



## Effects of a corrective heel lift with an orthopaedic walking boot on joint mechanics and symmetry during gait

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### ARTICLE INFO

**Keywords:**  
Rehabilitation  
Gait  
Biomechanics  
Orthopedics  
Brace

### ABSTRACT

**Background:** Orthopaedic walking boots are commonly prescribed following injury and surgery. The boot creates a leg length discrepancy which is thought to affect limb symmetry and gait mechanics. This study aimed to examine the effects of a corrective heel lift for the contralateral limb on the mechanics and symmetry of walking with an orthopaedic walking boot. **Research question:** Does a corrective heel lift reduce biomechanical alterations and asymmetries caused by an orthopaedic boot during gait?

**Methods:** Healthy males ( $n = 17$ ) walked with normal shoes (*Shod*), an orthopaedic boot (*Boot*), and a corrective heel lift on the contralateral limb to the boot (*Lift*). A 10-camera motion capture system (Vicon, 100Hz) and four force platforms (AMTI, 1000 Hz) recorded lower extremity biomechanics. Pairwise statistics tested for differences in hip and knee kinematics and kinetics, and a symmetry index quantified limb symmetry.

**Findings:** The *Boot* affected the sagittal and frontal plane hip mechanics and transverse plane knee mechanics ( $p < 0.05$ ), and increased the asymmetry compared to the *Shod* condition. The *Lift* improved the symmetry of some measures but increased the frontal plane hip asymmetry compared to the *Boot*. However, introducing the *Lift* did not change all kinematic variables affected by the boot.

**Significance:** The *Lift* reduced some of the asymmetries introduced by the *Boot*, but also introduced new asymmetry in the hip frontal plane motion. The leg length discrepancy caused by the boot is probably not the only cause of altered gait mechanics. Prescribing a heel lift to a patient with an orthopaedic walking boot should be based on the individual patient's needs.

### 1. Introduction

Orthopaedic boots are often used for stabilization after orthopaedic injuries or surgical interventions of the foot and ankle in place of a fiberglass cast [1,2]. These boots have been shown to have similar outcomes as fiberglass casts after one year, and have improved early range of motion (ROM) and increased comfort [3]. However, an orthopaedic boot elevates one foot and thus creates an artificial leg length discrepancy (LLD) [1]. LLDs have previously been shown to cause gait asymmetries [4], which in turn may lead to musculoskeletal problems of the back and lower limbs [5]. Although some degree of asymmetry is normal during gait [6], it is possible that the LLD amplifies the asymmetries and contributes to abnormal loading or injury [5]. It is therefore important to understand the biomechanical effects of walking boots when considering them as treatment for different injuries and

pathologies.

Walking boots have been reported to affect gait mechanics with differences in joint excursions and joint moments at the hip and knee in both limbs when wearing a walking boot on one foot [1,7,8]. One reason for these alterations is believed to be the artificial LLD created by the boot [2]. Although the literature agrees that LLDs causes asymmetrical mechanics, there are disagreements with regards to the amount of discrepancy required to cause problems and whether the long or short limb are affected most [5,9,10]. One study examined the effects introducing a heel lift on the contralateral limb to reduce the LLD on ground reaction forces (GRFs) during gait [2]. However, the authors concluded that the lift failed to return the GRFs to those seen during walking in normal shoes. However, the study did not report on joint mechanics or asymmetry, so the effect of the heel lift on those variables remain unknown.

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Altered lower extremity mechanics caused by a walking boot likely affects the degree of limb symmetry. Mechanical asymmetry during gait has been associated with chronic joint pain and the development of osteoarthritis [11]. However, the literature on the effects of a walking boot on gait symmetry is limited, and it is unknown whether introducing a contralateral heel lift can reduce any asymmetry introduced by the boot. A symmetry index (SI) is often used to quantify the degree of symmetry during gait, however, the most evident limitations with the traditional method [12] is that it only quantifies the symmetry at discrete time points and does not consider any potential time shifts between the limbs [6]. Therefore, Nigg et al. [6] developed an SI equation that addresses these limitations and is suitable for analyzing time series data such as joint mechanics during the gait cycle. Some asymmetry is considered normal in healthy locomotion [6,13], and although it is likely that the walking boot affects the symmetry, this has not yet been addressed in research. Further, it is also unknown if a heel lift worn on the contralateral limb reduces the LLD and asymmetries caused by the boot during gait.

This study aims to (1) assess biomechanical differences between walking in normal shoes, with an orthopaedic walking boot and a normal shoe, and with a walking boot and a shoe with an inserted heel lift, and (2) to quantify the degree of asymmetry in the lower extremity joint motions between the three conditions. We hypothesize that kinematics, kinetics, and levels of asymmetry will differ between conditions, and that the heel lift will reduce the negative effects of the boot.

## 2. Methods

### 2.1. Participants

An *a priori* power analysis (G\*Power 3.1) [14] showed that 17 participants would be sufficient to detect  $3 \pm 1.5^\circ$  differences in joint angles between the three conditions with 80% power, assuming a Wilcoxon signed-rank test with significance level of 0.05. Thus, 17 healthy individuals ( $25.1 \pm 4.3$  yrs.,  $1.81 \pm 0.07$  m,  $80.5 \pm 19.7$  kg, all male, all right-foot dominant) participated in this study. Written informed consent was obtained from each participant prior to testing according to the approval from the Institutional Review Board. All participants were free from orthopaedic injuries at the time of testing and were without previous lower extremity surgeries.

### 2.2. Procedure

The participants were equipped with 40 retroreflective markers allocated to specific anatomical landmarks according to the full body Plug-In Gait model [15]. All kinematic data was collected using a ten-camera motion capture system (Vicon, Oxford, UK) operating at 100 Hz, and kinetic data was recorded using force platforms (AMTI, Watertown, MA, USA) operating at 1000 Hz.

The participants were asked to walk across the capture space at their self-selected speed under three different conditions: (1) shod in their own athletic shoes [*Shod*], (2) equipped with an orthopaedic walking boot (Aircast, BetterBraces, Canada, 1.59 kg, heel elevation 35mm, Fig. 1) on one leg and their own athletic shoe on the other [*Boot*], and (3) equipped with the boot on one leg and the same athletic shoe with a heel lift on the contralateral foot [*Lift*]. A custom-made corrective heel lift was designed out of felt to match the 35 mm elevation created by the walking boot. A static trial was recorded for each of the walking conditions [1], and the order of the conditions was randomized. The boot was allocated randomly to the right or left foot of each participant (R=9; L=8). Three gait trials with clean force-plate foot-strikes were collected for each participant per condition.

### 2.3. Data analysis

The kinematic and kinetic data was imported into Visual3D (C-



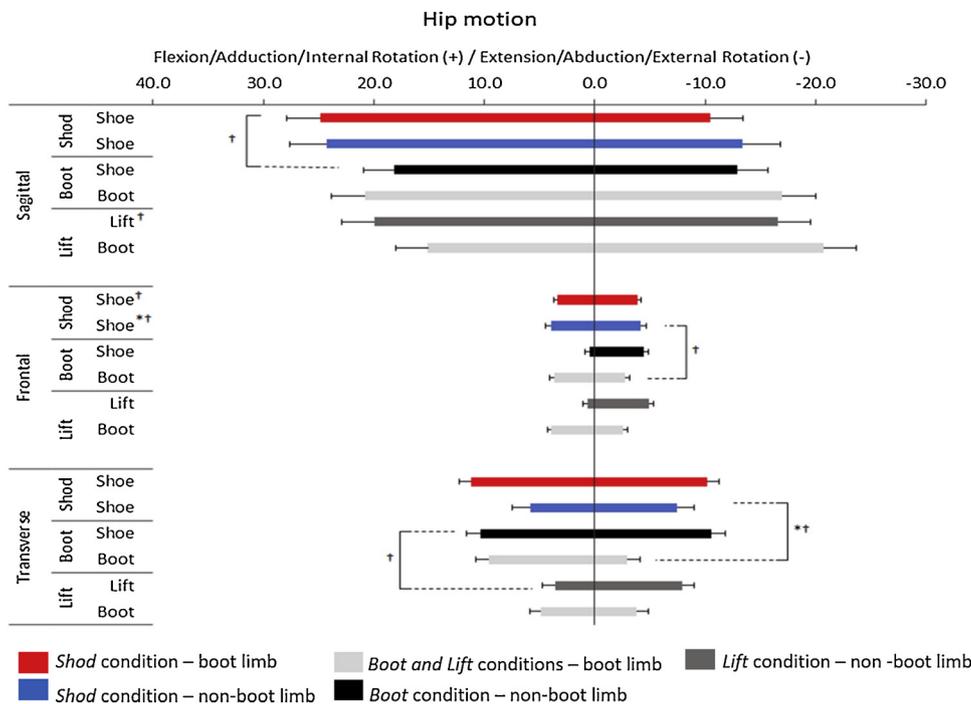
Fig. 1. The orthopaedic boot used for the study with reflective markers attached (Aircast, BetterBraces, Canada).

motion, Germantown, MD, USA), and was filtered using 2 Hz and 4 Hz low-pass Butterworth filters respectively, based on residual analyses [16]. All angles were determined to comply with traditional Cardan coordinate systems where flexion, adduction and internal rotation are considered as positive rotations [17].

The SI method developed by Nigg et al. [6] was used to quantify the symmetry of the hip and knee angles in the sagittal and frontal planes during the stance phase of the gait cycle. Mean and standard deviations for peak joint moments, peak displacement angles and overall joint ROM for the hips and knees over one full gait cycle were compared between conditions using paired statistics. The allocated boot side and walking speed were tested for covariance, and normality was assessed with a Shapiro-Wilkes test. Where appropriate, a Wilcoxon test determined significant differences between the variables, and elsewhere, repeated measures analysis of covariance (ANCOVA) was used to compare the three conditions. Cohen's D was calculated to indicate effect size (D) and was categorized according to standard conventions where  $< 0.5 = \textit{small}$ ,  $0.5-0.8 = \textit{moderate}$  and  $> 0.8 = \textit{large}$  [18]. All statistical analyses were performed in SPSS statistical software v 23 (IBM Corp., Armonk, NY, USA) and the alpha level was set at 0.05.

## 3. Results

The self-selected walking speed changed depending on the condition ( $p < 0.001$ ) and a Post-Hoc analysis revealed that the walking boot significantly reduced the walking speed compared to both other conditions (*Boot*:  $1.17 \pm 0.03 \text{ m}\cdot\text{s}^{-1}$ , *Shod*:  $1.25 \pm 0.03 \text{ m}\cdot\text{s}^{-1}$ ,



**Fig. 2.** Hip joint motion. The overall ROM of the hip for the three conditions across the three planes of motion. Statistical symbols next to the axis label indicate a difference in the overall ROM, symbols next to the graph indicate differences in the motion in the direction of the bar. \*indicates a significant difference compared to the *Boot* condition at  $p < 0.05$ , †indicates a large effect size compared to the *Boot* condition at Cohen's  $D > 0.8$ .

$p < 0.001$ ,  $D = 2.81$ , *Lift*:  $1.22 \pm 0.04 \text{ m}\cdot\text{s}^{-1}$ ,  $p = 0.004$ ,  $D = 1.61$ ), and no difference in walking speed existed between the *Shod* and *Lift* ( $p = 0.228$ ,  $D = 0.72$ ). The displacement analysis showed that the boot caused different joint excursions at both the hip and the knee, and the introduction of the lift did not restore all these differences (Fig. 2).

The *Shod* showed a moderate increase in peak hip flexion on the non-boot side compared to the *Boot* (*Boot*:  $18.1^\circ \pm 6.1$ , *Shod*:  $24.9^\circ \pm 4.14^\circ$ , 95% CI:  $17.8\text{--}25.3^\circ$ ,  $p = 0.192$ ,  $D = 0.73$ ), and the introduction of the heel lift did increase the peak hip flexion though not significantly (*Lift*:  $19.0^\circ \pm 4.1^\circ$ , 95% CI:  $15.7\text{--}21.4^\circ$ ,  $p = 0.600$ ,  $D = 0.5$ ) (Fig. 2). The frontal plane ROM was less for both hips in the *Boot* compared to the *Shod* (*Boot*:  $2.8^\circ \pm 1.6^\circ$ , *Shod*:  $1.5^\circ \pm 0.85^\circ$ , CI:  $2.7\text{--}4.4^\circ$ ,  $p = 0.091$ ,  $D = 0.92$ ), and the introduction of the *Lift* did not restore the motion (*Lift*:  $2.5^\circ \pm 0.9^\circ$ , CI:  $1.9\text{--}3.4^\circ$ ,  $p = 0.419$ ,  $D = 0.33$ ). External hip rotation on the boot side was less in the *Boot* than in the *Shod* (*Boot*:  $2.9^\circ \pm 1.6^\circ$ , *Shod*:  $7.4^\circ \pm 1.2^\circ$ , CI:  $4.3\text{--}5.9^\circ$ ,  $p = 0.001$ ,  $D = 1.74$ ), but not compared to the *Lift* ( $3.8^\circ \pm 1.1^\circ$ , CI:  $0.8\text{--}3.9^\circ$ ,  $p = 0.877$ ,  $D = 0.18$ ).

The *Lift* reduced the amount of knee flexion on the leg with the boot compared to the *Boot* (Fig. 3) (*Boot*: mean  $22.4^\circ \pm 4.2^\circ$ , *Shod*: mean  $24.5^\circ \pm 4.6^\circ$ , CI:  $21.0\text{--}25.9^\circ$ ,  $p = 0.381$ ,  $D = 0.56$ , *Lift*:  $19.0^\circ \pm 4.1^\circ$ , CI:  $18.3\text{--}23.1^\circ$ ,  $p = 0.068$ ,  $D = 0.91$ ). Further, the leg with the boot had more internal rotation at the knee joint during the *Boot* condition compared to the *Shod* condition (*Boot*:  $7.3^\circ \pm 1.6^\circ$ , *Shod*:  $-0.5^\circ \pm 1.8^\circ$ , CI:  $0.4\text{--}4.4^\circ$ ,  $p = 0.184$ ,  $D = 0.95$ ), with no difference with the *Lift* (*Lift*:  $6.5^\circ \pm 1.4^\circ$ , CI:  $6.0\text{--}7.7^\circ$ ,  $p = 0.623$ ,  $D = 0.09$ ). Further, the *Boot* did not affect the overall transverse plane ROM compared to the *Shod* condition (*Boot*:  $12.5^\circ \pm 1.6^\circ$ , *Shod*:  $13.3^\circ \pm 1.2^\circ$ , CI:  $12.1\text{--}13.7^\circ$ ,  $p = 0.269$ ,  $D = 0.34$ ), however introducing the *Lift* reduced it (*Lift*: mean  $8.7^\circ \pm 3.8^\circ$ , CI:  $9.1\text{--}12.1^\circ$ ,  $p = 0.211$ ,  $D = 0.99$ ).

The analysis of the joint moments indicated that both the hip and knee mechanics were affected by the *Shod* versus the *Boot* (Table 1). The boot increased the peak hip flexion and abduction moments on the boot side and caused increased extension moment and reduced internal rotation moment on the non-boot side. The *Lift* reduced the elevated hip flexion and abduction moments on the boot side and reduced the hip extension moments on both limbs. At the knee, the *Boot* caused increased flexion and extension moments on the boot side and increased the external rotation moment on the leg without the boot. The *Lift* only

minimally effected the knee kinetics, as it increased the internal rotation moment.

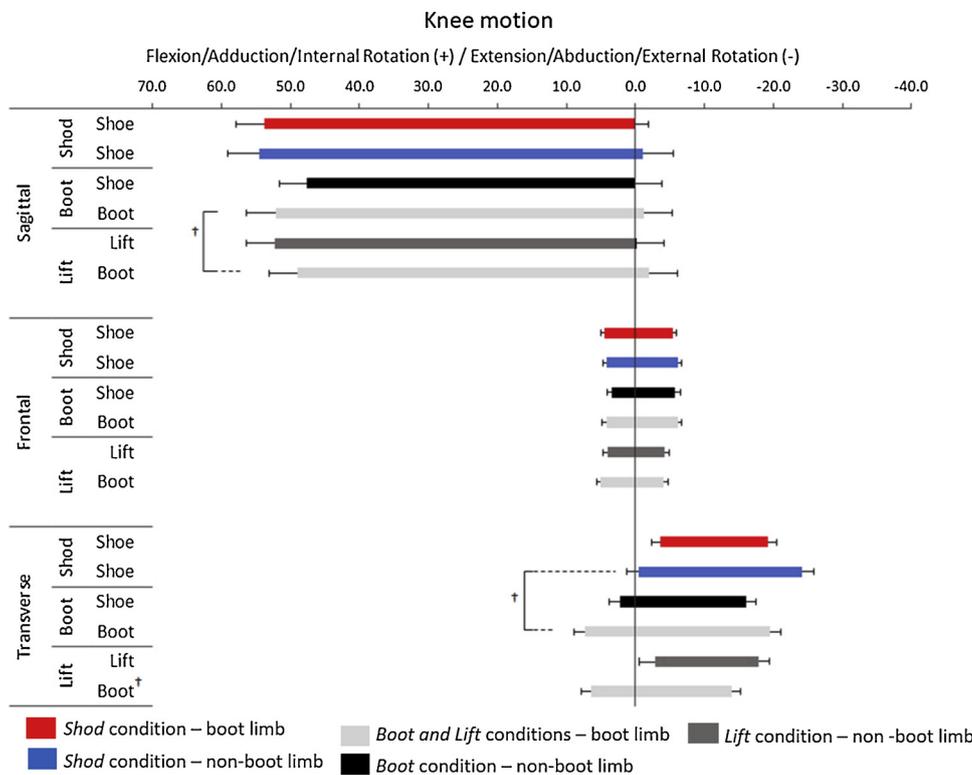
The SI analysis showed that the *Boot* had lower values for the hip, and higher values for the knee than the other conditions (Fig. 4). The *Lift* produced symmetry values more similar to the *Shod* condition in both the hip and the knee. However, the SI score of the frontal plane hip asymmetry increased beyond what was seen during the *Shod* condition. There were no statistically significant differences in the SI scores between the conditions due to the high variability ( $p > 0.05$ ).

#### 4. Discussion

We sought to evaluate the kinematic, kinetic, and symmetrical impacts of walking shod, with an orthopaedic boot on one leg and a shoe on the other, and with a boot on one leg and a corrective heel lift in the shoe of the contralateral limb. Key findings from this study were that introducing an orthopaedic walking boot changed the kinematics, kinetics and limb asymmetry at both the hip and knee joints (*Boot* condition). Further, although the corrective heel lift reduced some of the differences (*Lift* condition), it did not restore the gait mechanics observed during normal shod gait (*Shod* condition).

The literature on biomechanical implications of an orthopaedic walking boot is scarce, and most of the literature on this topic is limited to the gait of the leg wearing the boot [19,20]. Although Gulgin et al. reported bilateral data [1], they did not examine symmetry between the limbs and did not examine the effects of an added heel lift. Our kinematic analysis agreed with the previous research that wearing a walking boot has significant negative effects on the kinematics of the hip and knee [1,7,19]. In agreement with our results, many of the differences in joint mechanics have small absolute differences (less than  $5.0^\circ$ ) [1,7], so the clinical relevance of such small differences should be considered. Importantly, our study showed that the introduction of a corrective heel lift to reverse LLD did not completely restore the kinematics to those seen during normal shod gait (*Shod* condition).

The changes seen in our kinetic analysis during the *Shod* condition versus the *Boot* condition did not support the findings reported by Gulgin et al. [1], as we observed increased extensor moments on the boot limb. However, our analysis support earlier reports that the *Boot* condition caused differences in knee moments compared to the *Shod*



**Fig. 3.** Knee joint motion. The overall ROM of the knee for the three conditions across the three planes of motion. Statistical symbols next to the axis label indicate a difference in the overall ROM, symbols next to the graph indicate differences in the motion in the direction of the bar. \*indicates a significant difference compared to the *Boot* condition at  $p < 0.05$  †indicates a large effect size compared to the *Boot* condition at Cohen's  $D > 0.8$ .

condition [1,7]. It is possible that differences in the participant populations caused the differences in observations as previous studies included both male and female participants while ours included only male.

When the *Lift* was introduced, our analysis showed that several of the moments that were altered by the *Boot*, such as hip sagittal and frontal plane moments, were returned to values that were similar to that of the *Shod* condition, but that the knee moments often remained elevated. Importantly, the knee varus moment was increased during the *Lift* condition when compared to the *Boot* condition, which should be considered by clinicians, in particular when dealing with patients with knee pathology. The limited previous research on the effects of a corrective heel lift on joint moments prevents direct comparisons and conclusions, although our results are similar to those presented by Keefer et al. [2]. The authors reported that introducing a heel lift to reduce LLDs caused by a walking boot failed to completely restore

alterations in GRFs caused by the boot, and they suggested that modifications to the walking boot design should be considered to make them more like shoes to minimize kinetic alterations. Regardless, the lingering differences should be considered by medical professionals when prescribing walking boots to individuals with injury.

The symmetry analysis showed that the *Boot* condition reduced the asymmetry compared to the *Shod* condition in the hip joints, but increased the asymmetry at the knee. Due to the high variability in the data, the differences observed did not reach significance, however, clear trends were obvious and should likely not be ignored (Fig. 4). Altered SI scores induced by the boot have not been previously reported in the literature, so their effects are not well established. Currently, many studies relating to limb symmetry have been concerned with post-injury or surgical repairs, such as total hip arthroplasties and ACL reconstruction [21,22]. Current research agrees that pathologies tend to increase the degree of asymmetry and that asymmetry is a risk factor for

**Table 1**  
Mean (SD) peak joint moments reached at the hip and knee during the three conditions.

	Boot with shoe [ <i>Boot</i> ]		Both feet shod [ <i>Shod</i> ]				Boot with lift [ <i>Lift</i> ]			
	Boot	Shoe	Shoe	95% CI	Shoe	95% CI	Boot	95% CI	Lift	95% CI
Hip Flexion (Nm·kg <sup>-1</sup> )	1.45 (0.70)	1.09 (0.33)	1.16 (0.29) <sup>c</sup>	0.96-0.57	1.09 (0.24)	0.93-1.25	1.08 (0.38) <sup>c</sup>	0.94-1.67	1.09 (0.31) <sup>c</sup>	0.91-0.42
Hip Extension (Nm·kg <sup>-1</sup> )	0.91 (0.24)	1.09 (0.24)	0.82 (0.32)	0.71-1.02	0.69 (0.17) <sup>b</sup>	0.77-1.01 <sup>a</sup>	0.67 (0.31) <sup>c</sup>	0.63-0.94	0.59 (0.24) <sup>b</sup>	0.66-1.02 <sup>a</sup>
Hip Adduction (Nm·kg <sup>-1</sup> )	1.04 (0.36)	0.27 (0.29)	0.95 (0.36)	0.74-1.25	0.46 (0.24) <sup>c</sup>	0.21-0.52 <sup>a</sup>	0.99 (0.23)	0.77-1.26	0.42 (0.19) <sup>c</sup>	0.13-0.56
Hip Abduction (Nm·kg <sup>-1</sup> )	0.43 (0.26)	0.37 (0.08)	0.28 (0.16) <sup>c</sup>	0.24-0.48	0.49 (0.41)	0.23-0.52	0.28 (0.23) <sup>c</sup>	0.22-0.50	0.38 (0.20)	0.22-0.64
Hip Internal Rotation (Nm·kg <sup>-1</sup> )	0.25 (0.14)	0.18 (0.09)	0.20 (0.20)	0.12-0.34	0.12 (0.09) <sup>c</sup>	0.11-0.22	0.25 (0.17)	0.17-0.35	0.21 (0.16)	0.12-0.27
Hip External Rotation (Nm·kg <sup>-1</sup> )	0.20 (0.13)	0.21 (0.13)	0.19 (0.09)	0.14-0.26	0.26 (0.08)	0.16-0.32	0.22 (0.16)	0.13-0.30	0.21 (0.08)	0.12-0.30
Knee Flexion (Nm·kg <sup>-1</sup> )	0.58 (0.16)	0.42 (0.17)	0.46 (0.15) <sup>c</sup>	0.44-0.61	0.48 (0.23)	0.36-0.54	0.58 (0.39)	0.42-0.73	0.50 (0.17)	0.37-0.55
Knee Extension (Nm·kg <sup>-1</sup> )	0.56 (0.15)	0.43 (0.14)	0.37 (0.13) <sup>b</sup>	0.39-0.54 <sup>a</sup>	0.32 (0.16)	0.27-0.48	0.64 (0.34)	0.45-0.74	0.46 (0.14)	0.32-0.57
Knee Varus (Nm·kg <sup>-1</sup> )	0.39 (0.12)	0.38 (0.13)	0.43 (0.14) <sup>c</sup>	0.34-0.49	0.39 (0.12)	0.33-0.45	0.53 (0.45)	0.30-0.63	0.34 (0.09)	0.29-0.43
Knee Valgus (Nm·kg <sup>-1</sup> )	0.18 (0.10)	0.20 (0.15)	0.20 (0.10)	0.13-0.25	0.14 (0.22)	0.11-0.23	0.32 (0.57)	0.08-0.43	0.18 (0.16)	0.11-0.27
Knee Internal Rotation (Nm·kg <sup>-1</sup> )	0.07 (0.03)	0.06 (0.04)	0.05 (0.03) <sup>c</sup>	0.04-0.08	0.05 (0.04)	0.04-0.07	0.08 (0.07)	0.05-0.10	0.07 (0.04) <sup>c</sup>	0.04-0.07
Knee External Rotation (Nm·kg <sup>-1</sup> )	0.13 (0.06)	0.13 (0.06)	0.11 (0.05)	0.09-0.15	0.10 (0.07) <sup>c</sup>	0.08-0.14	0.23 (0.37)	0.06-0.30	0.11 (0.05)	0.08-0.15

<sup>a</sup> Indicates a significant difference compared to *Boot* condition at  $p < 0.05$ .  
<sup>b</sup> Indicates a large effect size compared to the *Boot* condition at Cohen's  $D > 0.8$ .  
<sup>c</sup> Indicates a moderate effect size compared to the *Boot* condition at Cohen's  $D > 0.5$ .

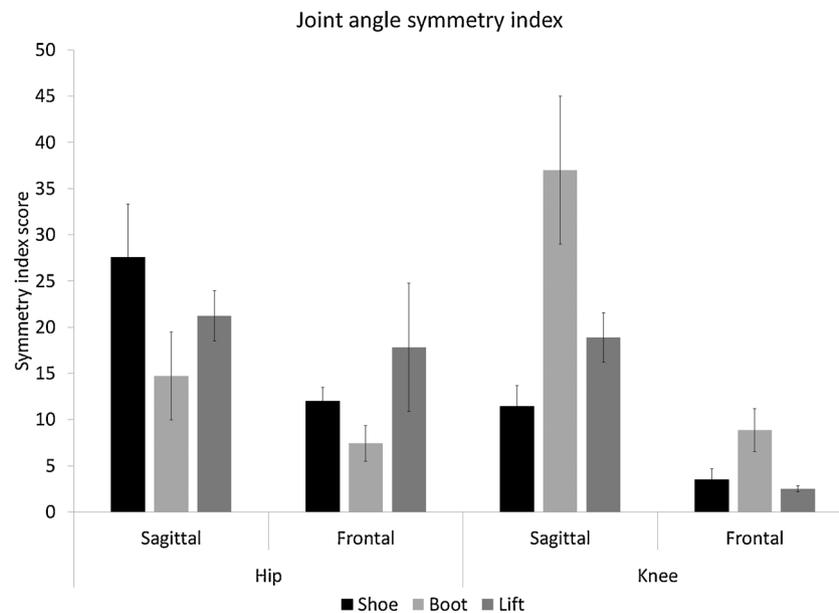


Fig. 4. Symmetry bar graphs indicating the degree of asymmetry between the limbs during the three conditions in the three planes of motion in both the hip and the knee.

injury [13,23], however, there is currently no consensus on the point at which asymmetrical movements are considered unfavorable. Despite a suggestion that an SI score of  $< 1.0$  can be considered to indicate low asymmetry [6], it has been highlighted that gait asymmetries even in healthy populations cannot be defined using a set value [24]. It must be acknowledged that several different methods exist for calculating the SI [6], and that the different methods may result in considerably different values [25]. It is therefore difficult to make direct comparisons between our data and previous research in attempts to determine if the degree of asymmetry might be disadvantageous. However, the data reported by Nigg et al. [6] is comparable to ours in magnitude, and it shows the large variability between individuals and in different movement planes. It has also been highlighted that asymmetrical movement patterns may be detrimental to rehabilitation exercises, and are predictive of poor recovery [23], which is of particular interest to those that may require an orthopaedic boot for an injury.

As expected, the *Lift* condition tended to produce SI scores more similar to the *Shod* condition in both planes at both the hips and the knees. However, the *Lift* condition also introduced increased asymmetry in the frontal plane of the hips, which were otherwise minimally affected by the *Boot* condition. The implications of this noticeable difference are currently unknown and should be the focus of further investigations. Importantly, increased frontal plane asymmetry has been associated with individuals at risk for osteoarthritis [26], although it is still unclear if the temporarily increased asymmetry due to the boot and heel lift is enough to warrant caution. Interestingly, introducing a walking boot did not compromise the frontal plane symmetry of the knees.

Alterations in sagittal plane loading of the hip have been associated with femoroacetabular impingement [27,28], so wearing a heel lift may be of particular interest to individuals with a history of impingement, or those at risk of impingement, such as those with a total hip arthroplasty. It appears that the implications of prescribing a corrective heel lift in combination with a walking boot depends on the patient. For example, in patients with previous knee pathology, where symmetry in the knees may be preferred, a corrective heel lift may be beneficial, while, if symmetry in the frontal plane hip motion is a concern, a lift may not be an appropriate choice.

The inability for a lift to correct all of a patient's gait mechanics while wearing an orthopaedic walking boot suggests there may be other

mechanisms accounting for some of the gait asymmetries in addition to LLD. One potential explanation is the weight added to only one limb because of the boot. One study reported the gait asymmetries when a weight was added unilaterally during walking [29]. It is therefore likely that some of the asymmetries and alterations in the mechanics we observed during the *Boot* condition, might have been caused by the weight of the boot. Further, in the study by Gama et al. the added weight was removed after ten minutes, yet some of the asymmetries remained [29]. This suggests that even wearing a walking boot for a short time period may have lingering effects on the mechanics, although it is not clear if this neuromuscular adaptation presents in individuals wearing walking boots.

This study is limited in that the population consisted of healthy individuals with no history of lower extremity injury. This was done as the aim of this study was to examine the effects of the three conditions (*Shod*, *Boot*, and *Lift*) on gait kinematics and limb symmetry. Future research should aim to include pathological individuals to understand how wearing a boot with and without a contralateral heel lift may affect gait in other populations. At the time of testing, the participants were not prescribed an orthopaedic boot, and only wore it during the testing occasion so there is some risk of a habitual effect. Keefer et al. suggested that prolonged wearing of the boot with and without the corrective heel lift might show clearer effects of each condition, but the authors also highlighted the difficulty in performing such research as few healthy participants would be willing to wear a boot for several days or weeks [2]. This study also only examined three trials of a single gait cycle, so the results might have differed if the analysis would have been performed on continuous gait. Finally, there is some inherent error in motion capture technology which may lead to small errors in joint motions and moment calculations.

## 5. Conclusions

The current study demonstrated that wearing an orthopaedic walking boot affects the joint mechanics and limb symmetry during gait. It also showed that introducing a corrective heel lift to the contralateral limb had positive effects on some mechanical variables but did not fully restore the gait to what was seen during *Shod* conditions. These findings suggest that factors other than LLDs may affect the gait mechanics in individuals walking with an orthopaedic boot. Future

research should take a multifactorial approach to the changes in gait introduced by a walking boot by including differently weighted boots and allowing for adaptation to walking in a boot, in addition to correcting for LLD. The findings from this study suggest that the suitability of a corrective heel lift in combination with a walking boot may depend on the patient needs and should be evaluated individually by the prescribing medical professional.

#### Author declaration

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We further confirm that any aspect of the work covered in this manuscript that has involved either experimental animals or human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

#### Declaration of Competing Interest

The authors declare no conflict of interest.

#### Acknowledgements

The authors would like to thank the HipKnee Arkansas Foundation for supporting this research with facilities and equipment. This work was supported by the National Institute of General Medical Sciences of the National Institutes of Health under Award Number P20GM125503. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

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