Gender and Foot Orthotic Device Effect on Frontal Plane Hip Motion During Landing From a Vertical Jump

Walter L. Jenkins, D.S. Williams, Brandon Bevil, Sara Stanley, Michael Blemker, Drue Taylor, and Kevin O’Brien

Excessive hip motion has been linked to lower extremity pathology. Foot orthoses are commonly used to control motion within lower extremity joints when lower extremity pathology and dysfunction are present. Few studies have investigated the effect of foot orthoses on hip angular kinematics during functional activities. Eighteen females and 18 males performed a vertical jump with and without a prefabricated foot orthoses to determine the biomechanical effect of foot orthoses on hip kinematics when landing from a jump. Data collection included three-dimensional motion analysis of the lower extremity. Paired t tests were performed to determine if differences existed within genders with and without foot orthoses. At the hip joint, there was significantly less hip adduction motion in the foot orthoses condition as compared with the no foot orthoses condition in females (p < .05). There were no differences between foot orthoses conditions in males. Females appear to have a different proximal response to foot orthoses when landing from a forward jump than males.

Keywords: kinematics, orthoses, jumping, clinical biomechanics, kinematics, sport

Foot orthoses are commonly prescribed by clinicians for treatment of lower extremity pathology and dysfunction (Eng & Pierrynowski, 1993; Finestone et al., 2004; Johanson et al., 1994; Johnston & Gross, 2004; Larsen et al., 2002; MacLean, et al., 2006; Pfeffer et al., 1999; Schwellnus et al., 1990; Simkin et al., 1989; Way, 1999). Secondary to the clinical success of foot orthoses, researchers have investigated their influence on lower extremity biomechanics during running and walking (Brown et al., 1995; Ferber, et al., 2003; Genova & Gross, 2000; Johnston & Gross, 2004; McPoil & Cornwall, 2000; Mundermann et al., 2003; Nawoczenski et al., 1995; Nester et al., 2003). When foot orthoses are used during walking and running, a decrease in lower extremity motion in the secondary planes (frontal and transverse) has been observed (McCulloch et al., 1993, Mundermann et al., 2003, Nawoczenski et al., 1995, Nester et al., 2003).

The influence of foot orthoses on jumping and landing from a jump has not been thoroughly investigated (Hertel et al., 2005; Jenkins et al., 2009; Joseph et al., 2008; Tillman et al., 2003; Yu et al., 2007). While Hertel et al. (2005) reported that foot orthotic devices had no effect on lower extremity kinematics, other investigators have reported that foot orthoses change ankle (Jenkins, et al., 2009; Tillman et al., 2003; Yu et al., 2007), knee (Joseph, et al., 2008), and hip (Jenkins et al., 2009) kinematics during jump landings.

Landing from a jump is one activity in which knee injuries occur in female athletes (Arendt & Dick, 1995; Arendt, et al., 1999, Boden, et al., 2000). Several investigators have reported changes in frontal plane hip angle between genders when landing from a jump (Ford et al.,2006; Hewett et al., 2005; Pappas et al., 2007; Schmitz et al., 2007). It has been theorized that sex differences in frontal plane hip motion is a component in the increased incidence of knee injuries in female athletes (Boden et al., 2000; Ford et al., 2006; Hewett et al., 2005; Pappas et al., 2007; Schmitz et al., 2007).

While the influence of foot orthoses on rearfoot mechanics is well documented, the effect on proximal joints is not as well described. Nester et al. observed minimal changes in hip kinematics during walking with foot orthoses (Nester et al., 2003). A more challenging activity, such as landing from a jump, has been shown to result in increased hip motion when compared with walking (Tillman et al., 2005). While the influence of foot orthoses on hip transverse plane kinematics during jump landings has been demonstrated (Jenkins et al., 2009), frontal plane hip kinematics has not. If females have greater frontal plane hip motion during jump landings than males (Ford et al.,2006; Hewett et al., 2005; Pappas et al., 2007; Schmitz, et al., 2007), and foot orthoses...
effect hip motion, then foot orthoses may decrease hip motion in females.

The purpose of this study was to determine the within and between gender differences in frontal plane hip kinematics when landing from a vertical jump with and without foot orthoses. It was hypothesized that foot orthoses will decrease hip adduction during single leg landing, in females, but not in males.

## Methods

Thirty-six healthy physical therapy students (18 females, 18 males) volunteered for this study. Subject characteristics are summarized in Table 1. Exclusion criteria consisted of current lower extremity injury, previous surgery in the lower extremity, or expressing an inability to perform the research protocol. A University Health Science Center Institutional Review Board approved this research. Each subject gave informed consent before participation in this study.

Each subject was given a pair of prefabricated foot orthoses. The Heat and Treat (35 durometer with a 4° rearfoot post; Foot Management, Inc., Pittsville, MD) foot orthoses were used in this study. In addition to the 4° rearfoot post, these devices were full length with a uniform medial longitudinal arch support. The same orthoses were used in all male and female subjects. Although these orthoses can be heat molded to each subject, the authors did not do so. Therefore, the foot orthoses were truly a prefabricated device with no customization for any subject.

All subjects were advised of and performed a standardized break-in for at least one week before participation in the study. Foot orthoses were worn 1–2 hr on the day they were given to the subject. Subjects were asked to progressively increase wear time until they could be comfortably worn for 8–10 hr. Subjects were instructed to contact the principle investigator if there were any wear or fit related issues with the foot orthoses. Once the subject had completed one week of foot orthoses wear without discomfort they were eligible for the testing protocol.

Thirty-nine reflective markers were positioned on each subject during the standing calibration to establish segmental coordinate systems for the pelvis, upper leg, lower leg and foot. Markers were placed bilaterally on the iliac crests, L5-S1 junction, greater trochanters, medial and lateral knee, medial and lateral malleoli, and medial and lateral metatarsal heads. In addition, tracking markers (at least 3 per segment) were placed bilaterally on the upper leg, lower leg and rearfoot. Before the motion trials the anatomical markers were removed leaving twenty-five reflective markers. Motion analysis was performed with a 8-camera 240 Hz Qualisys Motion Analysis System. (Qualisys International, Gothenburg, Sweden)

Three-dimensional (3-D) coordinates of each marker were reconstructed using a direct linear transformation method. Segment coordinate systems were established for the lower extremity. Each Z (vertical) axis was determined by the unit vector directed from the distal segment end to the proximal segment end. The Y axis (anterior) was determined by the unit vector that was perpendicular to both the frontal plane and the Z axis. The X axis (lateral) was determined by the application of the right hand rule. The three-dimensional coordinates were filtered using a second-order recursive Butterworth filter with a 12 Hz cutoff frequency. These data were used to calculate relative three-dimensional hip motion in an anatomical reference frame (C-motion, INC. Bethesda, MD). Based on marker placement and maximum residual error of the system, angles can be calculated with confidence greater than 0.89°. Frontal plane hip motion was defined as the femur moving on the pelvis. Positive values were defined as adduction; negative values are defined as abduction.

A standing calibration was performed for each of the orthotic conditions before all motion trials. The Vertec Measurement System (Lifestyle Sports, Dunkirk, NY) was used to determine maximum vertical jump height (Figure 1). Each subject was tested by maximally jumping off two feet, one on a force plate (AMTI, Watertown, MA), vertically with both elbows flexed to 90° and the upper arm parallel to the floor. Subjects were instructed to land from their jump on the left foot on a force plate approximately 20 inches in front of the take off point and take a step forward. During data collection subjects were required to jump 75% of their maximum vertical jump height 12 times. Seventy-five percent of the maximum vertical jump height was used during data collection to decrease the effects of fatigue. All jumps during the data collection were performed in the same fashion as the maximum vertical jump trials. Subjects were randomly assigned the order in which they were to perform the blocks of trials in each the foot orthoses conditions. Data were analyzed from initial foot contact to 0.25 s after initial contact.

Independent samples t test were performed to determine if there were any differences between groups for the subject characteristics (age, height, mass). Paired t tests were used to determine the differences between no foot orthoses and prefabricated foot orthoses conditions within genders. The SPSS version 15.0 was used for the statistical analysis. The level of significance for all tests was set at $p = .05$.

## Results

There were no significant differences between gender for age ($p = .15$). However, height ($p = .0001$), and mass ($p = .0001$) were significant different between genders (Table 1). Tables 2 and 3 summarize the female and

### Table 1 Mean (SD) of subject characteristics

<table>
<thead>
<tr>
<th></th>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>23.8 years (2.47)</td>
<td>24.6 (2.0)</td>
</tr>
<tr>
<td>Height</td>
<td>1.65 m (0.067)</td>
<td>1.81 (0.07)</td>
</tr>
<tr>
<td>Mass</td>
<td>58.83 kg (5.90)</td>
<td>84.89 (9.86)</td>
</tr>
</tbody>
</table>
male hip motion results. Females and males responded differently to the foot orthoses conditions. Males demonstrated no differences between foot orthoses conditions for hip adduction angle. However, in females there was significantly less peak hip adduction ($p < .05$) and less hip adduction excursion ($p < .05$) when wearing the foot orthoses as compared with the no foot orthoses condition (Figures 2 and 3).

Eleven of 18 women had a decrease in hip adduction excursion while 7/18 women had greater than or equal to the mean of 1.3° less hip adduction excursion with foot orthoses. Thirteen of 18 women had a decrease in peak hip adduction while 6/18 women had greater than or equal to the mean of 2.3° less peak hip adduction with foot orthoses.

**Discussion**

The results of this study demonstrated that foot orthoses reduce hip adduction during landing from a vertical jump in females, but not in males. Several investigations have reported kinematic changes in lower extremity joints during walking and running when subjects wore foot orthoses (Brown et al., 1995; Genova & Gross, 2000; Johanson et al., 1994; McPoil, & Cornwall, 2000; MacLean et al., 2006, Mundermann et al., 2003; Nawoczenski et al., 1995; Nester et al., 2003, Williams et al., 2003). However, the literature on jump landing kinematics with foot orthoses is minimal. In particular, proximal joints are less frequently observed. Subjects wearing foot orthoses have exhibited kinematic changes in the frontal plane (knee), and transverse plane (ankle and hip). Specifically, reduced knee joint valgus (knee abduction) was reported in a group of female basketball players when using foot orthoses (Joseph et al., 2008). Further, decreased tibial internal rotation (Tillman et al., 2003), and decreased hip internal rotation (Jenkins et al., 2009) have been observed when subjects landed from a jump in foot orthoses.

Several authors have suggested that an increase in hip adduction (frontal plane) is partially responsible for the increased incidence of knee injuries in female athletes.
Table 2 Females: hip adduction motion

<table>
<thead>
<tr>
<th>Type of FO Device</th>
<th>No Foot Orthoses</th>
<th>Foot Orthoses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excursion</td>
<td>11.31 degrees ± 5.17</td>
<td>9.83 degrees ± 4.12</td>
</tr>
<tr>
<td>Difference</td>
<td>1.48 degrees</td>
<td>p = 0.001</td>
</tr>
<tr>
<td>Peak</td>
<td>6.10 degrees ± 7.57</td>
<td>3.80 degrees ± 6.41</td>
</tr>
<tr>
<td>Difference</td>
<td>2.30 degrees</td>
<td>p = 0.001</td>
</tr>
</tbody>
</table>

Note. Significant in bold.

Table 3 Males: hip adduction motion

<table>
<thead>
<tr>
<th>Type of FO Device</th>
<th>No Foot Orthoses</th>
<th>Foot Orthoses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excursion</td>
<td>10.53 degrees ± 6.23</td>
<td>10.44 degrees ± 5.38</td>
</tr>
<tr>
<td>Difference</td>
<td>0.09 degrees</td>
<td>p = 0.85</td>
</tr>
<tr>
<td>Peak</td>
<td>-2.00 degrees ± 5.50</td>
<td>-2.52 degrees ± 5.37</td>
</tr>
<tr>
<td>Difference</td>
<td>-0.52</td>
<td>p = 0.52</td>
</tr>
<tr>
<td>P value</td>
<td>p = 0.001</td>
<td></td>
</tr>
</tbody>
</table>

Note. Negative values equal hip abduction.

Figure 2 — Females: hip: representative data; frontal plane motion.

Figure 3 — Males: hip: representative data; frontal plane motion.
(Boden et al., 2000; Decker et al., 2003; Earl et al., 2007; Ford et al., 2006; Hewett et al., 2005; Mascal, et al. 2003; Pappas et al., 2007; Powers et al., 1995; Schmitz et al., 2007). More specifically, it has been speculated that increased knee joint abduction (knee valgus) is a result of decreased strength in the hip joint abductors (Earl et al., 2007; Hewett et al., 2006; Mandelbaum et al., 2005). Furthermore, it has been suggested that the knee joint musculature is poorly designed to control frontal plane motion at the knee, leading to investigations of joints proximal and distal to the knee. A recent article describes that foot orthoses are able to increase muscle activity (EMG) in the hip abductor muscles (gluteus medius) during functional tasks (Hertel et al., 2005). Although we did not collect EMG activity in our study, this mechanism may be partly responsible for the decrease in hip joint adduction when our subjects wore foot orthoses.

Several authors have described that lower extremity segment and joint kinematics may be coupled (McCay & Manal, 1997; McClay & Manal, 1998; McClay & Manal, 1999; Nawoczenski et al., 1998; Williams et al., 2001). The planes of motion appear to be dependent on each other. Movement in the sagittal, frontal, and transverse planes are interdependent, and since movement of one joint is dependent on movement at other joints, an interrelationship between all planes of motion and between joints can be observed. Several authors have described females having greater hip adduction (frontal plane) and hip internal rotation (transverse plane) motion than males (Ford et al., 2006; Hewett et al., 2005; Pappas et al., 2007; Schmitz et al., 2007; Tillman et al., 2005). Previous work described reduced hip internal rotation motion with foot orthoses in females during jump landings. (Jenkins et al., 2009) Therefore since females have greater hip internal rotation and hip adduction (transverse and frontal plane) motion than males when landing from a jump, and foot orthoses may decrease hip internal rotation movement in females, it is reasonable that females also exhibit a reduction in hip adduction with a foot orthoses when landing from a jump. Further, the males in the current study remained in abduction throughout landing. This may partially explain why the orthoses had no effect in this group. If the hip remains relatively neutral or abducted, the support or balance provided by the orthoses would be unnecessary. The effect of orthoses in males who exhibit excessive hip adduction should be investigated.

In conclusion, we found that female subjects exhibited a significant decrease in hip adduction when wearing foot orthoses while males did not. Based on the results of this study, if a goal of treatment is to decrease the amount of hip adduction in females, a prefabricated foot orthoses may be one option for clinicians to consider.

Acknowledgments

The authors received custom-made and over-the-counter foot orthotic devices free of charge from Foot Management, Inc, 7201 Friendship Road, Pittsville, MD 21850. No author in this study has a financial relationship with Foot Management, Inc.

References


Earl, J.E., Monteiro, S.K., & Snyder, K.R. (2007). Differences in lower extremity kinematics between a bilateral drop-


