

## Young investigator

## Research article

# EFFECT OF ORTHOTICS AND FOOTWEAR ON STATIC REARFOOT KINEMATICS

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### ABSTRACT

This study examined the effect of foot orthotics and footwear on static rearfoot kinematics. Thirty-four subjects (5 males, 29 females) from physical therapy clinics and the college community gave informed consent to participate. Subject age was 42 (18) years; subject height was 1.7 (0.1) meters; subject body mass was 72.6 (12.1) kg. Markers were placed on specific sites of the lower leg and calcaneus to determine the rearfoot angle. Rearfoot angle was measured with a goniometer and digitized with video-based software (Ariel Performance Analysis System). A calcaneal mold was utilized to determine the position of the calcaneus in the shod conditions. Static rearfoot angles were measured in the following conditions: barefoot (B), barefoot with the calcaneal mold (BM), barefoot with the calcaneal mold plus the orthotic (BMO), shod with the calcaneal mold (SM), and shod with the calcaneal mold plus the orthotic (SMO). An independent t-test analyzed differences between each condition as measured with the APAS and goniometer. A one-way analysis of variance (ANOVA) was utilized to determine statistically significant differences among the 5 foot conditions ( $p \leq 0.05$ ). Independent t-tests revealed no significant differences ( $p > 0.05$ ) between the APAS and goniometer measurements within each condition. One-way ANOVA showed a significant difference ( $p \leq 0.01$ ) among the five conditions as measured by APAS. Post-hoc analysis determined that the difference between BM and SM; and the BM and SMO conditions were significantly different ( $p \leq 0.01$ ). It was observed that the orthotic slightly decreased the amount of calcaneal eversion in the standing position. The shoes worn in the study, though neutral in construction, did significantly alter rearfoot kinematics in comparison to BM.

**KEY WORDS:** Foot orthoses, calcaneal eversion, rearfoot motion, shoe construction.

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### INTRODUCTION

Rearfoot motion is a key component of the gait cycle. McGinnis (1999) describes rearfoot motion in the closed kinetic chain as, "The natural sequential pattern of pronation and supination during the stance phase of running; measured for research and clinical purposes in the frontal plane as the angle between the shoe and the lower leg." Pronation is a normal part of the gait cycle that aids in shock absorption

and adaptation to changing surfaces during the stance phase of the gait cycle. The motions associated with pronation include dorsiflexion of the talocrural joint, abduction of the forefoot, and eversion of the calcaneus. Abnormal pronation is quantified as maximum pronation beyond 25% of the stance phase of the gait cycle for walking (Genova and Gross, 2000). Pronation may also be abnormal if it occurs out of sequence or at the wrong time during the stance phase (Genova and Gross, 2000).

Foot orthotics are used to correct abnormal motion of the rearfoot, ankle, and lower leg during the gait cycle. Orthotics are used to restore dynamic stability and reduce the degree of excessive pronation of the subtalar joint during the stance phase of gait (McCulloch et al., 1993). McCulloch, et al. (1993) describe orthotics as "...devices (that) are designed to control the amount, rate, and temporal sequence of subtalar joint movement and restore normal biomechanical relationships in the lower extremity during stance." Nigg and coworkers (2004) listed the prescription of orthotics in order to "reduce the frequency of movement-related injuries, to align the skeleton properly, to provide improved cushioning, to improve the sensory feedback, and/or to improve comfort." A post is a type of orthotic that is placed in the rearfoot of the orthotic shell in order to "reposition the calcaneus in 'neutral' to control calcaneal eversion during the initial portion of stance phase of gait," (Genova and Gross, 2000). Orthotics, such as a wedge or post are often prescribed as a means to "control excessive subtalar and transverse tarsal joint motion during the stance phase of gait" (Nawoczenski et al., 1995).

The literature suggests that orthotic devices are effective in reducing the degree of abnormal pronation as well as clinical symptoms of the lower limb. Genova and Gross (2000) determined that the use of foot orthotics result in a significant reduction in maximum calcaneal eversion and calcaneal eversion at heel rise for subjects walking on a treadmill. This study also pointed to the fact that shoes with motion control features can also result in substantial reductions in the standing calcaneal eversion angle, and that shoe construction must be considered when prescribing and evaluating an orthotic. McCulloch and coworkers (1993) found that orthotic devices significantly changed rearfoot motion during stance phase of walking by reducing maximum pronation. There is also literature that suggests that orthotic usage has no impact on rearfoot kinematics. Williams and Davis (2003) determined that orthotics had no significant effect on rearfoot kinematics in runners. Ball and Afheldt (2000) state that despite the proposed benefits of orthotic usage, the mechanisms of cause and effect that permit orthotics to improve the client's condition are still unknown.

The calcaneal inversion/eversion component of subtalar motion is measured by using the posterior calcaneus and posterior midline of the leg as reference points. It is assumed that the neutral position ( $0^\circ$ ) is when the two posterior lines coincide (Mueller, 2005). Individuals without impairments present with  $5^\circ$  to  $10^\circ$  of calcaneal eversion and  $20^\circ$  to  $30^\circ$  of calcaneal inversion. Picciano et al. (1993)

used unilateral weight bearing stance to simulate the midstance position of gait. Also, static rearfoot weight bearing measurements are used clinically when assessing rearfoot motion (Cornwall and McPoil, 1995). Previous studies show diverse results that are difficult to reconcile because the methods and purposes of each study were slightly different (i.e. orthotic effectiveness in runners vs. walkers, effectiveness of inverted orthotics, orthotic effectiveness during stance phase, etc.). These studies open the way for more research to be done on the effectiveness of orthotics in rearfoot kinematics. Thus, the purpose of this study was to examine the effect of foot orthotics and footwear on static rearfoot kinematics. A secondary purpose was to validate manual goniometric measurements with angular measurements calculated for the Ariel Performance Analysis System.

## METHODS

### *Subjects*

Thirty-four subjects (5 males, 29 females) were recruited from area physical therapy clinics and the college community. Subject age was  $42 \pm 18$  yrs; subject height was  $1.7 \pm 0.1$  m; subject body mass was  $72.6 \pm 12.1$  kg. The subjects had worn orthotics within the last 12 months and were accustomed to wearing the orthotic on a regular basis. All subjects signed an informed consent that was approved by the Institutional Review Board at Wheaton College.

### *Instrumentation*

A JVC 9800 digital video camera operating at a speed of 60 fields per second was used to record two-dimensional shank and calcaneal position during the static trials. A calibration cube was placed within the camera field of view in order to calibrate the filming area. Sliding calipers were used to identify points of bisection of the distal leg and calcaneus. A goniometer was used to measure the rearfoot angle manually. Video digitization and data generation was completed with the Ariel Performance Analysis System software (Ariel Dynamics, Inc.).

### *Shoes*

In order to determine if the proposed change in rearfoot position is attributable to the orthotic and not to the type of shoe; each subject wore a new standardized neutrally constructed shoe (Brooks Radius®). Due to its construction characteristics the neutral shoe does not attempt to control for rearfoot motion or provide a large amount of stability to the subtalar joint.

### ***Subject preparation***

It should be noted that all manual caliper and goniometer measurements were completed by the same student investigator. She completed measurements on 25 pilot subjects before data collection began. Each subject was positioned prone with the foot and ankle to be measured extended approximately 6 inches off the examination table and the opposite lower extremity placed in a position of hip flexion, external rotation, abduction and knee flexion (Genova and Gross, 2000; Picciano et al., 1993). A distal calcaneal mark was made at the base of the calcaneus and a proximal calcaneal mark was made 3 centimeters above the distal mark. The distal leg mark was 6 centimeters above the palpated proximal margin of the calcaneus, and the proximal leg mark was placed 8 centimeters above the distal leg mark (Garbalosa, et al., 1994; Picciano et al., 1993). These marks were used as reference points for future calculated bisections of the leg. Straight edge calipers were placed at the medial and lateral calcaneus at the level of the distal calcaneal mark to measure the width of the calcaneus and then mark the distal bisection point on it. It has been shown that caliper bisections of the heel are a valid technique (LaPointe et al., 2001). With the subject standing, the distance between the subject's anterior superior iliac spines (ASIS) was measured with calipers to establish a consistent position for each subject to assume for all static standing measures. This measure was used to determine the distance between the lateral borders of the subjects' feet for the standing measures.

With the subject in the static standing position, calipers were used to establish the midpoint of the remaining 3 lower extremity marks as described by Genova (2000). At the proximal calcaneal mark, the caliper arms were placed at the medial and lateral calcaneus, 1.5cm anterior to the proximal calcaneal mark. The distal leg bisection was made by placing the medial and lateral caliper arms 1cm anterior to the distal leg mark. The proximal leg bisection was made by placing the medial and lateral caliper arms at the most medial and lateral points of the proximal leg at the level of the proximal leg mark. A line connecting the 2 leg points and a line connecting the 2 calcaneal points was drawn using a marker and straight edge. Retroreflective markers were placed on each of the 4 bisection points of the right and left leg. Each subject then stood in the static standing position for measurement of the calcaneal angle. The standing calcaneal eversion angle was measured for both legs with the goniometer as the acute angle between the leg and calcaneal bisection lines. The static standing calcaneal angle for both legs was

videod with the subject in the static standing position (see Figure 1).



**Figure 1.** Barefoot rearface angle measurement.

### ***Calcaneal mold preparation and static standing Measurements***

One of the primary limitations of studying rearfoot motion is the difficulty of measuring the movement of the foot inside of the shoe. If the calcaneal markers are placed over the heel counter of the shoe rather than the calcaneus the recorded movement is more representative of the movement of the shoe rather than the foot (Cornwall et al., 1995). A reliable method of quantifying calcaneal movement within the shoe has been devised by Polinsky (Genova and Gross, 2000). A calcaneal mold marker constructed of Orthoplast® was fashioned for each subject. The Orthoplast® was placed on the calcaneus and then extended posteriorly so that it would come out and over the heel counter of the shoe. The calcaneal mold was secured to the subject's heel with adhesive spray and tape. The previously placed calcaneal markers were transferred to the calcaneal mold (see Figure 2).



**Figure 2.** Barefoot with mold rearfoot angle measurement.

The subject then stood in the static standing position described earlier without shoes but with the calcaneal mold in place. The rearfoot angle was

measured with a goniometer and videoed for validation. Subjects then stood on their orthotics in the static standing position and the calcaneal angle was measured with the goniometer and videoed (see Figure 3). Subjects were asked to put on their shoes and assume the static standing position (see Figure 4). The calcaneal angle was measured with the goniometer and videoed for validation in the shod condition. Subjects then placed their orthotics in the shoes and stood in the static standing position while the calcaneal angle was measured with the goniometer and videoed. The entire data collection process took no longer than 10 minutes for each subject and the subject was allowed to take a break at any time. Also, the subject were not on their feet for more than 3 minutes at a time. Thus, it was felt that fatigue would not have an impact on the rearfoot angle measurements.



**Figure 3.** Orthotic rearfoot angle measurement.

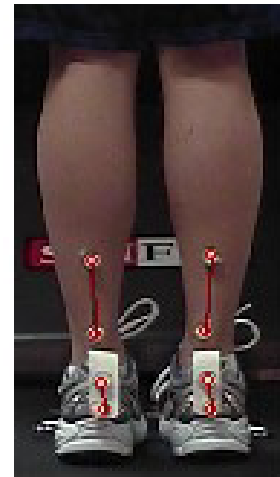
#### **Data reduction**

The Ariel Performance Analysis System was used to digitize, transform and digitally filter the position of the aforementioned markers on the two segments of both lower legs. Each of the 6 separate static standing angle measurements was digitized over 5 consecutive fields. The mean of the 5 segment angles were used for data analysis. The rearfoot angle was defined as the angle between the shank and the calcaneus. A positive angle represents calcaneal inversion, a negative angle represents calcaneal eversion, and a zero angle represents the neutral position.

#### **Data analysis**

*Static standing analysis:* An independent t-test was used to analyze differences between each condition as measured with the APAS and the goniometric measurements. A one-way analysis of variance (ANOVA) was utilized to determine statistically significant differences among the 5 foot conditions. A priori level of significance was set at  $p \leq 0.05$ . A

Tukey post-hoc test determined where the significant differences fell among the five groups. The statistical software GraphPad Prism version 4.00 for Windows, GraphPad Software, San Diego California USA, ([www.graphpad.com](http://www.graphpad.com)) was used to run the statistical analyses. The rearfoot angles for both feet of each subject were analyzed but no distinction was made between right and left feet statistically within each treatment condition.



**Figure 4.** Shod rearfoot angle measurement.

## **RESULTS**

The purpose of this study was to examine the effect of foot orthotics on standing rearfoot kinematics. The mean rearfoot angle for the barefoot (B) condition as measured by the APAS and goniometer was  $-9.4 \pm 8.5^\circ$  and  $-8.6 \pm 7.2^\circ$ , respectively. The mean rearfoot angle for the barefoot mold (BM) condition as measured by the APAS and goniometer was  $-12.4 \pm 8.2^\circ$  and  $-11.5 \pm 6.4^\circ$ , respectively. The mean rearfoot angle for the orthotic plus the mold (BMO) condition as measured by the APAS and goniometer was  $-11.0 \pm 8.7^\circ$  and  $-9.9 \pm 7.5^\circ$ , respectively. The mean rearfoot angle for the shoe with the calcaneal mold (SMO) condition as measured by the APAS and goniometer was  $-7.2 \pm 8.6^\circ$  and  $-6.4 \pm 8.0^\circ$ , respectively. The mean rearfoot angle for the shoe with the calcaneal mold plus the orthotic (SMO) condition as measured by the APAS and goniometer was  $-7.5 \pm 8.1^\circ$  and  $-8.1 \pm 7.2^\circ$ , respectively. Independent t-tests revealed no significant differences ( $p > 0.05$ ) between the APAS and goniometer measurements within each treatment condition. One-way ANOVA showed a significant difference ( $p \leq 0.01$ ) among the five conditions as measured by APAS. Post-hoc analysis determined that the difference between the BM and SM as well as the BM and SMO conditions were significantly different ( $p \leq 0.01$ , see Figure 5).

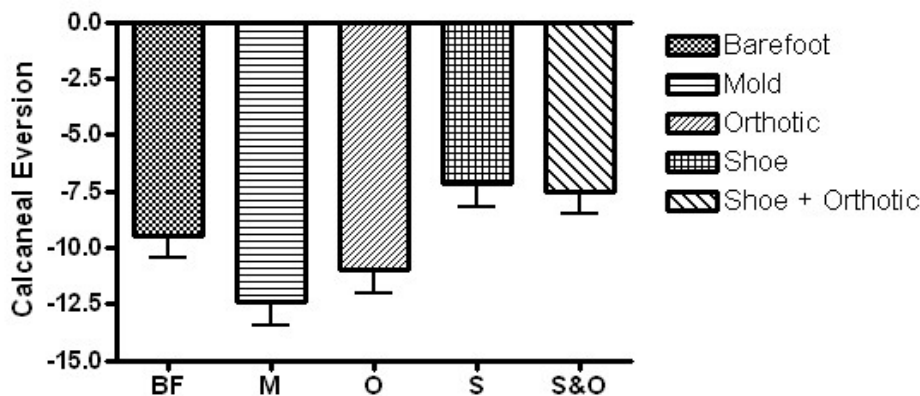


Figure 5. Rearfoot angles (deg) for each condition.

## DISCUSSION

Shoe construction and orthotics have been used to correct abnormal motion of the rearfoot during the gait cycle. Shoes and orthotics are used to restore dynamic stability and reduce the degree of excessive pronation of the subtalar joint during the stance phase of gait (McCulloch et al., 1993). Previous work has not been in agreement as to the effectiveness of shoes and orthotics in reducing excessive pronation. The present investigation analyzed the ability of shoes and orthotics to manipulate rearfoot kinematics during a static standing trial. No significant differences were noted between the measurements made by the APAS and those made manually with the goniometer, thus validating the goniometer measurements. We found no statistically significant difference between the BM and BMO conditions. However, the observed trend was that the orthotic slightly decreased the amount of calcaneal eversion in the standing position. Nigg (2004) reports that a reduction in calcaneal eversion with orthotics was significant but relatively small (2-3°).

Rearfoot angle measurements between the B and BM conditions were not statistically significant. The lack of statistical difference is encouraging that it means that our calcaneal mold placement was adequate. It is important to note that the BM condition now serves as the baseline from which we will compare the orthotic and shod conditions. However, the mold measurements did show an increase in calcaneal eversion. We were anticipating a slightly smaller difference than the reported ~3° between the barefoot and mold conditions as the mold was then used when calculating calcaneal eversion of the orthotic and two shod measurements. In examining the differences between the barefoot and the two shod conditions we showed a decrease in calcaneal eversion but not at a statistically significant level. However, there was a significant

difference between the mold and two shod conditions. This is more than likely due to the ~3° increase in calcaneal eversion from the barefoot to the mold conditions.

Although, there was only a slight, yet statistically significant, decrease in calcaneal eversion; all of the subjects replied affirmatively when asked if the orthotic made them feel better. While this was a subjective measure, there was little doubt the orthotics were essentially effective for each subject. Nigg (2004) states that comfort may be an important aspect of orthotic usage but the literature on the topic is scarce. Comfort may be related to fit, additional stabilizing muscle work, fatigue and damping of soft tissue vibrations. Undoubtedly, comfort is an integral part of proper shoe prescription and appears to also play a role in proper orthotic usage as well.

## CONCLUSIONS

It was concluded that there was a statistically significant difference across the barefoot-mold, shoe and shoe and orthotic conditions during a static standing trial. Our research concurs with the work of others on the effectiveness of foot orthoses decreasing calcaneal eversion. Although this difference was small, the subjects still gave a positive subjective rating of the effectiveness of their orthotic. Considering the many activities of daily living that take place in relatively static closed kinetic chain environments, it is encouraging to note that even small kinematic differences may be beneficial in helping individuals feel better while on their feet. Future research should focus on the role of subject perception of comfort in measuring orthotic effectiveness. Also, this perception measurement should be done using a valid assessment tool. Additional work should be completed on the effect of different types of shoe construction on static rearfoot kinematics.

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## KEY POINTS

- Previous literature concerning the effect of orthotics on lower extremity alignment is inconclusive.
- This study concurs with the work of others as to the effectiveness of orthotics on the reduction of calcaneal eversion.
- Even though the kinematic differences were small, subjects still reported a positive effect on their level of comfort with the orthotics as compared to not wearing the orthotics.

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