INTRODUCTION
The foot is the interface with the ground during gait. Therefore, differences in foot structures may result in differences in lower extremity mechanics. It is often suggested that low arch (LA) feet are flexible while high arch (HA) feet are more rigid in nature (Subotnick, 1981). Decreased flexibility at the foot is often associated with decreased overall lower extremity flexibility. This decreased compliance may result in a functionally stiffer gait pattern.

Stiffness during gait has been defined as the amount of vertical deflection of the body's center of mass for a given ground reaction force (McMahon and Cheng, 1990). Stiffness has recently been found to differ in individuals with different foot orientations during running (Viale et al, 1998). However, arch height was not characterized in this study. Running on stiffer surfaces results in greater initial peak ground reaction forces and vertical loading rates (VLR) (McMahon and Greene, 1979). It is therefore likely that a stiffer foot resulting in a stiffer gait will lead to a higher VLR. Finally, support moment (sum of the extensor moments of the hip, knee and ankle) may act to produce a stiffer landing.

Therefore, the purpose of this study was to compare lower extremity stiffness between HA and LA runners. It was hypothesized that HA runners would exhibit increased lower extremity stiffness associated with greater vertical loading rates and increased support moments.

PROCEDURES
The study included 20 HA and 20 LA with no lower extremity injury at the time of the experiment. Subjects were screened for inclusion in the HA or LA group using an arch ratio (Williams et al, in review). The arch ratio was defined as the height to the dorsum of the foot from the floor at 50% of the foot length divided by the individual’s truncated foot length. Arch ratio values fell at or outside 1.5 standard deviations of the mean DORS/TFL ratio measurement based on a sample of 102 feet. Retroreflective markers were placed unilaterally on the segments of the rearfoot, shank, thigh and pelvis. The subjects ran along a 25 m. runway at a speed of 3.35 m/s +/- 5%. Kinematic data were collected at 120 Hz using 6 camera VICON motion analysis system (Oxford Metrics Limited, UK and force data (BERTEC, Worthington, OH) were recorded at 960 Hz. Ten footstrikes were collected and averaged for each subject. The kinematic and force data were combined to calculate joint moments through inverse dynamics.

Stiffness was estimated dynamically using the mathematical model presented by McMahon and Cheng (1990). Support moment was analyzed at the time of initial peak VGRF (SMFZ), peak knee flexion angle (SMKF) and peak A-P propulsive ground reaction force (SMAP). Finally, VLR was determined by calculating the rate of rise of the heel strike transient of the vertical ground reaction force over the interval spanning 20% to 80% of this peak. Comparison between HA and LA subjects were made using a one-tailed student's t-test (p≤0.05) to determine whether
differences in stiffness existed between these groups. A backwards multiple regression was employed on support moment and loading rate variables.

**RESULTS and DISCUSSION**

**Table 1. Stiffness Characteristics**

<table>
<thead>
<tr>
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<th>HA</th>
<th>LA</th>
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<tbody>
<tr>
<td>Stiffness (N/m)</td>
<td>7.2(1.2)</td>
<td>6.5(1.0)*</td>
</tr>
<tr>
<td>Support time (s)</td>
<td>0.26(0.02)</td>
<td>0.27(0.02)*</td>
</tr>
<tr>
<td>Vert Disp (m)</td>
<td>0.07(0.01)</td>
<td>0.08(0.01)*</td>
</tr>
<tr>
<td>VLR (N/s)</td>
<td>62.5(13.6)</td>
<td>52.1(10.8)*</td>
</tr>
</tbody>
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N=Newtons, m=meters, s=seconds, *p≤0.05.

HA individuals showed no difference in support moment parameters. There was a significant relationship between loading rate and SMFZ and lower extremity stiffness (R=0.558, p=0.000). VLR and SMFZ explained 27.8% of the variance present in lower extremity stiffness (R=0.563, p=0.001).

![Knee Flexion Excursion During Stance](image)

The results of this study supported the hypothesis that HA runners exhibited greater lower extremity stiffness. Stiffness has been shown to be related to speed in the past (McMahon and Cheng, 1990). However, both groups in the current study ran at the same forward velocity. Therefore, differences in stiffness can be attributed to factors other than forward velocity. HA runners exhibited shorter contact times and less vertical displacement of the center of mass, which would account for the increased stiffness. Although decreases in joint excursions of hip flexion, knee flexion and ankle dorsiflexion could account for a decreased COM excursion, only knee flexion excursion was significantly lower (p=0.007) in the HA group by 4.2 degrees when compared to the LA group. The decrease in contact times in the HA group may be due to smaller COM and knee joint excursion resulting in a more efficient stretch-shortening cycle and a quicker return of energy (McMahon and Greene, 1979).

Loading rate was the primary predictor of lower extremity stiffness. The decreased vertical displacement of the COM combined with shorter contact times in the HA runners likely resulted in faster loading and higher lower extremity stiffness. Vertical loading rate has previously been suggested to increase the risk of stress-related injuries to the lower extremity (Radin, 1991). Therefore, HA runners may benefit from training techniques to increase COM excursion, thus decreasing vertical loading rate and lower extremity stiffness during running.

**SUMMARY**

Based on the results of this study, it appears that there is a greater lower extremity stiffness in individuals with a HA foot structure when compared to those with a LA foot structure. This difference appears to be the result of a decreased COM excursion and a decreased foot contact time. The COM excursion appears to be regulated primarily by the control of knee flexion excursion. This stiffer limb leads to a quicker loading rate, which may increase the risk of stress injuries to the lower extremity.

**REFERENCES**

McMahon and Cheng, *J. Biomech* 1990  
McMahon and Greene, *J. Biomech* 1979  
Viale et al, *Foot Ankle Int* 1998