

DOES SANDAL ARCH HEIGHT EFFECT FOOT AND ANKLE BIOMECHANICS?

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INTRODUCTION

The purpose of this study was to examine the immediate effects of sandal arch height on lower extremity biomechanics during gait. This study was part of a larger investigation of the structural properties and function of Birkenstock® footwear technologies. Each of the sandal designs studied employed a Birkenstock footbed (ie. a deep heel cup/medial longitudinal arch support). Five models of sandals were tested: Santa Cruz (SC), Iceland (IC), Arizona (AS, soft footbed), Arizona (AP, pronounced footbed), and Fulda (FU). Note that the aforementioned models shared had progressively larger arch heights. The following research question was addressed: *does sandal arch height affect foot and ankle biomechanics?*

METHODS

Data was collected on 20 subjects (mean age=27) with moderate pes planus, each wearing the five sandal models described. Through the use of specialized static test jigs the Arch Height Index (AHI) and Malleolar Valgus Index (MVI) were determined for each sandal condition following a 5-minute accommodation period. In addition, gait data (i.e. temporal/distance footfall parameters and three dimensional kinematics and kinetics) were collected for each sandal condition while each subject walked at his or her self-selected comfortable speed.

AHI is a measure of the dorsal arch height at one half of the foot length normalized by truncated foot length (i.e. heel to 1st metatarsalphalangeal joint distance). A ratio of standing to sitting AHI was formed to document each patient's arch height rigidity (Richards et. al., 2003). MVI, a measure of static hindfoot alignment, was formed by measuring the deviation between the midpoint of the ankle axis and the midpoint of the hindfoot normalized to ankle axis width (Song et. al. 1996). The GaitmatII™, a 3 meter long by half-meter wide matrix of switches whose contact closures are captured under computer control at 100 hz, was employed to measure the temporal and distance footfall parameters (e.g. step length (m), stance time (sec), and walking speed (m/sec)). A five M2 camera Vicon 460 system was used to capture the 3D coordinates of passive retro-reflective markers placed upon boney landmarks in accordance with the Helen Hayes marker system at 120Hz. The 3D kinematics were calculated by Plug-in Gait software employing an Euler angles solution. In conjunction with the Kistler forceplate (9261A) data, 3D kinetics were calculated as well. Note that only ankle angular excursions, moments and powers were included in this analysis. Gait speed was captured with a light-interrupt based timing system. Two-way mixed effect analysis of co-variance was performed, utilizing gait speed as a covariate. Post-hoc analysis consisted of the Bonferroni-Dunn test.

RESULTS AND DISCUSSION

As shown in Figure 1, MVI was lowest in the AS (8%) and greatest (ie, more pronated) in the FU (11.0%) conditions. Note that the sandals are depicted in the order of increasing arch height. This result was contrary to intuition – it was anticipated that the largest arch height would best correct for pronatory alignment. The test subjects exhibited the highest AHI while wearing the AS sandals in both sitting and standing conditions which is consistent with the MVI results. Self-selected gait speed was fastest and stance time shortest in the AS. SC was the most stable as indicated by the smallest support base. AP had

the shortest double support time. The changes in temporal and distance footfall parameters indicated that sandal arch height could affect one's gait pattern.

Although the test subjects had moderate Gastrocnemius equinus, their peak ankle dorsiflexion was $> 10^\circ$ across all sandal conditions during gait: AP had the highest (17.6°) while FU was the lowest (14.8°). Peak eversion was smallest in the FU (1.9°) and largest in the AP (2.9°). Similarly, peak external rotation was smallest in the FU (14.5°) and largest in the AP (17.6°). Note that FU also promoted the largest peak internal rotation (27.1°). Peak dorsiflexive moment was significantly smaller in the FU than all other sandal conditions while peak plantarflexion moment was largest. Peak adduction moment was largest in the larger arch height (AP, AS, FU) conditions. Peak ankle power generated was smallest in the FU and SC (*i.e. the extreme arch heights*). Sandals with increased arch height (AS, AP, FU) promoted faster walking speeds and larger peak adductory moments. AP sandals had larger peak DF, sagittal ROM, peak eversion, and peak external rotation. FU sandals had the smallest peak ankle DF, sagittal ROM, peak eversion, peak external rotation, peak DF moment, and peak PF moment, while having the largest peak internal rotation. Peak Ankle power generated was smallest for the SC and FU sandals.

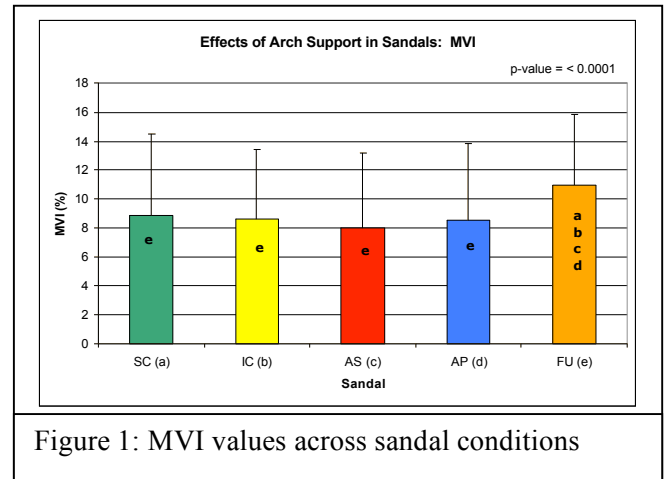


Figure 1: MVI values across sandal conditions

The AS sandal yielded the best static hindfoot alignment and arch height index, while promoting a faster walking speed and larger peak ankle power (generated) compared with most sandals. In a separate study - the greater the sandal arch height, the smaller the torsional and toe break shoe flexibility was found. Arch height can affect one's gait pattern as evidenced by the temporal and distance footfall parameters. There may be optimal shoe structural properties and arch support for optimal load distribution and ankle kinematics.

CONCLUSIONS

Sandal arch height had significant immediate effects on static hindfoot alignment, arch height index, spatial and temporal footfall parameters, and 3D kinematics and kinetics in 20 subjects with a pes planus foot type. Results suggest that there may be an optimal arch support height for this population and for a given individual. Additional studies are needed to document effects of accommodation and to optimize shoe selection criteria for specific foot type or pathologies.

REFERENCES

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