



Lower limb joint kinetics in walking: The role of industry recommended footwear

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ABSTRACT

The effects of current athletic footwear on lower extremity biomechanics are unknown. The aim of this study was to examine the changes, if any, that occur in peak lower extremity net joint moments while walking in industry recommended athletic footwear. Sixty-eight healthy young adults underwent kinetic evaluation of lower extremity extrinsic joint moments while walking barefoot and while walking in current standard athletic footwear matched to the foot mechanics of each subject while controlling for speed. A secondary analysis was performed comparing peak knee joint extrinsic moments during barefoot walking to those while walking in three different standard footwear types: stability, motion control, and cushion. 3-D motion capture data were collected in synchrony with ground reaction force data collected from an instrumented treadmill. The shod condition was associated with a 9.7% increase in the first peak knee varus moment, and increases in the hip flexion and extension moments. These increases may be largely related to a 6.5% increase in stride length with shoes associated with increases in the ground reaction forces in all three axes. The changes from barefoot walking observed in the peak knee joint moments were similar when subjects walked in all three footwear types. It is unclear to what extent these increased joint moments may be clinically relevant, or potentially adverse. Nonetheless, these differences should be considered in the recommendation as well as the design of footwear in the future.

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1. Introduction

Much remains unknown about the effects of current standard athletic footwear on lower extremity biomechanics and its potential role in development of disease and dysfunction. Footwear has been the subject of both lore and scientific research. Current standard athletic footwear in particular has been postulated to have certain benefits in human mechanics by lessening peak reaction forces or controlling certain aspects of motion [1–4]. Basic to further evaluating the effects of these shoes on the lower extremity is a better understanding of what intrasubject changes, if any, these shoes can cause during walking. While the study of joint kinetics provides valuable insight into the forces about a joint, including forces through muscles, tendons and ligaments, surprisingly few studies have been performed on the effect of various types of footwear on lower extremity joint kinetics. The evaluation of knee varus moment in particular may be especially meaningful in that it has been postulated to play a role in

increasing medial knee compartment osteoarthritis (OA) and has been shown to be greater in subjects with knee osteoarthritis compared to controls [5–7]. Of the potential biomechanical factors implicated in the development and/or progression of knee OA, changes in footwear represent the most easily modifiable.

The first study we are aware of evaluating the effects of footwear on joint kinetics was performed comparing high heeled shoes to barefoot walking. Kerrigan et al. [8,9] demonstrated that women's high heeled shoes change the extrinsic forces of the lower extremity, in particular increasing the knee varus moment and prolonging the knee flexor moment compared to barefoot walking. Later they found that the addition of even a moderate heel in women's dress shoes increased the peak knee varus moment and prolonged the knee flexor moment in women; men's dress shoes and sneakers also increased the extrinsic knee varus moment in early stance in shod compared to barefoot walking in men [10,11]. The latter finding, however, was only slight and was interpreted as being due to a similar increase in walking speed with shod compared to barefoot walking. Hypothesizing that there are footwear factors other than heel height that can cause knee varus moment changes, Franz et al. [12] recently reported that the addition of material under the medial aspect of the foot by way of flexible arch support also increases peak knee varus moment in both walking and running. While all of the above studies have been

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performed in healthy subjects, Shakoor and Block [13] compared shod to barefoot walking in subjects with knee osteoarthritis and found increased peak knee adduction and extension moments and increased peak hip adduction, internal and external rotation moments during shod compared to barefoot walking. They also reported an increase in stride length with shod compared to barefoot walking. For benefit or hindrance, there is evidence that footwear can modify certain parameters of gait.

The aim of the present study is to rigorously evaluate the kinetic effects of standard athletic footwear in healthy individuals while controlling for both footwear type as well as the speed of walking. The majority of the above studies were performed using the subjects' own shoes and none were performed explicitly controlling for speed of walking which may be important insofar as subjects tend to walk faster with shoes compared to barefoot and peak joint moments have been shown to increase generally with the speed of walking [15]. None of these studies examined athletic footwear provided to subjects based upon individual foot structure, as is typically directed by the athletic footwear industry. While athletic footwear has been speculated to have beneficial kinetic effects, we hypothesize that providing subjects the current standard industry recommended footwear type may have potentially harmful kinetic effects, given that standard athletic footwear has both a higher heel (as compared to the forefoot) and typically some amount of medial posting or arch support. We also sought to further examine kinetic parameters while our entire subject population walked in the three different standard footwear types: cushion, stability, and motion control.

2. Methods

2.1. Subjects and procedures

Sixty-eight healthy volunteers (36 females) were recruited from the local population. Subjects had no history of musculoskeletal pathology and were without musculoskeletal injury at the time of testing. The analysis used all subject data (mean age $\pm$ standard deviation, 34 ± 11 y; height, 1.72 ± 0.08 m; mass, 65.7 ± 8.9 kg). The experimental protocol was approved by the Institutional Review Board for Health Science Research, and written informed consent was obtained from each subject.

Running footwear was provided to each subject. To realistically examine the characteristics of shod walking, control shoes were provided based upon each individual's foot mechanics as assessed by an experienced physical therapist. Typically, the footwear industry recommends stability, cushioned, and motion control shoes for those individuals characterized clinically as having neutral, hypomobile, and hypermobile foot mechanics, respectively. To quantify these commonly subjective categories, using a modified navicular drop test [16] subject specific foot mechanics were classified as hypomobile (0–3 mm drop), neutral (4–6 mm drop), or hypermobile (≥ 7 mm drop). Based upon these classifications, subjects were provided the industry recommended footwear type in both the Asics footwear line (Asics Corporation, Hyogo, Japan) and the Brooks footwear line (Brooks Sports, Inc., Bothel, WA), referred to from this point forward as Shoes A and Shoes B, respectively. Specifically, hypomobile subjects were provided cushioned shoes, neutral subjects with stability shoes, and hypermobile subjects with motion control shoes (Table 1 and Fig. 1). To comprehensively examine the kinetic differences between barefoot and shod walking, a secondary analysis was performed in which subjects were provided the two footwear types not customarily recommended in the Brooks footwear line. Thus, each subject was asked to walk in four shod conditions, the order of which was randomized.

A marker set consisting of 16 retro-reflective markers was placed over anatomical landmarks on the pelvis and lower extremity of each subject by the same physical therapist. There was a strong tendency during walking for subject's arms and/or clothing to interfere with markers placed directly on the left and right anterior and posterior superior iliac processes. For this reason, a rigid cluster of four markers was securely fastened directly to the subject's sacrum via self-adherent wrap. Accordingly, the static calibration procedure included four pointing trials to determine the virtual positions of the left and right anterior and posterior superior iliac processes relative to a coordinate system defined by the marker cluster. The motion of each lower extremity segment was tracked by markers on the lateral femoral condyles, lateral malleoli, lateral mid-thighs, lateral mid-shanks, heels, and second metatarsal heads. Excluding the markers placed over the heels and second metatarsal heads, all marker placements were unchanged between conditions.

Subjects were first instructed to walk twice down a 15-m laboratory walkway at their self-selected comfortable walking speed. The average walking speed was recorded and then matched on an AMTI instrumented treadmill (AMTI, Watertown, MA) while each subject performed a 2-min walking acclimation period. Following this period, subjects were asked to complete an additional 2-min walking period during which two 15-s recordings of data were collected. A similar procedure followed for the collection of each shod condition and of barefoot walking at identical walking speeds. Three-dimensional kinematic data were obtained at 250 Hz using a 10 camera VICON 624 motion analysis system (Vicon Peak, Lake Forest, CA). Synchronized ground reaction force (GRF) data were captured at 1000 Hz using an AMTI instrumented treadmill (AMTI, Watertown, MA) described in detail elsewhere [17]. The treadmill consists of two side-by-side force platform units (330 mm $\times$ 1395 mm) situated behind a larger unit (660 mm $\times$ 2750 mm) providing a continuous treadmill surface for walking. Walking data were obtained by having the subject walk with each foot striking one of the side-by-side units.

2.2. Data analysis

Treadmill GRF data were analyzed in a pre-processing algorithm developed in house and implemented in LabVIEW (National Instruments, Austin, TX). The pre-processing algorithm detected gait cycle events, initial contacts and toe-offs, for each foot during walking. Joint extrinsic moment data in the sagittal, coronal, and transverse planes were calculated through a full inverse dynamic model implemented using VICON Plug-in Gait. Joint moments were normalized by body weight and barefoot height.

For each condition, eight consecutive cycles from one of the two captured trials of walking gait were averaged. Data for the left and right sides were combined for each subject. Average curves of joint moments and ground reaction forces (GRF) in three dimensions were graphed over the gait cycle (0–100%). Maximum and minimum moment and GRF values at characteristic peaks during stance were obtained from each subject's average curves. Statistical significance in kinetic maxima and minima at the hip, knee, and ankle between primary conditions, walking barefoot and in the industry recommended footwear type, was assessed by a one-way analysis of variance (ANOVA) for repeated measures followed by a Fisher's LSD for pair-wise comparisons. A secondary comparison of knee joint moments was made between walking barefoot and in the cushion, stability, and motion control footwear types. Again, statistical significance was assessed using a second one-way analysis of variance (ANOVA) for repeated measures followed by a Fisher's LSD for pair-wise comparisons. Applying a Bonferroni adjustment for the primary pair-wise comparisons of 15 kinetic parameters and of stride length, statistical significance for primary condition comparisons was defined at $p < 0.003$ (0.05/16). Statistical significance for secondary comparisons was left at $p < 0.05$.

3. Results

3.1. Barefoot versus industry recommended footwear

The group-mean walking speed was 1.28 ± 0.16 m s⁻¹, which by design was identical between all walking conditions. Walking shod was associated with an identical increase in stride length for both

Table 1
Footwear specifications.

Measure	Cushion		Stability		Motion control	
	Shoe A	Shoe B	Shoe A	Shoe B	Shoe A	Shoe B
Last shape	Semi-curved	Semi-curved	Semi-curved	Semi-curved	Semi-curved	Straight
Posting	None	None	Dual density	Dual density	Dual density	Dual density
Lasting	Solyte 45 Combination	Combination	Solyte 55 Combination	Stroebel Board	Solyte 65 Combination	Stroebel Board
Shore (midsole/posting)	53	59	53/65	59/(63/70)	55/65	59/(63/70)
Cushioning	GEL [®] units (silicon)	Hydroflow [®]	GEL [®] units (silicon)	Hydroflow [®]	GEL [®] units (silicon)	Hydroflow [®]
Midsole height, mm (rearfoot/forefoot)	24/14	24/12	223/132	24/12	23/13	24/12

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