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Original research

The effect of footwear and foot orthoses on transverse plane knee motion during running – A pilot study

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ABSTRACT

Objectives: This study aimed to determine the immediate effects of footwear and foot orthoses on transverse plane rotation of the knee joint during the stance phase of jogging gait.
Design: An experimental, within subjects, repeated measures design.
Methods: Three-dimensional knee kinematics were estimated in the transverse plane by surface-mounted markers as 14 asymptomatic participants ran in four randomised conditions; neutral shoe, neutral shoe with customised orthoses, neutral shoe with prefabricated orthoses, and a stability shoe. Peak internal/external rotation joint angles and ranges of motion (ROM) during loading response, midstance and propulsion were determined. Immediate subjective comfort was also recorded for each condition using a 100 mm visual analogue scale.
Results: Significant main effects of condition were observed for all outcomes except transverse plane knee ROM during loading response ($p < 0.05$). All significant differences occurred between the stability shoe and another condition, with less knee internal rotation in the stability shoe (mean differences ranged between 1.7° and 6.1°) ($p < 0.05$). The neutral shoe with prefabricated orthoses was reported as more uncomfortable than all other testing conditions.
Conclusions: The stability shoe reduced peak knee internal rotation throughout stance phase of jogging more than any other condition. Importantly, it was subjectively as comfortable as the other conditions. These results identify the ability for footwear alone to induce immediate proximal kinematic effects. The use of the kinematic theory behind foot orthoses therapy is also questioned.

1. Introduction

Injuries to the knee are the most common lower limb injury sustained during running.[1] As a treatment strategy of knee injuries in clinical practice, foot orthoses are routinely used with the belief that they have a direct effect on the knee. Excessive pronation (hindfoot eversion) of the subtalar joint with associated internal rotation of the tibia relative to the femur (transverse plane knee rotation) has been postulated to be a causative factor of lower limb overuse injuries such as anterior knee pain.[2] In an attempt to understand both the mechanism of injury and the orthoses in executing their effect, biomechanical modelling techniques have been used to investigate the role of altered knee biomechanics, and specifically lower leg rotation.[3] Central to these investigations has been the immediate role of foot orthoses. Foot orthoses have been shown to exert their effects on the lower limb through a number of pathways including alteration of joint kinematics, kinetics (i.e. joint moments), attenuation of impact forces and neuromotor control paradigms.[3,4] However, the most widely used clinically is the kinematic theory, which is based on the premise that excessive pronation of the subtalar joint is reduced by the use of foot orthoses which in turn restores the joint coupling relationship between the foot and lower leg.[3] To date though, the literature relating to the effect of foot orthotics on knee kinematics demonstrates small effects (i.e. <3°).[3]

While there is some literature describing the instantaneous effect of foot orthoses, the influence of the shoe that orthoses are placed into is not well understood. There currently exist many types of athletic footwear often recommended for specific foot postures. For example, practitioners often prescribe stability footwear to people with a pronated foot posture.[5] Presently, few studies exist which describe the effect of athletic footwear on knee joint kinematics. Without the background knowledge of the biomechanical effect of footwear, it is impossible to isolate the effects provided by the orthotic (custom or prefab) over and above the use of a shoe alone. Acknowledging the relationship in movement between the

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foot and leg as well as the fact that runners routinely use a combination of footwear and foot orthoses, it is essential for research to describe the effect of footwear and orthoses on transverse plane knee rotation. Therefore, the aim of this study was to determine the immediate effect of footwear and foot orthoses on transverse plane kinematics of the knee joint during the stance phase of running.

2. Methods

An experimental, within subjects, repeated measures design was used. A convenience sample of 14 participants (nine female; five male; mean age 22.3 ± 2.3 years; mean height 1.73 ± 0.13 m; mean body mass 68.9 ± 14.1 kg) were recruited from the local population. Volunteers were deemed eligible if they had a pronated right foot (classified as ≥+6 on the six item version of the foot posture index (FPI-6)),[6] were aged between 18 and 40 years and had a heel strike running pattern upon visual inspection. Volunteers were excluded if they had any neuromuscular conditions or history of lower limb injury or surgery that compromised biomechanical function. The study was conducted in accordance with the Declaration of Helsinki[7] and approved by the local Human research ethics committee (Protocol number 0000025255). All participants provided written, informed consent before participation.

Each participant underwent a three dimensional analysis of their knee joint kinematics whilst running in four different conditions. A neutral shoe (ASICS GEL Pulse 3) was the reference condition. The three experimental conditions were (1) neutral shoe with customised foot orthoses, (2) neutral shoe with prefabricated foot orthoses and (3) a stability shoe (ASICS GEL Foundation). To make the custom foot orthotics, a neutral suspension plaster cast of each participant's feet were taken in a non-weight bearing, subtalar joint neutral position. These casts were corrected to a calcaneal vertical position with a minimal medial expansion, with the arch height of the device defined by the participant's navicular height when the foot was placed in subtalar joint neutral. The custom foot orthoses were manufactured from 4 mm polypropylene with a 350 density EVA heel post and 2 mm, shell length multiform top cover. All devices were made by a podiatrist (RS) with 20 years' experience in orthoses manufacture. The Vasyli Medical prefabricated orthoses were full length and constructed from 80 shore density open cell ethylene vinyl acetate (EVA). The order of testing conditions was randomised using a computer-generated random number matrix.[8]

To describe knee kinematics, a six-degree of freedom marker set (21 × 9.5 mm retro-reflective markers) was used (Table 1). This marker set consists of previously published knee and foot–shoe complex marker sets.[9–12] Anatomical landmarks were identified using standard guidelines.[9,13] A static reference trial was collected in each condition whilst the participant stood in neutral alignment in order to determine the position of the markers in three-dimensional space. Prior to the capture of data, participants underwent multiple practice trials. During data collection, each participant was asked to run along a 20 m instrumented runway. To ensure consistency in the definition of knee coordinate systems for each condition, the markers on the leg (Lateral and medial malleolus, lower leg cluster, lateral and medial femoral epicondyles and greater trochanter) and pelvis (Left and right ASIS and PSIS) used to define the axes of rotations were not removed between testing conditions. Kinematic data were collected using a 12-camera Optitrack motion capture system (Natural Point, UK) at 100 Hz. A Kistler force platform (9286b, Kistler, Switzerland) was embedded in the runway to define gait events. Five successful trials (defined as when the whole of the right foot contacted the force platform) were collected during each testing condition. Each trial was timed with a stopwatch in order to calculate running speed. After the completion of data collection for each condition, participants were asked to rate the subjective comfort using a 100 mm visual analogue scale (VAS) which has been proven to be a reliable measure.[14] In making their decision, participants were asked to consider the fit of the upper, cushioning of the forefoot arch on heel and support of the foot inside the shoe as they ran.

Marker trajectory data were captured, tracked and labelled in AMASS 1.032 software (C-Motion, Inc. USA), and post-processed in Visual3D (Version 4, C-Motion Inc. USA). Marker trajectory data were filtered using a 7 Hz low-pass, zero-lag 4th order Butterworth filter.[15] Anatomical frames were defined based on previous methods.[10,16] The lower limb was modelled as four segments; pelvis, thigh, lower leg and foot–shoe complex. The knee joint was defined as the articulation between the thigh and lower leg, with the anatomical coordinate systems defined based on the clusters in the dynamic trials. An XYZ cardan sequence was used to represent the order of rotations of the knee, with rotation around the x-axis defined as flexion/extension, around the y-axis being abduction/adduction and around the z-axis being internal/external rotation. The knee joint was constrained to three rotational degrees of freedom through the global optimisation approach described by Lu & O'Connor.[17] Transverse plane knee joint rotation using anatomical landmarks to define anatomical coordinate systems have previously been shown to be repeatable ($r^2 > 0.64$,[11] within session CMC = 0.969[12]) and consistent with output from models using functional methods.[11] The duration of stance phase was time normalised to 101 points.

Given the prior established relationship between foot eversion and transverse plane rotation of the lower leg,[18] peak internal and external rotation angles were calculated, as was transverse

Table 1
Anatomical marker locations.

Segment	Reference markers	Tracking markers
Pelvis	Right anterior superior iliac spine Right posterior superior iliac spine Left anterior superior iliac spine Left posterior superior iliac spine	Right anterior superior iliac spine Right posterior superior iliac spine Left anterior superior iliac spine Left posterior superior iliac spine
Thigh	Right greater trochanter Right lateral femoral Epicondyle Right medial femoral Epicondyle	4 plate mounted markers on distal 1/3 of thigh segment (right leg)
Lower leg	Right lateral femoral Epicondyle Right medial femoral Epicondyle Right lateral Malleolus Right medial Malleolus	4 plate mounted markers on distal 1/3 of shank segment (right leg)
Foot–shoe complex	Right lateral Malleolus Right medial Malleolus 1st metatarsal head 5th metatarsal head	Posterior calcaneus 1st metatarsal head 2nd metatarsal head 5th metatarsal head