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The mechanical relationship between the rearfoot, pelvis and low-back

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ABSTRACT

The purpose of this study was first to investigate whether foot pronation (measured as calcaneal eversion) induced an anterior tilt of the pelvis and increased the degree of lumbar lordosis. Second the study investigated whether foot supination (measured as calcaneal inversion) induced a posterior pelvic tilt and a decreased lumbar lordosis.

Participants placed their feet in 18 different foot positions while standing on a rigid platform. Seven of these positions ranged from 15 degrees of foot eversion to 15 degrees of foot inversion and 11 positions ranged from 40 degrees of external foot rotation to 40 degrees of internal foot rotation. Pelvic tilt and lumbar lordosis were estimated using a 3D motion analysis system.

Foot pronation and supination did not have a significant relationship with pelvic tilt ($r = 0.3$) and lumbar lordosis ($r = 0.05$). Internally rotating the legs caused the pelvis to tilt anteriorly and externally rotating the legs caused the pelvis to tilt posteriorly ($r = 0.58$). There was no relationship between leg rotation and lumbar lordosis ($r = 0.24$). Since the effects of pelvic tilt on the lumbar spine were only noticeable when pelvic tilt was exaggerated beyond values seen this study it seems unlikely that there is a link between induced foot pronation and an increase in lumbar lordosis.

1. Introduction

Foot orthoses are prescribed to limit subtalar joint pronation during walking and running. By limiting excess pronation, foot orthoses manufacturers claim that their product can help prevent overuse injuries such as low-back pain. The postural effect of subtalar motion on structures above the ankle joint, such as the pelvis and low-back is not well understood. The purpose of this study was therefore to investigate the supposed mechanical relationship between the feet, the pelvis and low-back.

During walking the subtalar joint pronates to absorb the shock of heel strike and to allow the rigid foot to become flexible to adapt to the underlying terrain [1,2]. Supination of the subtalar joint following midstance enables the foot to become a rigid lever required to push the body in the direction of travel. During walking, subtalar pronation peaks at 6.3 degrees (±3.2 degrees); this occurs at 37.9% of the stance phase [3]. Excessive pronation during walking is defined as subtalar pronation that is excessive in amplitude and/or prolonged in duration. As a result, the subtalar joint fails to re-supinate in terminal stance [4,5]. Excessive pronation has been linked to several overuse injuries including patellofemoral syndrome [6], plantar fasciitis [7] and mechanical low-back pain [8].

Movement of the subtalar joint (pronation and supination) occurs across the three cardinal planes. During subtalar pronation, the calcaneus everts causing the talus to slide medially and inferiorly. Because the talus is tightly located in the deep socket formed at the distal end of the tibia and fibula, this medial downward movement of the talus induces an internal rotation of the tibia [4,9]. During supination, the movements are reversed and the tibia externally rotates [10]. Rotation of the tibia is accompanied by rotation of the femur in the same direction but of lesser amplitude [11,12]. It has been hypothesized that internal rotation at the femur causes the head of the femur to exert pressure on the posterior portion of the acetabulum. This backwards push on the posterior aspect of the pelvis would cause the pelvis to tilt anteriorly [12,13]. Because the pelvis is tightly connected to the lumbar spine at the sacro-iliac joint by an extensive fibrous connection, an anterior tilt of the pelvis could increase the forward curvature of the spine, or lumbar lordosis [14,15]. Based on this chain of mechanical events, excessive subtalar pronation has been hypothesized to influence the degree of lumbar lordosis [4,16].

Although several authors have suggested the possibility of excess pronation during two-legged stance and gait affecting the posture of the pelvis [12,13] and lumbar spine [4,16], none have provided data to support the proposed mechanical link between subtalar movement and low-back mechanics and none have

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investigated the effects of subtalar supination. The purpose of this study was to investigate the supposed mechanical relationship between the feet, pelvic and lumbar posture. Specifically, the aim was to determine whether the amplitude of subtalar pronation and supination (measured by calcaneal eversion and inversion, respectively), knee rotation and hip rotation had an effect on the degree of pelvic tilt and lumbar lordosis. We hypothesized that subtalar pronation would cause the pelvis to tilt anteriorly which would result in an increase in lumbar lordosis. We also anticipated that subtalar supination would cause the pelvis to tilt posteriorly subsequently decreasing the angle of lumbar lordosis. We explored these hypotheses by manipulating calcaneal position and measuring the accompanying changes in pelvic tilt and lumbar lordosis during bipedal quiet standing.

2. Methods

2.1. Participants

15 participants (5 men and 10 women, age 25.4 ± 1.7 years, height 1.75 ± 0.09 m, mass 66.5 ± 12.3 kg; mean ± SD) volunteered to take part in this study. All participants met the following inclusion criteria: (1) free of back and lower-limb injury, (2) no noticeable gait abnormalities, and (3) able to stand unassisted for 1 h. All participants gave their written and informed consent before participation in this study. This study was approved by the Behavioral Research Ethics Board at the University of British Columbia.

2.2. Experimental conditions

Participants were instructed to stand quietly in 18 randomized foot positions, which were divided into two blocked tasks: calcaneal inversion/eversion and foot internal/external rotation.

2.2.1. Task 1: calcaneal inversion/eversion

To induce excessive pronation and supination, the participants placed their feet parallel on two platforms with their second toes aimed straight ahead. A hinge on the inner edge of the platform allowed the feet to be placed in each of eight positions: 5, 10 and 15 degrees of inversion, a neutral position and 5, 10 and 15 degrees of eversion. Calcaneal eversion was hypothesized to cause internal knee and hip rotations. Calcaneal inversion was hypothesized to cause external knee and hip rotations.

2.2.2. Task 2: foot internal/external rotation

In order to magnify the effects of calcaneal movement above the subtalar joint, participants also stood with their legs internally or externally rotated (in- or out-toeing). The participants placed their feet on two rotating platforms. The pivot was located at the back and center of the heel. This device rotated their feet to line up the second toe at the appropriate angle. The platforms oriented the feet: 40, 20, 10, 5, 2.5 and 0 degrees both internally and externally. These positions were chosen because they closely approach the average range of internal and external rotation at the hip joint.

2.3. Protocol

Participants were instructed to relax hip and abdominal muscles as they looked straight ahead with their arms across their chest. Data collection began when the experimenter assessed that the participant had relaxed by visual assessment of the shoulders dropping and the feet conforming to the platforms. Once the participant had relaxed, each position was held for 30 s. Data were collected during the middle 10-s period. Rest breaks were provided as necessary in order to prevent fatigue.

2.4. Data collection

Kinematic variables were collected with four motion capture cameras (Optotrak 3020, Northern Digital Inc, Waterloo, ON) surrounding the motion capture area. Infrared markers were placed bilaterally on the anterior superior iliac spine, posterior superior iliac spine, mid-superior aspect of the iliac crest, and greater trochanter. Rigid bodies consisting of three markers were placed bilaterally on the lateral sides of the femur and tibia. Three markers were placed on the spinous processes of the L1, L4 and S2 vertebrae [17]. Three-dimensional kinematic variables were computed using Visual3D (C-Motion Inc., Germantown, MD) and data were further processed with custom-written Matlab routines (Mathworks Inc., Natwick, MA).

Subtalar pronation/supination was computed as calcaneal movement in the coronal plane. Two markers were attached 8 cm apart on the posterior aspect of the shank to form a line connecting the knee and ankle joint centers and 2 markers were attached 3 cm apart along a line bisecting the calcaneus on the foot (Fig. 1A).

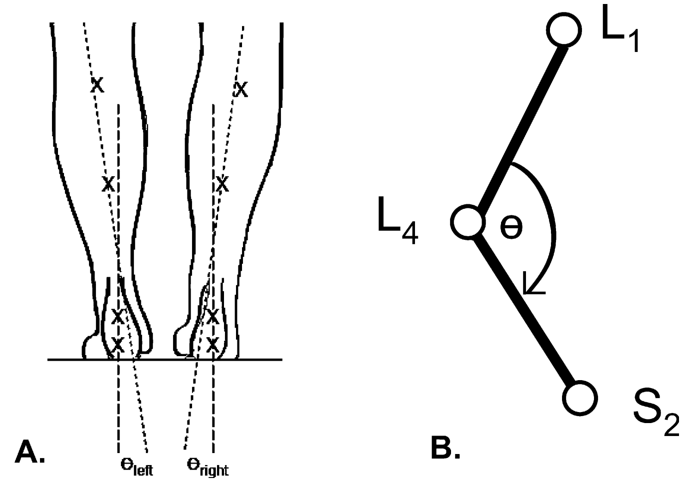

Fig. 1. (A) Calcaneal angle was defined as the acute angle at the intersection of a line bisecting the calcaneus and a line bisecting the lower leg. (B) Method for calculating the magnitude of lumbar lordosis from three markers placed on the spinous process of the L1, L4 and S2 vertebrae.

Subtalar angle was measured as the acute angle between the distal midline of the shank and the midline of the calcaneus [18].

Lumbar curvature was computed in the sagittal plane. An imaginary line was drawn between the L1 and the L4 marker. A second imaginary line was drawn between the L4 and the S2 marker. Both lines were projected onto the sagittal plane. Lumbar curvature was measured as the angle between the two lines (Fig. 1B) [17].

Shank rotation was measured relative to thigh rotation, thigh rotation was measured relative to pelvis orientation and pelvis orientation was measured relative to the left thigh. All positions were expressed as a change from the neutral position.

2.5. Statistical analysis

The relationships between subtalar angle and pelvic tilt and between subtalar angle and lumbar lordosis were assessed with a linear regression model. The predictor variable was subtalar angle and the outcome variables were pelvic tilt or lumbar lordosis. A regression model was also used to assess the relationship between thigh rotation and pelvic tilt and between thigh rotation and lumbar lordosis. The correlation between pelvic tilt and lumbar lordosis was also investigated. Data were analyzed using SPSS Graduate Pack 14.0 for Windows (SPSS Inc, Chicago, IL). Significance was set *a priori* at 0.05. Data are presented as means and standard deviations (SD).

3. Results

3.1. Task 1: foot inversion/eversion

In the first task, placing the feet in eversion caused subtalar pronation relative to the neutral position and placing the feet in inversion caused subtalar supination (Fig. 2). Increases in subtalar pronation resulted in increased internal knee and hip rotation while subtalar supination resulted in external knee and hip rotation (Fig. 3). The correlations between subtalar angle and knee rotation ($R = 0.69$, $R^2 = 0.48$, $F_{1,103} = 93.65$, MS = 271.42, $p < 0.001$) and hip rotation ($R = 0.80$, $R^2 = 0.64$, $F_{1,103} = 183.14$, MS = 877.90, $p < 0.001$) were statistically significant (critical $R > 0.51$). The correlation between subtalar angle and pelvic tilt ($R = 0.30$, $R^2 = 0.09$, $F_{1,103} = 10.34$, MS = 46.06, $p = 0.002$) was not statistically significant (Fig. 4). The relationship between subtalar angle and lumbar lordosis ($R = 0.05$, $R^2 = 0.003$, $F_{1,96} = 0.25$, MS = 1.81, $p = 0.62$) was not statistically significant (Fig. 4). The correlation between pelvic tilt and lumbar lordosis was not statistically significant ($R = 0.04$, $p = 0.68$).

3.2. Task 2: foot external/internal rotation

Internally rotating the feet with the platform caused internal thigh rotation and externally rotating the feet caused external