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Inter-relationship between rearfoot and midfoot frontal plane motion during walking

Mark W. Cornwall *, Thomas G. McPoil

Gait Research Laboratory, Department of Rehabilitation Sciences, Program in Physical Therapy, Northern Arizona University, AZ 86011, United States

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Abstract

Background: Because of the complex nature of foot motion during locomotion, the relationship between the rearfoot and midfoot warrants additional investigation.
Objective: Explore the relationship between frontal plane motion of the rearfoot and midfoot during the stance phase of walking.
Method: Using an electromagnetic motion analysis system, the frontal plane motion of the rearfoot and midfoot of 153 individuals (55 men, 98 women) were collected. The resulting motion patterns for each segment of the foot were then correlated to determine if all subjects exhibited the same relationship between the two segments. Those subjects with a statistically significant negative correlation between the rearfoot and midfoot were then compared on eight rearfoot variables with the group of subjects with a statistically significant positive correlation.
Results: The mean correlation between the rearfoot and midfoot segments was found to be −.307 with a standard deviation of .094. Counter-rotation between the rearfoot and midfoot segments was not seen in 18.9% of the subjects.
Conclusions: This study indicates that a significant group of individuals do not demonstrate the typical counter-rotation pattern of motion between the rearfoot and midfoot during walking. Possible reasons for and the likely clinical implications of this atypical motion pattern are discussed.

Keywords: Kinematics; Walking; Foot; Rearfoot; Midfoot; Mechanics

1. Introduction

The evaluation and management of mechanical foot disorders is frequently a challenge to clinicians. One of the reasons for this challenge is the lack of information concerning how various segments of the foot move relative to each other, especially during activities such as walking. In an attempt to understand and study the complex nature of foot mechanics, the foot is often divided into at least two functional units, rearfoot or hindfoot and the midfoot.

Of these two functional units, the rearfoot has been studied the most and has generally focused upon the calcaneus, possibly because of its close relationship with the subtalar joint as well as the relative ease with which it can be measured during walking [1–5]. The most common method of measuring rearfoot motion during walking has been to reference movement of the calcaneus to that of the tibia [6–10].

Anatomically, the midfoot consists of the navicular and cuboid bones. The articulation of these bones with the talus and calcaneus constitute what is generally termed the midtarsal joint [11]. Although the midtarsal joint is composed of two separate anatomic articulations, the transverse tarsal region is often described as a single functional unit with two distinct axes: the longitudinal and the oblique [11,12]. Using the early work of Manter and Hicks, a theoretical model for motion at the midtarsal joint has been proposed [12,13]. Motion about the longitudinal axis is considered to be primarily in the frontal plane and consists of inversion and eversion [12,14–16]. By utilizing methodology analogous to the rearfoot, the navicular bone is used to represent the midfoot

* Corresponding author at: Gait Research Laboratory, Department of Rehabilitation Sciences, Program in Physical Therapy, P.O. Box 15105, Flagstaff, AZ 86011, United States. Tel.: +1 928 523 1606; fax: +1 928 523 9289.
E-mail address: mark.cornwall@nau.edu (M.W. Cornwall).

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segment and its movement is measured relative to a proximal segment, either the tibia or the calcaneus. As such, inversion and eversion of the midtarsal joint is represented by movement of the navicular bone in the frontal plane [6]. Using this model, the typical motion of the midfoot during normal walking has been shown to be inversion about its longitudinal axis during the "loading" response and then eversion during the mid-stance and propulsion phases of walking [6,11,16]. This motion pattern is directly opposite to that which typically occurs at the rearfoot during normal walking [3,6,12]. This counter-rotation movement between the two segments is considered to be the direct result of the interdependence of the two functional units and is most likely necessary to maintain a plantigrade position of the foot during the stance phase of walking or standing.

As was mentioned previously, effective treatment of mechanical foot problems is often a significant challenge. The previously published studies have looked at the concurrent movement of the rearfoot and midfoot and have shown that the variability of midfoot motion during walking is much greater than that of the rearfoot [6]. This greater variability would suggest that perhaps not all subjects demonstrate the same relationship between the two functional segments of the foot during walking. As such, perhaps not all individuals demonstrate a counter-rotation movement of the midfoot relative to the rearfoot. If this is the case, it might help to explain why some patients respond better to orthotic interventions than others or why some individuals develop mechanically related foot disorders despite having a fairly normal foot posture based upon a static evaluation. It might also help to explain why individuals with apparently similar rearfoot motion patterns do or do not develop mechanical foot problems.

The purpose, therefore, of this study was to further explore the frontal plane relationship between the rearfoot and midfoot segments during the stance phase of walking. It is anticipated that such information will further improve our basic knowledge and understanding of foot function.

2. Methods

2.1. Subjects

One hundred fifty-three individuals (55 men, 98 women) between the ages of 18 and 41 years (mean = 26.2 years) served as subjects for this study. At the time of the study, none of the subjects had a history of congenital deformity, pain, or traumatic injury to either of their lower extremities for at least 6 months prior to participation in the study. Table 1 lists the demographics for the subjects who participated in the study. The Institutional Review Board at Northern Arizona University approved the study prior to the start of data collection and all subjects provided informed written consent.

Table 1
Demographic information on the subjects used in this study

	n	Age (years)	Height (cm)	Mass (kg)
Male	55	26.7 (5.2)	176.6 (6.4)	79.0 (11.8
Female	98	26.9 (4.7)	165.1 (4.7)	63.4 (9.9)
Total	153	26.2 (4.9)	169.2 (7.8)	68.4 (12.8)

Values in parentheses are standard deviations.

2.2. Instrumentation

Movement of the tibia, calcaneus, and navicular bones of each subject's right extremity was measured using the 6D-RESEARCH electromagnetic motion analysis system (Skill Technologies Inc., Phoenix, AZ USA 85014). This system is based upon the Fastrak tracking device (Polhemus, Colchester, VT USA 05446) and uses an electromagnetic transmitter with up to four electromagnetic sensors. The sensors measure 2.8 cm × 2.3 cm in size and have a mass of 17 g. The signals from each sensor are input to a digital signal processor that computes the sensor's position and orientation relative to a transmitter. It has an effective accurate range of 76-cm radius from the transmitter. Within this range, it has an accuracy of .8 mm and .15° RMS [17]. Although a 76-cm radius is typically too small for recording a full walking stride, it is sufficient for analyzing the stance phase of a single limb [18]. For the present study, the electromagnetic transmitter was positioned at a height of 96 cm, at the midway point of a six meter raised walkway. The walkway was raised to a height of 76 cm to avoid any possible distortion of the electromagnetic fields caused by metal reinforcement in the laboratory's concrete floor. Three electromagnetic sensors were used to collect the angular position data of the tibia, calcaneus, and navicular during walking. Joint coordinate system angles for the ankle as defined by Allard et al. [19] were calculated using the calcaneal and tibial sensors. Adaptation of this definition was used to calculate joint coordinate system angles between the navicular and the calcaneus sensors. As such, movement about an anterior–posterior axis (Y) was defined as inversion/eversion. The sampling rate for each sensor was 60 Hz and the resulting angles were smoothed using a 6 Hz low-pass digital Butterworth filter.

The temporal occurrences of heel-strike, foot flat, heel off and toe off were recorded using four force-sensing switches (Interlink Electronics, Camarillo, CA USA 93012). The switches were secured to the plantar surface of each subject's right heel, first metatarsal head, fifth metatarsal head, and hallux using adhesive tape. The signal produced by each switch was recorded and synchronized with the kinematic data.

2.3. Procedure

Following the recording of the subject's height and body mass, the three electromagnetic sensors were attached to the right lower extremity of each subject using double-sided adhesive tape. A sensor was placed on the tibial tubercle,