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Changes in foot and lower limb coupling due to systematic variations in step width

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Abstract

Background. Motion at the midfoot joints can contribute significantly to overall foot motion during gait. However, there is little information regarding the kinematic coupling relationship at the midfoot. The purpose of the present study was to determine whether the coupling relationship at the midfoot and subtalar joints was affected when step width was manipulated during running.

Methods. Twelve subjects ran over-ground at self-selected speeds using three different step widths (normal, wide, cross-over). Coupling at the midfoot (forefoot relative to rearfoot) and subtalar (rearfoot relative to shank) joints was assessed using cross-correlation techniques.

Findings. Rearfoot kinematics were significantly different from normal running in cross-over running ($P < 0.05$) but not in wide running. However, coupling between rearfoot eversion/inversion and shank rotation was consistently high ($r > 0.917$), regardless of step width. This was also the case for coupling between rearfoot frontal plane motion and forefoot sagittal plane ($r < -0.852$) and forefoot transverse plane ($r > 0.946$) motion. There was little evidence of coupling between rearfoot frontal plane motion and forefoot frontal plane motion in any of the conditions.

Interpretation. Forefoot frontal plane motion appeared to have little effect on rearfoot frontal plane motion and thus, had no effect on motion at the subtalar joint. The strong coupling of forefoot sagittal and transverse plane motions with rearfoot frontal plane motion suggests that forefoot motion exerts an important influence on subtalar joint kinematics.

Keywords: Forefoot; Rearfoot; Midfoot; Running; Step width; Joint coupling; Shank rotation

1. Introduction

The coupling between movements of the foot and tibia during running has been suggested to be a possible mechanism of overuse injuries (Powers et al., 2002; Sutlive et al., 2004; Williams et al., 2001). This coupling mechanism is a result of the function of the subtalar joint, which is suggested to act like a mitered hinge, whereby pronation and supination of the foot is transferred respectively into internal and external rotation of the shank (Inman et al., 1981). It has been suggested that excessive or prolonged pronation may cause excessive or prolonged internal rotation of the shank (Tiberio, 1987). As a consequence, this could alter the normal kinematics and kinetics of the lower limb and result in an increased risk of injury to bone and/or soft tissue structures.

Studies investigating foot function during gait have typically approximated foot pronation and supination using calcaneal eversion and inversion, as this component is the simplest to measure (Edington et al., 1990). However, Lundberg (1989) and Nester et al. (2002)

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showed that significant amounts of rotation occur at the midfoot joints, and there is growing evidence that motion at the midfoot contributes significantly to overall foot motion during walking and running (Carson et al., 2001; Hunt et al., 2001; Woodburn et al., 2004). Despite this, little is known about how the midfoot joints influence the subtalar coupling mechanism during gait. In the present study, we therefore investigated the association between midfoot joint motion (rotation of forefoot relative to the rearfoot) and the kinematic coupling at the subtalar joint (rotation of the rearfoot relative to the shank) during running. More specifically, we determine whether forefoot motion is coupled to rearfoot motion and thus has an effect on shank rotation.

Studies investigating the biomechanical coupling between the foot and shank have traditionally examined this relationship using kinematic data determined at discrete points in the stance phase, e.g. maximum rearfoot eversion (Nigg et al., 1998; Reinschmidt et al., 1997; Stacoff et al., 2000). However, this approach may not reveal the complete relationship between the segments since it does not measure the continuous coupling throughout the entire stance phase (DeLeo et al., 2004; Hamill et al., 1999). It is important to include measures of continuous coupling, as it has been suggested that asynchronous motion (poor coupling) between rearfoot eversion/inversion and knee flexion/extension may also contribute to overuse injuries at the knee (Stergiou et al., 1999; Stergiou and Bates, 1997). It has been postulated that, during the initial phase of stance, both knee flexion and rearfoot eversion act to induce shank internal rotation and, during the latter phase of support knee extension and rearfoot inversion, induce shank external rotation (Hamill et al., 1992). This implies that if rearfoot inversion occurred at a different time than the onset of knee extension, then an antagonistic relationship would be present and thus the risk of injury would increase. This injury mechanism, however, is based on the assumption that rearfoot eversion and inversion, respectively, are strongly mechanically coupled with shank internal and external rotation; however, there has been little research to determine if this relationship is continuous throughout the stance phase. In the present study, we therefore used continuous measures to quantify joint coupling.

Variations in step width occur frequently during running and have been shown to significantly affect the maximum rearfoot eversion (Williams and Ziff, 1991). Such changes in rearfoot eversion would presumably also alter tibial and forefoot kinematics since they are connected to the rearfoot via the subtalar and midfoot joints, respectively. Therefore, investigating if subtalar and midfoot joint coupling alters when the kinematics of rearfoot is manipulated should determine how rigidly shank, rearfoot and forefoot motions are linked during gait. Thus the purpose of the present study was to determine if the coupling relationship between the shank, rearfoot and forefoot changed when step width was manipulated during running.

2. Methods

2.1. Subject population

Twelve subjects (six males, six female; mean age (SD), 29.9 (4.9) years; body mass, 61.2 (15.1) kg; and height, 171.2 (9.5) cm) volunteered to participate. Inclusion criteria were that subjects were currently participating for at least 2 h per week in exercise involving running, had been free from injury of the lower extremity in the last six months, had no obvious malalignment and did not wear foot orthotics. The study was approved by the institutional ethics committee, and written informed consent was obtained from all subjects.

2.2. Experimental protocol and equipment

Eighteen reflective markers (7 mm diameter) were attached to the skin of the foot and lower leg of the right limb (Fig. 1). The shape of joint rotation curves based on external markers have been found to be similar in running to those based on pins placed directly into the bones, although segmental rotations can be slightly overestimated using such an approach (Reinschmidt et al., 1997). Furthermore, landmarks that were known to demonstrate greater skin movement artefact relative to the underlying bones during motion (Cappozzo et al., 1996) were avoided where possible. Thus it was assumed that skin mounted markers represented the motion of the underlying bones. The markers were placed over the following locations: head of fibula (HFIB), tibial tubercle (TTUB), along the lateral distal aspect of the shank (SHN1,2,3,4), lateral malleolus (LMAL), medial malleolus (MMAL), peroneal tubercle (LCAL), superior calcaneus (SCAL) and inferior calcaneus (ICAL) placed on a vertical bisection line of the posterior calcaneus, sustentaculum tali (MCAL), medial calcaneus (MCAL2), navicular tuberosity (NAV), medial side of first metatarsal base (P1MT), medial side of first metatarsal head (D1MT), lateral side of fifth metatarsal base (P5MT), between the second and third metatarsal head (D3MT). A solitary marker was also placed on the left foot in the same location as D3MT. Before starting the dynamic trials, a calibration trial was recorded. All subjects assumed a standardised standing posture with the heel centres 0.18 m apart and the long axes of the feet (heel to second metatarsal head) at an angle of 11.6° to each another (McIlroy and Maki, 1997). Markers HFIB, TTUB, LMAL, MMAL, ICAL, MCAL and P1MT were used to identify the location of key anatomical landmarks with respect to other