THE ANKLE-HIP TRANSVERSE PLANE COUPLING DURING THE STANCE PHASE OF NORMAL WALKING

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The aim of this study was to investigate the strength and features of a possibly existent ankle-hip transverse plane coupling during the stance of walking. Fifteen healthy volunteers walked on a 10m walkway in their natural speed using sandals. Kinematic data were obtained with a 3-dimensional motion analysis system. Calculation of the cross-correlation (r=-0.78) indicated a strong ankle-hip coupling, with ankle external rotation (foot pronation) coupled with hip internal rotation, and ankle internal rotation (foot supination) coupled with hip external rotation. Vector coding technique (Φ=41.01°) showed that ankle and hip joints present similar displacement magnitudes. The results agree with suggestions of ankle-hip transverse plane interdependency and an important kinetic energy transmission between the shank and thigh in this plane of movement.

KEY WORDS: gait, ankle, hip, foot, coupling, kinematics, transverse plane.

INTRODUCTION:

The transverse plane instability of the lower extremities during sports and daily-living activities performed in closed kinetic chain has been related to the development of several overuse injuries at the hip, knee and ankle-foot joints (McPoil & Knecht, 1985; Tiberio, 1988). The transverse plane motion of the segments and joints of the lower limbs, during the stance phase of walking, are theoretically considered to take place and to be controlled mostly at the ankle-foot complex and hip joint with the knee working as a transmitter of part of the thigh and shank transverse plane kinetic energy, both in the proximal and distal directions. As a result, impaired function of foot, ankle and/or hip specific structures could alter the mechanics of the whole kinetic chain, being partially responsible for instability presence at joints anatomically close and distant to these structures (McPoil & Knecht, 1985; Tiberio, 1988).

Therefore, according to this model, the thigh and shank would present a temporally similar kinematic behavior, in the transverse plane of motion. Thus, there should be a relatively close temporal coupling between the ankle and hip internal-external rotations during this period of walking. Ankle external rotation, synchronous with subtalar joint pronation (Nester, 2000), would be coupled with hip internal rotation (thigh and shank internal rotation), and ankle internal rotation, synchronous with subtalar joint supination (Nester, 2000), would be coupled with hip external rotation (thigh and shank external rotation), during the stance phase (McPoil & Knecht, 1985; Tiberio, 1988).

Studies which investigated the existence of this relationship had found weak correlations between hip and ankle-foot motions, indicating a lack of temporal similarity and, thus, a weak ankle-hip coupling (Reischl et al., 1999; Nester, 2000). However, these studies used methodological procedures which may have compromised their conclusions. Reischl et al. (1999) used discrete variables to describe hip and foot motions and timings, what could have underestimated the continuous nature of the joint motions and of the possibly existent temporal similarity (Li & Caldwell, 1999). Nester (2000) analyzed entire time-series data of hip and ankle transverse plane motions, regarding the continuity of the variables. However, they carried out a Pearson correlation coefficient analysis for that purpose and low correlations demonstrated by this statistical procedure do not guarantee a lack of temporal similarity between continuous variables (Derrick et al., 1993). Hence, it is still unknown if there is interdependency between the transverse plane mechanical behavior of the shank and thigh and a resultant ankle-hip coupling, in this plane of movement, during gait.

Therefore, the aim of the present study was to investigate the strength and characteristics of a possible coupling between the ankle and hip transverse plane motions during the stance phase of normal walking.

METHOD:

Subjects: Fifteen young healthy subjects (8 male, 7 female) with mean age, mass and height of 23.06 years (SD 1.53), 64.46Kg (SD 9.71) and 1.71m (SD 0.06), respectively, participated in the study. The volunteers should not present rearfoot, forefoot and tibial excessive varisms or a valgus alignment of these structures. They should neither present any restriction in the range of motion of eversion-inversion of the calcaneus at the ankle joints and of internal-external rotation of the hips nor present any lower limbs length difference greater than 1cm. Furthermore, they could not present any pathology or pain in the lower limbs or lumbopelvic complex for at least 1 year.

Instrumentation and Procedures: A 3-dimensional motion analysis system (ProReflex, Qualisys Medical AB, Gothenburg, Sweden) was used to capture passive markers positions and obtain kinematic data about the pelvis and right lower extremity. The anatomic markers were positioned on specific locations in order to allow the construction of the rigid bodies and coordinate systems for the pelvis, thigh, shank and foot, during the data processing. Rigid clusters, each containing 3 tracking markers, were attached to the pelvis, right thigh, right shank and right calcaneus. It was used a 120Hz collection frequency. The participants walked in their natural speed throughout a 10m walkway wearing tracking sandals with flat sole surfaces made from rigid EVA. Six trials were carried out for each subject. Two tracking markers were attached to the lateral surface of the right sandal's sole in order to permit the identification of the stance phase period, according to Ghoussayni et al. (2004).

Data Processing and Analysis: The data were processed through the Visual 3D Motion Analysis Software (C-Motion, Inc., Rockville, USA). Ankle and hip internal-external transverse plane rotations were defined as the movement of the calcaneus relative to the shank and the movement of the thigh in relation to the pelvis, respectively, in the local Z-axes. A 4th order Butterworth lowpass filter with a cut off frequency of 6 Hz was used for data smoothing (Winter, 2005).
To determine the strength of the temporal similarity of ankle-hip continuous coupling a cross-correlation coefficient was calculated in order to analyze the relationship between the angular displacement curves of the ankle and hip joints in the transverse plane of motion (Li and Caldwell, 1999). Correlation coefficients (r) of 0.7 to 1.0 or -0.7 to -1.0 indicated strong coupling, coefficients of 0.3 to 0.69 or -0.3 to -0.69 indicated moderate coupling, and coefficients of 0.0 to 0.29 or 0.0 to -0.29 represented weak or no coupling (Pohl et al., 2006). Positive and negative r values indicated that the joints displacements were evolving in the same or opposite directions, respectively. The r values were calculated for time shifts (k) between -7 and 7. The r value correspondent to k=0 ($r(0)$) represented the strength of the real temporal similarity between the data sets. The 95% confidence interval of the highest r value between the -7 to 7 range of k was used to identify a possible significant time shift between the ankle and hip displacement curves. When the $r(0)$ value of each trial was smaller than the lower boundary of the 95%CI a significant time shift (delay of one joint displacement relative to the other one's displacement) was identified in the stance phase analyzed (Li and Caldwell, 1999).
The Vector Coding Technique (VCT) was used to give information about the relationship between the joint displacement magnitudes of the ankle-hip coupling (Pohl et al., 2006). Angle-angle diagrams were constructed for the joint displacements and an angle of the resultant curve was calculated: $\Phi_i = \text{abs}[\tan^{-1}(y_{i+1} - y_i / x_{i+1} - x_i)]$ where x and y represented ankle and hip rotations, respectively, and i = 1, 2, and n.
The Φ values could vary between 0° and 90°. Values over 45° indicated greater ankle displacement and values under 45° demonstrated greater hip displacement. A Φ value near to 45° indicated similar magnitudes of ankle and hip displacements (Pohl et al., 2006). Mean

Φ values were calculated for each trial curve and than for each subject. Subjects' means were then averaged to describe the coupling.

RESULTS:

The mean cross-correlation coefficient (*r*) observed was -0.78 (SD 0.10) showing a strong temporal similarity between movements in opposite directions (Figure 1). There was no significant time shifts during any of the trials.
The vector coding technique generated a mean Φ value of 41.01° (SD 3.91) demonstrating similar magnitudes of ankle and hip displacements (Figure 2).

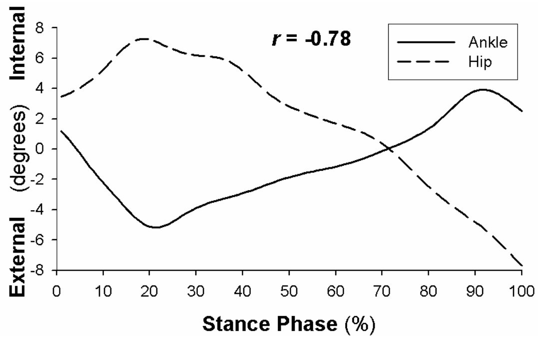

Figure 1: Mean ankle and hip transverse plane rotations during the stance phase and mean *r* of the curves temporal similarity.

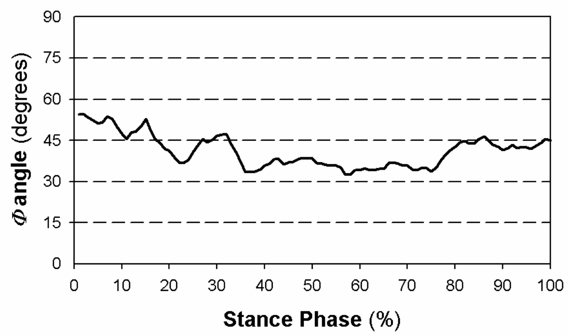

Figure 2: Mean Φ value during the stance phase.

DISCUSSION:

The cross-correlation coefficient of -0.78 observed demonstrates a strong temporal coupling between internal-external rotations of the ankle and hip joints. The negative value indicates that external rotation at the ankle is synchronous with hip internal rotation and ankle internal rotation is coupled with external rotation at the hip joint. In addition, it was not found any significant time shift during all trials demonstrating that there are no important delays between the joint motions. This result agrees with the theoretical suggestions that the thigh and shank transverse plane rotations occur in a similar timing and that, consequently, foot pronation and supination (synchronous with ankle joint complex external and internal rotations) is temporally coupled with hip internal and external rotation, respectively (McPoil & Knecht, 1985; Tiberio, 1988). The only exception was observed during the final 10% of the stance phase, when ankle and hip motions tended to occur in the same direction (Figure 1).
Although the coupling was classified as strong 3 participants presented mean *r* values between -0.54 and -0,67, which indicated moderate temporal similarity. These individuals may present less transmission of transverse plane kinetic energy through the knee. These results may be related to the great between-subjects variability of knee internal-external rotation (Kadaba et al., 1989). During normal walking the knee presents some quantity of internal-external rotation, absorbing part of the transverse plane kinetic energy exchanged between the shank and thigh. However, some individuals may present decreased knee

transverse plane stiffness during the stance of walking allowing greater rotation magnitudes and energy absorbing to occur. It can be consequent to decreased stiffness of passive structures which crosses the knee, such as myofascias, ligaments and the capsule. This can be facilitated by increased knee flexion positions which cause the knee ligaments and capsule to stay loose (Tiberio, 1988). Decreased knee stiffness may also be consequent to decreased active stiffness as a result of lower levels of co-contraction of the muscles that crosses this joint.

The averaged Φ, demonstrated by the VCT, demonstrates that the ankle and hip joints present similar displacement magnitudes in the transverse plane with the hip tending to present slightly grater magnitudes of internal-external rotation. The displacement of the ankle is greater during the first 15% of the stance phase indicating greater magnitude of ankle external rotation (foot pronation) compared to hip internal rotation. After this period the hip displacement becomes greater than ankle displacement until 80% of the stance, demonstrating greater hip external rotation than ankle internal rotation (foot supination). During the last 20% of the stance phase ankle and hip displacements take place with similar magnitudes. Although there are the above mentioned displacement asymmetries in the ankle-hip coupling the observed mean Φ values are only slightly different from the Φ value which indicates similar displacements (Φ = 45°) (Figure 2).

The results are in accordance with the theoretical suggestions that ankle and hip internal-external rotations are strongly coupled as a result of an important transverse plane interdependency between the shank and thigh during the stance phase of walking (McPoil & Knecht, 1985; Tiberio, 1988). New studies are necessary to understand the ankle-hip transverse plane coupling during other sports and daily-living activities performed in closed kinetic chain such as running and landing from jumps. Studies which compare individuals who present or not abnormal movement patterns related to overuse injuries, such as excessive foot pronation, are also necessary.

CONCLUSION:

The cross-correlation coefficient observed demonstrated that there is a strong ankle-hip temporal coupling in the transverse plane of motion. The negative value of this correlation indicated that ankle external rotation (foot pronation) is synchronous with hip internal rotation and that ankle internal rotation (foot supination) is synchronous with hip external rotation. Furthermore, the ankle and hip displacement magnitudes of this coupling are very similar. These results agree with the models which have suggested ankle-hip transverse plane interdependency and an important kinetic energy transmission between the shank and thigh in this plane of movement, during the stance phase of walking.

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