HIGH-SPEED COUPLING CHARACTERISTICS OF THE FOOT AND SHANK DURING THE STANCE PHASE OF RUNNING

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INTRODUCTION

Motions of the foot and tibia during locomotion, or their kinematic coupling, have been highlighted as a factor that may be important in the aetiology of lower limb injury [1]. Particularly, transference of excessive eversion motion of the rearfoot to internal rotation of the tibia through the subtalar joint has been linked to overuse injuries of the knee [2,3,4]. The relative timing of motions of the foot and shank during locomotion may also be an additional factor in injury predisposition [3]. Coupling of the foot and shank has been examined by the ratio of the range of angular motion of these adjacent segments [3], although [2] indicated that differences in the rates of rotation between the two adjoining segments might be a better indication. Continuous relative phase angles have also been used [5], although many of these studies have involved low subject numbers [6]. Rotations about the longitudinal axis of the shank have been difficult to quantify accurately, primarily due to motion of skin-mounted markers relative to the underlying bone [7]. Recently, a lightweight, custom-moulded plate contoured to the shape of each subject's tibia has been used to minimise this error and allow higher frequency aspects of the motion to be captured during locomotion [8]. The aim of this study was to assess movement coupling between the rearfoot and shank during the stance phase of barefoot running, utilising high-speed kinematic analysis and an evaluation of the relative movement rates, ranges of motion and timing of peak velocities. It was hypothesised that timing and magnitudes of angular velocities of rearfoot eversion and tibial internal rotation would be influenced by the inclusion of high frequency components in the displacement data, with velocities being greater than previously recorded [8,9].

METHODS

Twenty-five healthy male subjects (mean age 26 ± 5.2 years, height 1.78 ±0.05 m and mass of 80.5 ±9.6 kg) ran barefoot (3.35 $m.s^{-1}$) along a runway whilst the landing kinematics of the right foot and shank on a large Kistler force platform were recorded by 8 ProReflex (Qualisys, Sweden) cameras at 1000 Hz. At least 15 dynamic running trials were collected per subject. An individually moulded plate was used to track rapid movements of the tibia [8] and foot movements were monitored using a multi-segment foot model so that eversion/inversion movements of the calcaneus segment with respect to the tibia could be calculated. Data was filtered using a standard low-pass Butterworth digital filter (cut-off freq. 40 Hz). Movement coupling was assessed by means of a coupling ratio of calcaneal eversion (EV) to tibial internal rotation (TIR) range of motion (ROM), and by determining the ratio and timing of peak angular velocity of the calcaneus and tibia.

RESULTS AND DISCUSSION

The range and velocity of EV motion of the rearfoot tended to be larger compared to the tibia, producing coupling ratios greater than 1.0 (Table 1). The ROMs and ROM coupling ratio values were similar to that found in the literature [3,4,10]. Peak ang. velocity of the tibia was more than double that previously reported [2,10], which can be explained by the maintenance of high frequency movement transients in the displacement data due to the high sample rate and marker attachment procedure used in this investigation [8]. TIR peak ang. velocities displayed greater differences to the literature than EV peak ang. velocities (4.6 times v 3.77 times greater) [10], suggesting that if a velocity ratio had been performed in that study they would have been different to that presented here. For 14 subjects (56%), peak internal rotation velocity of the tibia occurred before peak eversion velocity of the calcaneus, suggesting proximal motion control [2]. ROM ratio was significantly correlated to TIR ROM (-0.689 p=0.000), but not EV ROM (-0.026, p=0.901) suggesting TIR excursions have more influence on this ratio despite being smaller in magnitude than EV excursions [6]. This highlights the importance of reducing marker displacement error during capture of tibial rotation data.

During the impact phase, when motions of the lower limb segments combine to transmit force and attenuate shock, the relative velocity of adjacent segments and the timing of velocity changes may be more important than excursion differences for the identification of factors associated with overuse injury. At lower sample frequencies, peak ang. velocity is underestimated to varying degrees for each segment, increasing the likelihood of a misinterpretation of the velocity coupling. The present investigation will be expanded to evaluate the influence of different foot types (static and dynamic) on the high frequency coupling parameters reported here.

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Table 1: Coupling parameters (group means ± SD) for barefoot running.

	Calcaneal Eversion EV	Tibial Internal Rot. TIR	Coupling Parameters	
Range of Motion (deg)	10.24 ± 2.37	7.19 ± 3.1	Ratio (EV/TIR)	1.66 ± 0.62
Peak Ang. Vel. ($rad.s^{-1}$)	-7.70 ± 2.61	-6.95 ± 2.24	Ratio (EVpeak/TIRpeak)	1.25 ± 0.55
Time to Peak Ang. Vel. (ms)	17.16 ± 11.71	14.06 ± 7.41	TIR-EV peak time	-3.09 ± 13.76