SEGMENT COORDINATION RESPONSE TO ALTERATIONS IN FOOT STRIKE PATTERN

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INTRODUCTION

The timing and magnitude of segment rotations during running have been investigated as possible mechanisms for lower extremity injury. The relative timing, or coordination, of foot and shank rotations is mechanically linked due to the anatomy of the subtalar joint. Bates et al. suggested a disruption in timing between calcaneal eversion and internal tibial rotation may cause excessive knee joint stress [1]. Compared to the rearfoot (RF) strike pattern, the forefoot (FF) strike pattern has been characterized by greater rearfoot inversion at touchdown forcing the rearfoot to rotate through greater eversion excursion and excursion velocities [2]. Greater eversion excursion has been found to correlate with greater tibial internal rotation excursion; a mechanism that may increase stress to the soft tissue of the knee [3]. Due to these factors, those who naturally run with a FF strike pattern may be predisposed to knee injury. Runners may be instructed to switch strike patterns depending on the type of injury to which they are predisposed.

Dynamical systems techniques, such as vector coding, quantify the continuous spatial coordination between segment rotations and may reveal a richer set of kinematic information than more traditional discrete analyses. Therefore, the purpose of this study was to quantify adjustments in shank and foot coordination via a modified vector coding technique when runners change from their preferred to an alternate strike pattern.

METHODS

Ten natural RF strike runners (6 males, 4 females, age = 28±4 yrs, mass = 67.86±9.36 kg, height = 1.72±0.12 m) and 4 natural FF strike runners (4 females, age = 27±6 yrs, mass = 63.79±9.74 kg, height = 1.68±0.05 m) participated in this study. RF strike was defined as landing on the heel. FF strike was defined as landing on the forward section of the foot or toes without the heel making contact with the ground. Each subject gave approval for participation in accordance with University IRB policy.

Reflective markers were placed on the leg and foot of the right limb. Three-dimensional (3D) motion was recorded with an eight camera motion capture system operated at 200 Hz. Subjects ran on a treadmill at their preferred running speed (RF runners = 3.02 ±0.45 m/s, FF runners = 2.91±0.21 m/s) with their preferred and the alternate strike pattern for 5 minutes. Kinematic data during the last minute of each condition was used to calculate 3D lower extremity segment angles using a right-hand orthogonal Cardan Xyz rotation sequence. Segment angles were referenced to the lab coordinate system. Phase angles (γ) were derived by a vector drawn between two adjacent time points on an angle-angle plot of shank internal/external (IR/ER) segmental rotation and foot segment inversion/eversion (INV/EV)[5].

$$\gamma_i = \tan^{-1}\left[(y_{i+1}-y_i)/(x_{i+1}-x_i)\right]$$

Phase angles were drawn relative to the right horizontal and categorized into one of four coordination patterns (Table 1) [6]. Mean phase angles were determined by circular statistics and averaged over early (1-33%), mid (34-66%), late stance (67-99%). Effect sizes (ES) were calculated to assess differences between groups.

Table 1: Phase angle categories

Coordination Pattern	Coupling Angle Definition
Anti-phase (i)	$112.5^{\circ} \le \gamma < 157.5^{\circ}$ $292.5^{\circ} \le \gamma < 337.5^{\circ}$
In-phase (ii)	$22.5^{\circ} \le \gamma < 67.5^{\circ}$ $202.5^{\circ} \le \gamma < 247.5^{\circ}$
Exclusive shank segment rotation (iii)	$0^{\circ} \le \gamma < 22.5^{\circ}$, $157.5^{\circ} \le \gamma < 202.5^{\circ}$, $337.5 \le \gamma \le 360^{\circ}$
Exclusive foot segment rotation (iv)	$67.5^{\circ} \le \gamma < 112.5^{\circ}$ $247.5^{\circ} \le \gamma < 292.5^{\circ}$

RESULTS AND DISCUSSION

Rearfoot Running When running with a rearfoot strike pattern, FF runners exhibited greater maximum INV (ES=0.7) and foot excursion (ES=0.9) than RF runners. Rearfoot running resulted in greater maximum foot EV (RF ES=0.7; FF ES=1.3) and increased shank IR (RF ES=0.3; FF ES=0.3) for both groups. The pattern of coordination was different between groups indicated by differences in mean phase angle for mid (ES=0.9) and late stance (ES=0.7) (Figure 1a). Both groups began with an in-phase coordination pattern but FF runners had an abrupt shift in coordination while the shift for RF runners was more gradual. RF runners had anti-phase and exclusive foot segment rotation coordination patterns for mid and late stance respectively whereas FF runners had exclusive shank segment rotation and in-phase coordination patterns.

Forefoot Running There was no difference in segment angles, excursion, or coordination patterns between groups when running with a forefoot strike pattern. RF runners altered their coordination pattern from anti-phase to exclusive foot rotation during mid stance compared to the rearfoot running condition (ES=1.2). FF runners also altered coordination from in-phase in rearfoot running to exclusive foot segment coordination in mid stance during forefoot running (ES=0.8) (Figure 1b).

CONCLUSION

All subjects experienced greater maximum foot EV during the rearfoot running condition which may contribute to increased stress to the knee. Forefoot running resulted in foot EV without shank IR (exclusive foot rotation) which is not consistent with the segment interaction suggested by Bates et al [1]. Rearfoot and forefoot strike patterns had fundamentally different coordination patterns. RF runners were able to match the coordination pattern of the FF runners during the forefoot strike pattern but FF runners were not able to match the coordination pattern of RF runners during the rearfoot strike pattern. These differences may not have been realized with traditional kinematic analysis.

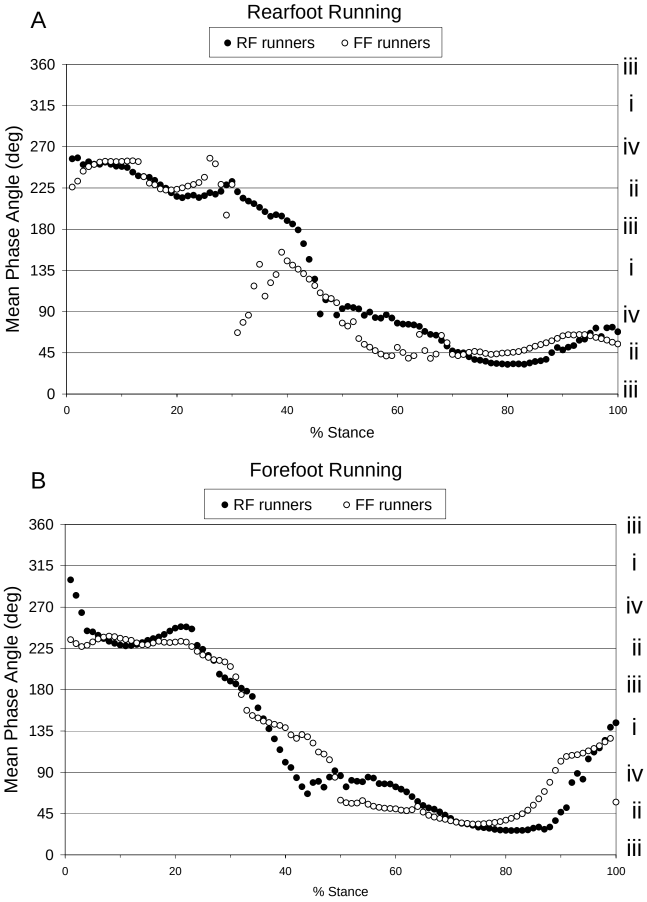

Figure 1: Mean phase angle between foot EV/INV and shank IR/ER during (A) rearfoot running and (B) forefoot running. Refer to Table 1 for coordination pattern definitions of (i) anti-phase, (ii) in-phase, (iii) exclusive shank rotation, and (iv) exclusive foot rotation.

REFERENCES

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