GENDER DIFFERENCES IN INTER-SEGMENT FOOT KINETICS DURING RUNNING

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Gender differences in kinetics may be associated with the incidence of specific overuse injuries. However, inter-segment foot kinetics during running have not been investigated between genders. The purpose of this study was to compare multi-segment foot kinetics during running between males and females. Eleven males and nine females ran barefoot with rearfoot strike at 3.3 m/s ± 10% along a 10 m runway. Segmental moment and power at midfoot and ankle in sagittal plane were calculated, and peak moment, positive and negative power were compared by gender. Peak positive and negative midfoot power were significantly larger in females than in males. These results suggest the soft tissues across midfoot contract more concentrically or eccentrically in females. The contribution of midfoot to shock absorption and forward propulsion seems to be different according to gender.

KEYWORDS: multi-segment foot model, moment, power, rearfoot strike.

INTRODUCTION: A foot has multiple joints, and each segment plays a complementary role in absorbing impact forces and transmitting propulsive forces. With the prevalence of multi-segment foot models, foot kinematics have been extensively investigated. On the other hand, there is a lack of studies that have investigated inter-segment foot kinetics because most studies used a single-segment foot model to evaluate foot kinetics. However, it has been demonstrated that the traditional single-segment foot model overestimates ankle joint power by 35% on average as compared to the multi-segment foot kinetics model during gait (Bruening et al., 2012). Another study reported that midfoot plays an important role in absorption of impact forces and transmission of propulsive forces during running (Deschamps et al., 2020). Therefore, the use of multi-segment kinetic foot models is essential for the accurate understanding of inter-segment foot kinetics.

Gender is a risk factor for specific overuse injuries in running. The incidence of plantar fasciitis and stress fractures was higher in females than in males (Scher et al., 2009; Hollander et al., 2021). Although the mechanisms have not been fully understood, the differences in foot kinematics and kinetics between genders may be one of the contributing factors. Regarding foot kinematics, females showed greater foot segmental motion during running than males (Takabayashi et al., 2017). In terms of kinetics, females also showed increased midfoot moment and power during landing and jumping phases in drop-jump than males (Matsumoto et al., 2023). These findings suggest that the mechanisms related to absorbing and generating forces differ between genders, and the foot may contribute greatly to both functions in females. Nevertheless, no studies have investigated gender differences in foot kinetics during running.

The purpose of this study was to compare inter-segment foot kinetics during running in healthy subjects between males and females. We hypothesized that females would exhibit greater midfoot moment and power.

METHODS: Eleven males (mean [SD]; ages 25.3 [2.8] years, height 171.1 [5.8] cm, body mass 70.0 [12.2] kg) and nine females (mean [SD]; ages 24.8 [1.5] years, height 160.4 [5.2] cm, body mass 53.2 [9.0] kg) participated in this study.

A three-dimensional motion analysis system (Motion Analysis Corp., Santa Rosa, CA, USA) with eight infrared cameras and a force plate (9260AA6, Kistler, Winterthur, Switzerland) was used. Participants were attached to reflective markers and an insole-type foot pressure sensor (pedar®, novel gmbh, Germany), and their running movements on a 10m runway were recorded. Markers were placed in accordance with the Rizzoli foot model, which is a multi-segment foot model (Leardini et al., 2007) (Figure 1). The Infrared cameras and pressure sensor were sampled at 200Hz, and the force plate was sampled at 1000Hz. Participants ran barefoot at 3.3 m/s ± 10% with rearfoot strike pattern.

Stance phase was determined by vertical ground reaction force (GRF) with a threshold of 5% body mass. Strike patterns were defined by strike index (Cavanagh and Lafortune, 1980). The marker data and ground reaction force were filtered using a fourth-order Butterworth low-pass filter with cut-off frequencies at 12 Hz and 20 Hz, respectively. Inter-segment foot kinetics were calculated using the foot model developed by Bruening et al. (2012). This model consists of the shank, rearfoot, and forefoot. The centers of the ankle joint (rearfoot relative to shank) and midfoot (forefoot relative to rearfoot) were defined as the midpoint between the medial and lateral malleoli and the midpoint between the navicular and the cuboid, respectively. Each segmental moment and power were calculated using the inverse dynamic approach. The navicular and cuboid markers were projected onto the pressure sensor, and the pressure data was divided into rearfoot and forefoot at the boundary between these two markers to obtain each segmental pressure. The pressure ratios of each segment for every frame were calculated by dividing the segmental pressure by the total pressure. Three-dimensional GRF and free moment divided by the pressure ratio of each segment were distributed to each segment (Saraswat et al., 2014). The center of pressure (COP) of each subarea calculated by the pressure sensor was used as each segmental COP in the inverse dynamic approach. The inertial parameters for each segment were used from the previous study (de Leva P, 1996; Matsumoto et al, 2022). Three-dimensional joint reaction forces and moments were calculated from distal to proximal using the Newton-Euler equation. The resultant power for each segment was calculated as the scalar product of moment and angular velocity. Each segmental moment and power were normalized by body weight for each participant. Segmental moments and power were averaged over 3 trials for each participant and normalized to 100% of the stance phase. All calculations were performed using an in-house made program written in MATLAB (The Mathworks Inc., Natick, MA, USA).

All parameters were confirmed for normality by Shapiro-Wilk test. Peak moment, positive and negative power in sagittal plane at ankle and midfoot were compared between genders using independent t-tests or Mann-Whitney U tests depending on the results of Shapiro-Wilk test (α = 0.05).

Figure 1: Marker placement

RESULTS: No differences in running speed and stance time between groups.

Peak positive and negative midfoot power were significantly larger in females than in males (8.03 [1.81] vs. 6.40 [1.27] Watt/kg, -4.08 [0.64] vs. -3.22 [0.72] Watt/kg) (Table 1). Figure 2 shows the kinetic waveforms of ankle and midfoot in sagittal plane for the two groups. There were no significant differences in other parameters between genders.

Table 1: Comparisons of peak moment, peak positive and negative power at midfoot and ankle (mean [SD]).

Variable of interest	Segment	Males (n=11)	Females (n=9)	*P*
Peak plantarflexion moment [Nm/kg]	Midfoot	-2.00 [0.21]	-2.10 [0.24]	0.364
	Ankle	-2.39 [0.25]	-2.35 [0.27]	0.738
Peak positive power [Watt/kg]	Midfoot	6.40 [1.27]	8.03 [1.81]	0.038*
	Ankle	7.31 [1.51]	7.95 [1.17]	0.341
Peak negative power [Watt/kg]	Midfoot	-3.22 [0.72]	-4.08 [0.64]	0.016*
	Ankle	-4.66 [1.33]	-4.58 [1.02]	0.890

Note: * indicates females significantly greater than males (*P* < 0.05).

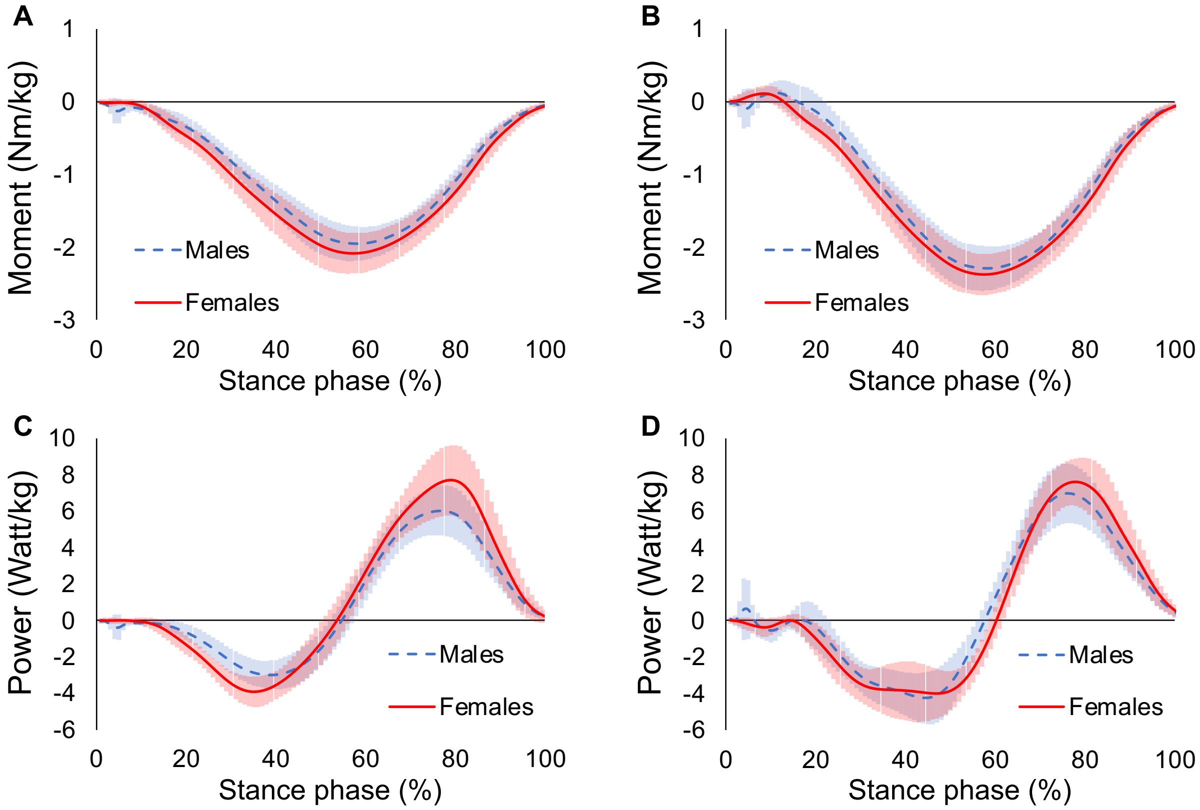

Figure 2: Kinetic waveforms in sagittal plane between the two groups during the stance phase of running. Standard deviations are visualized as bands. The dashed blue line represents males, and the solid red line represents females. A) midfoot moment (Dorsiflexion (+)/Plantarflexion (-)), B) ankle moment (Dorsiflexion (+)/Plantarflexion (-)), C) midfoot power (Generation (+)/Absorption (-)), D) ankle power (Generation (+)/Absorption (-)).

DISCUSSION: In the present study, we compared inter-segment foot kinetics during running between genders. Females exhibited greater negative power in 34% and greater positive power in 78% of stance phase. The former corresponds to the absorption phase and the latter to the propulsive phase, respectively (Figure 2C). The reason for these differences could be attributed to the finding that midfoot mobility is greater in females than in males. The foot is more flexible in females because arch stiffness is lower than that of males (Zifchock et al., 2006). Moreover, females showed significantly greater peak dorsiflexion angle and excursion in sagittal plane at midfoot during running (Takabayashi et al., 2017). Therefore, increased dorsiflexion angular velocity was expected in early to mid stance, and increased plantarflexion angular velocity in mid to late stance. This may explain the large peak positive and negative power observed in females in the present study. The foot has a functional dome structure consisting of the medial longitudinal arch, lateral longitudinal arch, and transverse arch which are supported by the plantar aponeurosis, muscles, and ligaments (Caravaggi et al., 2009; Kelly et al., 2014). This structure allows the foot to change its posture according to load changes, however arch collapse causes the soft tissue stretch. The increased peak negative power in females suggests that the intrinsic and extrinsic foot muscles across midfoot suffered larger eccentric demand, and possibly midfoot contributes to greater shock absorption compared to males. Subsequently, the decreased arch height is raised by midfoot plantarflexion during propulsive phase. Concurrently, intrinsic foot muscles provide proper arch stiffness and contribute to generating positive power (Kelly et al., 2015). Increased arch stiffness enables the foot to transmit forces efficiently, however, females have a flexible foot (Zifchock et al., 2006). Hence, intrinsic foot muscles appear to have an increased concentric demand in females to compensate for foot stiffness, and midfoot contribution in propulsion seems to be greater in females than in males.

CONCLUSION: This study compared the differences in multi-segment foot kinetics between healthy males and females during running. We found that midfoot contributed greatly to the absorption of impact forces and the transmission of propulsive forces in females. We suggest that gender should be taken into account for analysing inter-segment foot kinetics. Our findings provide a basis for the design of clinical and training interventions.

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