Using Dynamic Optimization to Understand Muscle-Tendon Dynamics during Running with Different Footwear Stiffness

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Summary

Understanding the influence of footwear longitudinal bending stiffness on muscle-tendon dynamics is crucial for optimizing running performance and reducing injury risk. This study used dynamic optimization to examine how variations in footwear stiffness affect joint kinematics, joint kinetics, and muscle-tendon interactions during running. Results indicate that increased footwear stiffness influenced muscle-tendon length, velocity, and tendon force, with minimal effects on joint moments. Running speed was the primary factor affecting muscle excitation and tendon force. These findings suggest that footwear stiffness impacts muscle-tendon behavior but does not significantly impact joint mechanics at the ankle.

Introduction

The triceps surae muscle group and tibialis anterior (TA) play key roles in running biomechanics, contributing to propulsion and energy absorption. Footwear longitudinal bending stiffness has been shown to affect running mechanics [1,2], yet its impact on muscle-tendon dynamics remains unclear. Previous studies have primarily focused on joint kinematics and kinetics, to infer muscle behavior [1]. Alternatively, ultrasonography has been used to capture *in vivo* changes in muscle fiber length and velocity, providing insight into muscle-tendon interactions with stiffer shoes [2]. However, these methods present challenges in capturing the full scope of muscle-tendon dynamics during running. To address this gap, this study examined how longitudinal bending stiffness of footwear influences joint kinematics, joint kinetics, and muscle-tendon dynamics during running using dynamic optimization.

Methods

20 participants (10 female, 10 male) ran on a force-instrumented treadmill in three footwear conditions at two speeds (2.7 m/s and 3.5 m/s). The footwear conditions were a minimalist shoe that was flexible and had either 1) no (0.05 Nm/deg), 2) 1mm (0.14 Nm/deg), or 3) 1.5 mm (0.30 Nm/deg) carbon fiber plate to vary the longitudinal stiffness of the shoe. A musculoskeletal model in *OpenSim* [3] was used to perform inverse kinematics and dynamics, while dynamic optimization was applied to estimate muscle-tendon dynamics for the triceps surae and TA muscles.

Results and Discussion

Speed influenced muscle-tendon behavior, with the faster running speed (3.5 m/s) resulting in higher muscle-tendon length, normalized muscle fiber velocity, tendon force, and muscle excitations compared to slower running (2.7 m/s) for the triceps surae and TA. Increased footwear stiffness led to increased muscle-tendon length, reduced muscle fiber velocity and increased tendon force for the triceps surae and TA. However, ankle joint angles and moments were not affected by stiffness variations.

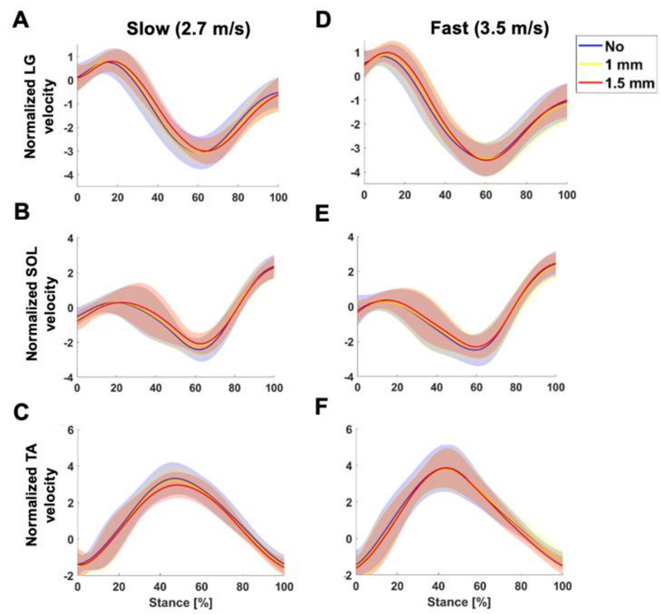

Figure 1: Mean (A, D) gastrocnemius lateralis (LG), (B, E) soleus (SOL), (C, F) TA normalized muscle fiber velocity during stance across three footwear condition (no, 1mm, 1.5mm) and two running speeds (2.7 m/s and 3.5 m/s). The blue, yellow, and red lines represent the no, 1mm footwear condition, and 1.5mm footwear condition. Shaded areas indicate standard deviation.

Conclusions

Footwear stiffness primarily alters muscle-tendon function rather than joint-level mechanics at the ankle. Future research should incorporate participant-specific measurements to enhance the accuracy of muscle-tendon force estimations and provide a more individualized approach to understanding the biomechanical impact of footwear stiffness on running.

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References

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