Ankle dorsiflexion increases the passive stiffness of the metatarsophalangeal joint

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Summary

Research on foot function has primarily focused on the anatomical region between the talus and the toes. We hypothesized that, due to the mechanical linkage between the Achilles tendon and the toes, the ankle joint angle affects forefoot stiffness. In our study, using a custom-made, pneumatically driven device, we found that 20° of ankle dorsiflexion increases the passive stiffness of the meta-tarsophalangeal joint by 50%. Therefore, when analyzing foot function, the ankle joint angle should be considered.

Introduction

Passive metatarsophalangeal joint (MPJ) stiffness has been linked with performance enhancement in sports. For instance, higher passive MPJ stiffness is associated with improved jump height [1] and running economy [2], suggesting that stiffer joints may enhance performance by decreasing energy loss and providing stability during movement. Since a 20° dorsiflexion of the ankle joint is associated with a stretching of the Achilles tendon and plantar fascia [3], we hypothesized that ankle dorsiflexion increases MPJ stiffness compared to a neutral or plantarflexed ankle position. To measure passive MPJ stiffness, we have developed a simple and effective device that can be used as a diagnostic tool in training rooms, at competition venues or in healthcare facilities.

Methods

Passive MPJ stiffness of 19 subjects (13 m, 6 f, 24 ± 6 yrs, 75.4 ± 9.6 kg, 1.79 ± 0.08 m, forefoot length 8.01 ± 0.6 cm) was measured with a custom-made, pneumatically driven device (Figure 1, left). The toes were positioned on a forefoot plate, with the first MPJ aligned with the plate axis. A pneumatic cylinder (Festo, Esslingen, Germany) generated pressure (1 bar ≙ 41 N) to move the forefoot plate upwards, inducing toe dorsiflexion. Pressure was regulated by a pressure control unit and valves (Festo, Esslingen, Germany). The angle of the forefoot plate was measured using a potentiometer (MCP05, linearity 1%, Megatron, Putzbrunn, Germany). The MPJ angle was defined as the angle between the rearfoot and the forefoot plate, and stiffness was defined as the joint moment needed to deform the toes by 60° dorsiflexion, normalized to forefoot length. We used slow angular velocities of 40-50°/s to avoid triggering the muscle's stretch-reflex and tendon's viscoelastic response [4]. In a pretest, the force needed to move the forefoot plate to 60° was determined. Then, this force was applied 10 times to the toes at ankle angles of 20° plantarflexion, 0° and 20° dorsiflexion, respectively. To account for a possible creep effect and further minimize velocity effects, the mean of the last five repetitions was used for statistical analysis. The between-day and within-day reliability of the device was excellent (ICC = 0.99; $p < 0.001$). Statistics: one-way ANOVA.

Results and Discussion

The MPJ was significantly stiffer ($p < 0.001$) when the ankle joint was in 20° dorsiflexion (59.9 ± 19.7 N/rad) compared to a 0° ankle angle (40.3 ± 13.2 N/rad) or a 20° plantarflexed ankle (37.7 ± 12.4 N/rad). These differences were consistently observed in all subjects (Figure 1, right). There were no significant differences ($p > 0.05$) in MPJ stiffness between 20° ankle plantarflexion and 0° ankle angle.

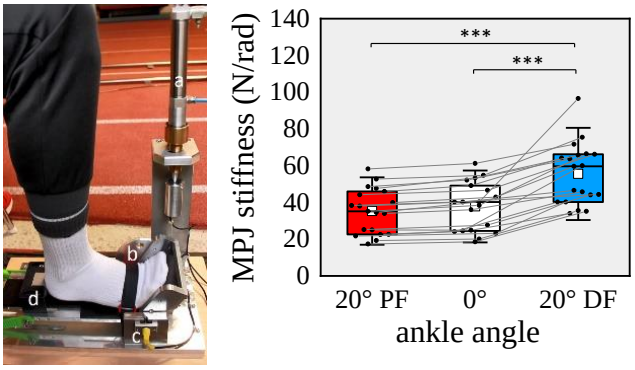

Figure 1: Custom-made device for measuring MPJ stiffness (left); a) pneumatic cylinder, b) pulley connected to the forefoot plate, c) potentiometer, d) heel cap; MPJ stiffness (right) in 20° ankle plantarflexion (PF), 0° ankle angle and 20° ankle dorsiflexion (DF); *** statistically sig. difference ($p < 0.001$) between the conditions.

Conclusions

The forward tilt of the shank appears to play a crucial role in foot function, making the ankle angle an integral part of any analysis of MPJ stiffness. Further studies are needed to clarify whether the strength of the toe flexor muscles influences MPJ stiffness. Stiffening the MPJ through exercise and training might be equally beneficial for the foot complex than stiffening it with carbon plates.

References

[1] Jia SW et al. (2022). *J Sports Sci*, **40**: 638-45.
[2] Man HS et al. (2016). *Gait Posture*, **49**: 303-08.
[3] Shiotani H et al. (2023). *Med Sci Sports Exerc*, **55**: 66-73.
[4] Blanpied P & Smidt GL (1992). *J Biomech*, **25**: 29-39.