Passive metatarsophalangeal joint stiffness: Reliability of a novel portable device

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Summary

The objective of this study was to introduce a novel, portable test device for measurements of passive metatarsophalangeal joint stiffness. The findings demonstrate excellent within-day and between-day test-retest reliability of the device. The portable test device has the potential to function as a future diagnostic instrument in training settings or healthcare facilities.

Introduction

Passive stiffness of the metatarsophalangeal joint (MPJ) has been associated with various performance metrics. Research has demonstrated a correlation between higher passive MPJ stiffness and enhanced running economy [1], as well as increased jump height [2]. In addition, there are correlations between passive MPJ stiffness and other biomechanical measures for stiffness, such as leg and vertical stiffness, indicating that passive stiffness may influence overall performance [1, 3]. Consequently, it is essential to develop a device for measuring MPJ stiffness in training settings. Therefore, we designed a portable, pneumatic-driven test device. The aim of the present study was to investigate the within-day and between-day test-retest reliability of the device for measuring passive MPJ stiffness.

Methods

A total of 19 healthy students participated in the study (6 f, 13 m, 24 ± 6 yrs, 75.4 ± 9.6 kg, 1.79 ± 0.08 m, sport/week: 8.1 ± 4.8 hrs, forefoot length: 8.0 ± 0.6 cm). Passive MPJ stiffness was measured twice in one day for within-day reliability and on two separate days within a week for between-day reliability, using a custom-made, pneumatic-driven device (Figure 1, left). Toes were positioned on a forefoot plate, with the first MPJ aligned with the plate axis and the shank oriented vertically. A pneumatic cylinder (Festo, Esslingen, Germany) generated pressure (1 bar ≙ 41 N) and moves the forefoot plate upwards into 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. 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 around 50°/s to avoid triggering the muscle's stretch-reflex and tendon's viscoelastic response [4]. In a pretest, the force needed to deform the forefoot plate to 60° was determined. To take a possible creep-effect into account and to additionally minimize velocity effects, the mean of the last 5 repetitions was used for statistics. Statistics: Intraclass correlation coefficient (ICC 3,1).

Results and Discussion

ICC indicated both excellent test-retest reliability for comparing MPJ stiffness between-day (ICC = 0.993, 95% CI: 0.98-0.99, $p < 0.001$) and within-day measurements (ICC = 0.999, 95% CI: 0.99-0.99, $p < 0.001$, Figure 1, right).

Table 1: Mean MPJ angles (°), angular velocities (°/s) and passive stiffness (N/rad) for the three measurements.

	Baseline	Within-day	Between-day
Angle	61.0 ± 3.0	61.2 ± 3,4	61.7 ± 3,7
Angular velo.	53.3 ± 5.4	53.3 ± 5.4	53.9 ± 5.4
Stiffness	37.8 ± 13.1	37.6 ± 12.6	37.5 ± 13.2

In addition, there were no significant differences ($p > 0.05$) between the three measurements of mean MPJ angle, angular velocity or stiffness (Table 1).

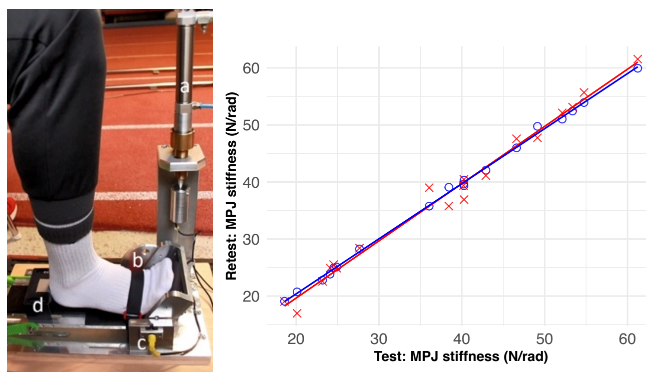

Figure 1: Pneumatic-driven device for measuring force-deformation properties of the MPJ (left); a) pneumatic cylinder, b) pulley connected to the forefoot plate, c) potentiometer, d) heel cap; Passive MPJ stiffness (right): between-day (red) ICC = 0.99, $p < 0.001$; within-day (blue) ICC = 0.99, $p < 0.001$.

Conclusions

These findings demonstrate that the portable test device provides reliable passive MPJ stiffness measurements, which are comparable to those of motor-based devices [5]. Its portability allows rapid, on-site diagnostics, making it highly practical for sports settings and rehabilitation, where real-time assessments and adjustments are imperative.

References

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