A Reliable Device to Measure First Ray Mobility

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INTRODUCTION: First Ray Mobility (FRM), superior translation of the first metatarsal when subjected to a dorsally directed load, plays an important role in the clinical diagnosis and evaluation of foot pathologies and treatment planning. However, there are no commercially available tools to measure 1st ray mobility with high inter-rater reliably. We developed Version 2 of the first ray mobility and positioning device (MAP1st V2) to solve this unmet need by enabling the application of consistent loading and foot positioning, irrespective of the clinician's experience.

METHODS: The current reliability study includes 32 subjects (64 feet). The cohort is comprised of 10 bilateral asymptomatic rectus subjects, 15 bilateral asymptomatic planus subjects, 1 bilateral asymptomatic cavus subject, 3 asymptomatic subjects of mixed foot types, 1 unilateral subject with Hallux Valgus, and 2 subjects with Hallux Rigidus (one bilateral planus, one bilateral rectus). Foot type was determined for each subject by the arch height index (AHI) as described by Hillstrom et al (2013). Since MAP1stV2 encompasses two units (right and left) the reliability analysis was performed for each foot separately.

MAP1st V1, the first-generation device, had an Arduino powered actuator to displace the first ray by applying 50N of force beneath the 1st Metatarsal-phalangeal joint in an upward direction. All other measures were manually acquired via graticules. MAP1st V2 is fully automated, runs on a tablet-based App, and uses displacement transducers to measure foot length, truncated foot length, and first ray displacement. After the foot is placed within the device a snowboard style binding grounds the rearfoot while an adjustable cushioned element grounds the 2nd though 4th metatarsal heads. The first metatarsal head is elevated in response to a 50 N vertically applied load. Ten cycles of first ray mobility movements were performed to control the recent strain history of the viscoelastic tissues in the participant's foot. The ICC(2,1), with absolute agreement, was computed for intra-rater (test-retest; remove-replace) and inter-rater reliability which included ICC values, 95% CI, and B&A plots (bias and limits of agreement). The results were collected, computed, and stored in a proprietary smartphone-based App. FRM and position were measured (stiffness calculated) and replicated to yield 3 trials. Test-retest ICC(2,1) were computed between trials 1 and 2 for each rater. Each participant then removed their foot from the MAP1st V2 device and the rater repositioned the foot within the device prior to collecting trial 3. Remove and replace reliability was computed between trials 2 and 3. Inter-rater reliability was computed between trials 3 for each rater. Descriptive summaries (mean, SD, SEM) of FRM (vertical displacement in response to a 50-N load), position (vertical displacement in response to a 5-N load), and stiffness (computed as the load (N) divided by displacement (mm)) were performed. Note: each rater had 30+ years-experience making biomechanical measures of the foot (one a Biomedical Engineer, one a Physical Therapist). Intra-class correlation coefficients (ICC), and their 95% confidence intervals, were computed to determine the MAP1stV2 intra-rater and inter-rater reliability using SPSS (version 27). The ICC(2,1) model was used for this 2-way random analysis with absolute agreement. Bland Altman plots were also constructed to determine the limits of agreement and bias between trials.

RESULTS: As shown in Table I, both intra-rater and inter-rater reliability were obtained for the MAP1stV2 bilaterally.

DISCUSSION: MAP1stV1 achieved an inter-rater ICC of 0.58 when normalized by truncated foot length. A ruler-based device demonstrated an inter-rater ICC of 0.06 (Morgan et al 2021). We may conclude that the design improvements to MAP1stV2 substantially improved the reliability for measuring FRM.

Table I: First Ray Mobilty Reliability ICC (95%CI)

Sitting Left				
Rater 1 - Intra-rater Reliability		***Rater 2 - Intra-rater Reliability***		***Inter-rater Reliability***
Test-Retest	*Remove-replace*	*Test-Retest*	*Remove-replace*	*Rater 1 - Rater 2*
0.954 (0.906-0.978)	0.851 (0.711-0.926)	0.679 (0.473-0.831)	0.925 (0.851-0.963)	0.847 (0.709-0.922)
Sitting Right				
Rater 1 - Intra-rater Reliability		***Rater 2 - Intra-rater Reliability***		***Inter-rater Reliability***
Test-Retest	*Remove-replace*	*Test-Retest*	*Remove-replace*	*Rater 1 - Rater 2*
0.902 (0.806-0.952)	0.888 (0.779-0.945)	0.800 (0.625-0.899)	0.894 (0.792-0.948)	0.846 (0.708-0.923)
Mean Intra-rater Reliability ICC(2,1) = 0.862				
Mean Inter-rater Reliability ICC(2,1) = 0.847				

SIGNIFICANCE/CLINICAL RELEVANCE: Individuals with first ray hypermobility may now be studied with greater reliability with a tablet-controlled, App-based technology and compared with other measures of foot structure and function. This tool for measuring first ray hypermobility, in conjunction with devices to measure rotational first metatarsophalangeal joint flexibility, arch height index, and plantar pressures, may be relevant to detecting onset and progression of clinical pathology affecting the foot and ankle although further research is required.

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