Comparing Kinematics of OpenSim Multi-Segment Foot Models During Low- and High-Demand Tasks

Karley D. Baringer[1]*, Chloe E. Baratta B.S. [1], Christopher W. Reb D.O. [2], and Jennifer A. Nichols Ph.D. [1]
[1] University of Florida, Gainesville, FL; [2] Pennsylvania State University, Hershey, PA

Introduction: The biomechanics of the foot are complex. Yet, common practice in gait analyses is to use a single-segment foot model [1] that simplifies the foot by defining it as a single rigid segment. In contrast, multi-segment foot models (MFMs) define the foot as multiple interconnected rigid segments, thereby enabling measurement of intersegmental motion. Capturing the foot's kinematic complexity is essential when analyzing demanding tasks (e.g., hopping) or evaluating foot pathologies. To our knowledge, there are two publicly available MFMs [2, 3] in OpenSim, an open-source musculoskeletal simulation platform, but they have not been directly compared. Understanding how differences in modeled kinematics affect simulation output across a variety of tasks is important for model selection. Thus, the aim of this study was to compare the joint angles across the foot and ankle estimated by these two MFMs during low- and high-demand tasks.

Materials and Methods: Joint angles estimated by the Maharaj2021 and KULeuven MFMs were compared during three tasks: walking, double-leg heel-rise, and single-leg vertical hop. Briefly, both models include the same five segments (talus, calcaneus, midfoot, forefoot, toes), but their joint definitions differ considerably. Maharaj2021 has three orthogonal degrees of freedom (DOF) at the ankle and one DOF along an oblique axis at each other joint (subtalar, midtarsal, tarsometatarsal, metatarsophalangeal). KULeuven has one DOF at the ankle and subtalar joints and two DOF at each subsequent joint; all are defined by oblique axes. To facilitate a direct comparison, equivalent motion capture data from one healthy adult (male, 23 years) input into both models. Thus, reported differences reflect differences in kinematic model, not experimental data. Experimental data were collected using a 30-camera system and a 74-marker set that combined the Helen Hayes full-body and the Rizzoli multi-segment foot marker sets. Multiple trials of each task were collected. The MFMs were scaled and joint angles for each trial were calculated using inverse kinematics in OpenSim v4.1. For comparison, all joint angles were normalized to percent activity and decomposed into components about the anatomical reference frame.

Results: Overall, there were considerable differences between the joint angles estimated by the Maharaj2021 and KULeuven models, though the magnitude of the differences was generally small. For all tasks, the largest average difference was in plantarflexion/dorsiflexion of the midtarsal joint, with an average difference of 20.6°, 14.0°, and 14.0° for vertical hop, heel rise, and gait, respectively (Fig. 1a). The smallest difference across all tasks was in inversion/eversion of the metatarsophalangeal joint (vertical hop 1.36°, heel rise 1.33°, gait 1.29°) (Fig. 1b).

Conclusion: This study highlights the importance of MFM selection when analyzing foot motion, as the underlying kinematic model affects qualitative and quantitative characteristics of estimated joint angle curves. Notably, both models were originally validated for only walking and/or running. Thus, the results of this study illustrate the need for further work exploring which model is best for capturing the kinematics of high-demand tasks, such as hopping and heel-rise, which respectively require high loading and large range of motion. Immediate future work will also evaluate to what extent our results are generalizable across a larger population.

References: **[1]** Kadaba et al. (1990) *J Orthop Res* (8):383-392 **[2]** Malaquias et al. (2017) *Comput Methods Biomech Biomed Eng* (20):153-159 **[3]** Maharaj et al. (2021) *Comput Methods Biomech Biomed Eng* (25):554-565

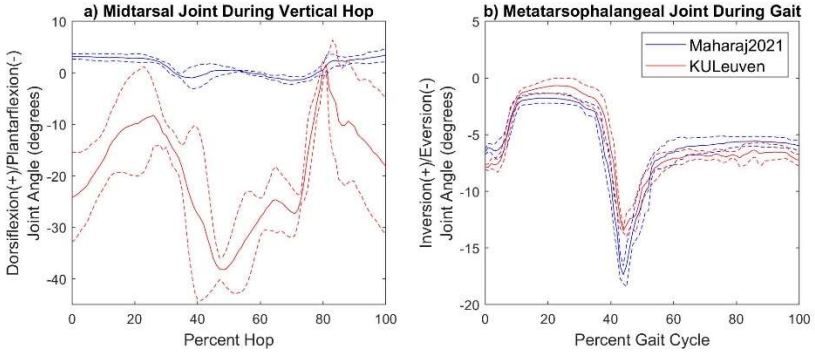

Figure 1. Mean (solid) ± std. dev. (dashed) joint angles for the Maharaj2021 (blue) and KULeuven (red) models. Representative curves are provided for the midtarsal (a) and metatarsophalangeal (b) joints, which had the largest and smallest differences between models, respectively. Representative data was selected from a total of 45 curves (3 tasks x 5 joints x 3 rotations per joint).