INSOLE: AN IN-SILICO TOOL TO PREDICT INDIVIDUAL RESPONSE TO CORRECTIVE INSOLES DURING WALKING.

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Introduction

Corrective in-shoe insole are prescribed for a range of static and dynamics foot deformities including but not limited to clubfoot, excessive eversion as well as flexible flat foot [1]. These insoles aim to provide additional support, using a specific geometry and/or stiffness to either promote or limit a specific motion of the foot. They are typically designed and prescribed based on subjective assessment of gait as well as clinical experience. This often results in limited personalization and by extension the possibility of sub optimal results. This is further limited due the time-consuming testing and manufacturing processing making the testing of multiple insoles infeasible.

Along with many other medical and clinical problems, the addition of *in-silico* techniques may allow for an improvement in personalization and by extension, improvements in function following prescription.
To do so, we aimed to develop an *in-silico* pipeline to first estimate individual subject's response to an insole of known properties. Once developed such a model can be deployed in the prescription pathway to supplement the standard design pathways.

Methods

For this proof of concept, 8 subjects with a flatfoot deformity were taken from a historical dataset containing motion capture data while walking shod with and without a corrective insole, as well as insole manufacturer information. Motion capture data was used in combination with a state-of-the-art musculoskeletal model [2] to estimate joint kinematics during walking in both conditions.

A low-fidelity insole model representation was then defined whereby insoles were modelled as a set of spring elements which develop force/torque when a specific joint is moved. In this way, these springs can limit or resist specific motions.

The predictive model used a baseline condition (i.e, shod without insole) whereby measured motion was used to reduce the MSK model and outputs to a set of joint level torques which, when applied to the model in a forward simulation would result in the measure baseline condition. With the addition of the spring insole model – the response to an insole with specific stiffness can then be estimated.

For this proof of concept, we first used a calibration phase whereby insole model parameters were optimized until a minimum difference between measured (i.e., average of all shod with insole conditions) and estimated kinematics was achieved. Optimized insole parameters were then used in another set of forward simulations for trials which were not used in the calibration process. The root-mean squared error between measured and estimated kinematics were then used to assess the accuracy of our predictive model.

Results

Representative parameter optimization results can be found in Figure 1 whereby the reference (i.e., shod without insole), measured (i.e., shod with insole), and estimate insole response are shown.

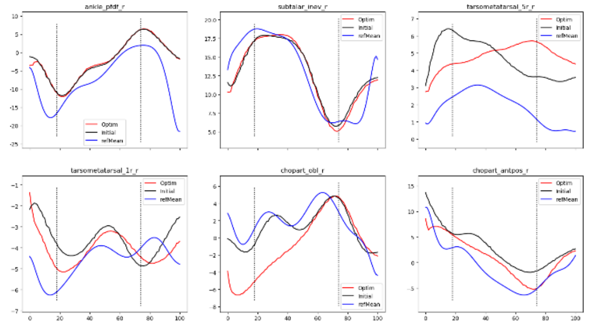

Figure 1: Example parameter optimization results. Degrees of freedom shown: ankle plantar-dorsi flexion, subtalar inversion-eversion, tarsometatarsal 1st and 5th ray, chopart oblique, and anterior-posterior. In black is the unoptimized response estimation, blue is the measured response, and red is the estimation following optimization.

Following optimization, average (±standard deviation) error between measured and estimate kinematics were 3.57 (2.55), 3.75 (1.31), 1.76 (1.19), and 3.40 (4.73) degrees for the chopart oblique and anterior-posterior, and tarsometatarsal 1st and 5th ray joints respectively.

Discussion

The developed predictive model shows a proof on concept for the implementation of a rapid low-fidelity spring-based insole model. The predictive ability of this model was tested on the same subjects who were used for calibration introducing bias toward better results. The ability to estimate insole model parameters from information available from the manufacturer would provide a more sound and robust approach and forms the basis of on-going work. Once validated, such a framework can assist the in-silico design of corrective insoles for correcting dynamic foot deformities.

References

1. Elftman et al, Foot Ankle Clin, 8:473-489,2003.
2. Malaquias et al, Comput Methods Biomech Biomed Engin, 2:153-159,2016.

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