Automatic Foot-Ground Contact Model Personalization Can Consistently Adjust Force Plate Positions

Spencer T. Williams, Claire V. Hammond, Benjamin J. Fregly
Department of Mechanical Engineering, Rice University, Houston, Texas, United States
Email: stwilliams@rice.edu

Summary

Small errors in force plate positions can significantly impact downstream kinetic analyses. This study evaluates a novel computational method to reduce these errors using physics-based force plate position adjustments added within an existing FGC model personalization process. The results indicate that this method successfully and robustly adjusts experimental data to be more consistent with physics.

Introduction

The optimization of treatments for movement impairments using personalized neuromusculoskeletal models requires the creation of models consistent with both rigid body dynamics and the available experimental data [1,2]. Automatically personalized foot-ground contact (FGC) models have been shown to improve the tracking of experimental data in dynamically consistent gait simulations [3]. However, simply tracking experimental kinematic and force data may make unsafe assumptions about sources of error. These “ground truth” data can be inconsistent if a force plate position is not known accurately within a lab coordinate system, resulting in incorrectly calculated center of pressure (CoP) locations; even CoP errors of less than a centimeter can cause errors of over 10% in downstream joint moment calculations [4]. This study evaluates the efficacy and reliability of a novel computational method to reduce force plate data errors by incorporating physics-based force plate position adjustments into an existing FGC model calibration process [5].

Methods

The FGC calibration process used an OpenSim [2] model of a post-stroke subject walking on an instrumented treadmill at a self-selected speed of 0.8 m/s. Personalized FGC models were calibrated for both feet simultaneously using the Ground Contact Personalization (GCP) tool in the Neuromusculoskeletal Modeling Pipeline [5]. For each run, GCP placed a dense grid of contact elements, linear springs with nonlinear viscous damping and linear viscous friction, across the bottom of each foot, calibrating contact element parameters to reproduce experimental ground reactions by making minimal adjustments to experimental foot kinematics. This standard process was followed without modifications for Run 1. For Run 2, the FGC model optimization was allowed to adjust freely the positions of the left and right force plates in the ground plane, effectively changing ground reaction moments (GRMs) by changing the point about which moments were calculated. Run 3 used the same settings as Run 2 except the experimental force plate data file was replaced with a file containing the adjusted plate positions from the Run 2 solution, thereby testing the solution robustness. Finally, Runs 4-11 were the same as Run 3 except in each case, errors of 1 cm were artificially introduced in various directions to initial force plate positions to test the consistency of the results from different initial guesses.

Results and Discussion

The personalized FGC models had lower tracking errors with adjusted force plate locations (Table 1). Frontal plane GRM errors were especially reduced, decreasing from 5.655 to 1.771 Nm on the right from Run 1 to Run 2. Final positions and tracking errors were highly consistent across Runs 2-11.

Conclusions

These results indicate that adjusting force plate positions in FGC model calibrations produces adjusted ground reaction data more consistent with physics. A limitation of this study is that the actual location errors are unknown. Nonetheless, these results support further investigation of this approach.

Acknowledgments

This work was supported by grant 1842494 from the U.S. NSF and grant R01 EB030520 from the NIH.

References

[1] Meyer AJ et al. (2016). *Bioeng. Biotech.*, **4**.
[2] Seth A et al. (2018). *PLos Comput. Biol.*, **14(7)**.
[3] Williams ST et al. (2024). *Proceed. Am. Soc. Biomech*.
[4] McCaw ST and DeVita P (1995). *J. Biomech.*, **28(8)**: 985-988.
[5] Hammond CV et al. (2024). *bioRxiv*.

Table 1: RMS tracking errors in GCP Runs. Force plate position shifts for Runs 4-11 are reported relative to the new positions obtained in Run 2. Moments were calculated about midfoot superior markers projected onto the floor as within GCP [5]. Results are averaged for Runs 4-11.

	Rotation (°)	Translation (mm)	Force (N)	Moment (Nm)	Right plate shift (mm)	Left plate shift (mm)	Runtime (min)
Run 1	1.196	7.075	7.523	2.932	0	0	23.99
Run 2	0.636	5.334	5.204	1.139	19.213	23.430	11.66
Run 3	0.632	5.212	5.238	1.141	0.242	0.226	9.63
Runs 4-11	0.632	5.261	5.218	1.140	0.216	0.197	11.37