CAN EMG-DRIVEN MUSCULOSKELETAL MODELS ESTIMATE INDIVIDUAL MUSCLE DISPLACEMENTS?

Christopher P. Cop (1), Kristen L. Jakubowski (2, 3), Alfred C. Schouten (1, 4), Bart Koopman (1), Eric J. Perreault (5, 6), Massimo Sartori (1)

1. University of Twente, NL; 2. Emory University, USA; 3. Georgia Institute of Technology, USA; 4. Delft University of Technology, NL; 5. Northwestern University, USA; 6. Shirley Ryan AbilityLab, USA

Introduction

Many movement disorders, including those caused by stroke and spinal cord injury, affect the neural control of muscle force and stiffness. To address this, neurorehabilitation seeks to restore healthy control patterns for each patient. In this context, electromyography (EMG)-driven musculoskeletal models are computational tools that enable studying relationships between muscle activation, muscle dynamics, and joint dynamics. EMG-driven models follow a bottom-up approach, i.e., they obtain joint level variables (such as joint torques and stiffness) from their constituting muscle-tendon units (MTUs), typically modelled as Hill-type muscle models. Several parameters of each constituting MTU are optimized to minimize the fitting error between reference and estimated joint torques, and a recent study proposed to minimize the fitting errors between reference and estimated joint torques and stiffness simultaneously [1]. Due to technical challenges, EMG-driven models are mostly validated at the joint level, and whether the neuromechanical states of the underlying MTUs are physiologically consistent remains an open question. This study presents the first attempts to validate EMG-driven model-based estimates of gastrocnemius medialis (GM) muscle displacements against experimental measurements via B-mode ultrasonography.

Methods

An experimental approach was used to obtain reference GM muscle displacements and joint torques and stiffness [2]. Four healthy young adults were seated with their right foot rigidly secured to a rotary motor, which was instrumented to measure ankle torque and displacement. Participants completed two different tasks: a torque-matched task and an EMG-matched task, where participants produced voluntary plantarflexion torque or average triceps surae EMG at 15% of their maximum, respectively, with the aid of real-time visual feedback. The motor moved the subject's ankle through a 20-degree sinusoidal motion at 0.5 Hz. Small stochastic perturbations were superimposed on the large sinusoidal movement to quantify ankle impedance using time-varying system identification [3]. We evaluated the stiffness component of the estimated ankle impedance. B-mode ultrasound of the GM muscle-tendon junction was used to track muscle displacement.

Experimentally recorded EMGs and joint angles were used to drive an EMG-driven model [1]. For each subject, reference joint torque and stiffness from the torque-matched task were used to calibrate the EMG-driven model, while the EMG-matched task was only used for validation purposes. Modeled muscle displacements were defined as changes in GM fiber length (l^{GM}) in the direction of the Achilles tendon, i.e., $l^{GM}\cos\varphi^{GM}$, where φ^{GM} is the GM pennation angle.

Results

Preliminary results show that the EMG-driven model that was calibrated solely at the joint level accurately characterized a muscle-level variable, i.e., displacements of the GM muscle (Table 1). Fitting errors were greater in the task that was not used to calibrate the model.

Subject	Torque-matched task	EMG-matched task
1	26	26
2	14	28
3	31	41
4	13	111

Table 1: Normalized error between modeled and experimental GM muscle displacements. Results expressed as percentage of experimental RMS.

Discussion

While our results (Table 1) show the EMG-driven models described experimental data well in the task used to calibrated the models, fitting errors were greater in the task not used to calibrate the model. This suggests that our calibrated models are not yet generalizable to any type of movement. Our results emphasize the need to validate complex musculoskeletal models across spatial scales. We envision that our novel approach combining expertise from different scientific communities will help us improve model parameter calibration, eventually leading to calibrated EMG-driven models that can simulate functional movements relevant to neurorehabilitation.

References

1. Cop et al., *J Biomech* **145**: 111383, 2022.
2. Jakubowski et al., *IEEE Trans Biomed Eng* **69**: 12, 2022.
3. Ludvig et al., *IEEE Trans Biomed Eng* **59**: 2012.

Acknowledgements

Supported by ERC Starting Grant INTERACT (803035), NIH R01AR071162, F31AG069412, and ASB GIA.