Prepared by Samuel Hamner
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FAQs

ABOUT OPENSIM

Q: What is the relationship between muscle forces and EMG data that we have collected?

A: Muscle models in OpenSim generate force based on three parameters: activation, muscle fiber length, and muscle fiber velocity. The muscles have "control" inputs we call excitations, and the models represent the electro-mechanical delay from these excitations to activation with a first order differential equation. From more details on the theory behind these muscle models, check out this great review paper by Felix Zajac:

Zajac FE. Muscle and tendon: properties, models, scaling, and application to biomechanics and motor control. Crit Rev Biomed Eng. 1989;17(4):359-411.

Q: What anthropometric database is used for the model scaling?

A: OpenSim does not use a database for scaling. The model is scaled based on measurements of experimental markers. Check out Chapter 14 of the OpenSim User's Guide for more details on scaling.

Q: Have you considered the delay within activation dynamics in your model? If yes, how?

A: Yes, the muscle models in OpenSim model the electro-mechanical delay between muscle excitation (or the electrical neural signal sent to the motor-neuron junction) and activation (i.e., the level of force production). From more details on the theory behind our muscle models, check out this great review paper by Felix Zajac:

Zajac FE. Muscle and tendon: properties, models, scaling, and application to biomechanics and motor control. Crit Rev Biomed Eng. 1989, 17(4):359-411.

Q: How do you incorporate BIODEX data into your simulations?

A: BIODEX data can be used to determine the strength, or torque generating capacity of your subject. Researchers have used this information to modify the optimal muscle forces used in their model. For an example, check out the paper by Anderson & Pandy from 2001. They explain, "Values of peak isometric muscle force and tendon slack length were adjusted so that the maximum isometric torque-angle curves for each joint in the model matched average torque-angle curves measured for the five subjects."

Anderson FC, Pandy MG. Dynamic optimization of human walking. J Biomech Eng. 2001; 123(5):381-90.

Q: Can one extract the muscle force magnitudes, points of origin and direction of action? What is the reference frame used?

A: While this is not currently a pre-packaged analysis in OpenSim, it is definitely possible to extract this information with a plug-in or a custom API main program. I believe there are other researchers working on something similar to export muscle force information into a finite element analysis.

Q: What are typical settings that are modified during the RRA?

A: RRA is an optimization algorithm whose goal is to minimize the non-physical "residual" forces acting on a dynamic simulation. The settings modified for RRA are the inputs to the optimization algorithm, which include the excitation limits (i.e., min/max controls) for the residual actuators along with the tracking weights for each of the coordinates (i.e., joint angles).

Q: I am new to these kind of simulations and would like to make a new model of a simple experimental set up (in this case an inverted pendulum). What software could I use to generate this for dynamic analysis?

A: For dynamic simulations of rigid body systems, like a double pendulum, check out Simbody(TM), which is the rigid-body dynamics engine used by OpenSim. It is open-source and freely available with a well-tested and stable API. The project page is https://simtk.org/home/simbody.

Q: Is there anyway that you can incorporate stretch activation of muscle to try and get the model to predict the activation of muscle before foot strike?

A: Sure! You could develop a custom controller in the OpenSim API that is based upon the stretch of muscle or tendons in the model and map that back to predicted activations. This is definitely something you could do with OpenSim.

Q: Is the orientation (i.e., pennation angle) or constitution of fibers (e.g., slow vs. fast) taken into account in the muscle models?

A: Yes, we do model the orientation, or pennation angle, of muscle fibers, but no, we do not model slow versus fast twitch fibers. For more details on the theory behind these muscle models, check out this great review paper by Felix Zajac:

Zajac FE. Muscle and tendon: properties, models, scaling, and application to biomechanics and motor control. Crit Rev Biomed Eng. 1989;17(4):359-411.

Q: Has anyone used Opensim to simulate pathological gait, like stroke patients or OA patients? What is the difficulty of simulating pathological gait?

A: Yes, students and researchers in the Neuromuscular Biomechanics Lab at Stanford have created muscle-actuated simulations of individuals with cerebral palsy with a crouch gait. Check out a recent study led by Kat Steele.

Steele, K.M., Seth, A., Hicks, J.L., Schwartz, M.S., Delp, S.L. Muscle contributions to support and progression during single-limb stance in crouch gait. Journal of Biomechanics, vol 43, pp 2099-2105.

Q: Would it be possible to open a C-3D file directly in OpenSim?

A: This is a popular feature request, and we are working on getting it implemented for a future release of OpenSim.

Q: Why would you need to scale the model's muscle strength at all? Does this reflect the model's development from cadaver data?

A: Yes, the optimal force or max strength of the muscles in the model used for this study were based on Delp, 1990 (see reference below), which determined muscle parameters from cadavers. While the strength of the model was not increased to study running (Hamner et al., 2010) , other researchers have noticed that the "strength" (i.e., optimal force) of the muscles has to be increased for movements with higher forces and accelerations, like running and cutting, or for pathological gaits, such as crouch gait.

Delp SL et al., An interactive graphics-based model of the lower extremity to study orthopaedic surgical procedures. IEEE Trans Biomed Eng. 1990; 37(8):757-67.

Q: Can you briefly describe available ways to compute muscle forces in OpenSim besides CMC?

A: Yes, OpenSim has another tool called Static Optimization, which has been used by numerous researchers to estimate muscle forces. Check out this paper describing static optimization:

Anderson FC, Pandy MG. Static and dynamic optimization solutions for gait are practically equivalent. J Biomech. 2001,34 (2):153-61.

Q: Do you take synergistic muscles into account?

A: No, we do not explicitly model synergistic muscle groups. Computed muscle control treats each muscle as an independently controlled actuator. However, our results show that CMC activates muscles in the observed synergistic groups.

Q: What muscle models are included in OpenSim and what do you have to develop yourself? Are there some generic muscle models available get one started?

A: There are 3 muscle models implemented in OpenSim (listed below). For the running study, I used Thelen2003Muscle.

(1) Delp1990Muscle, based on the model described in Delp et al., 1990.

Delp SL et al., An interactive graphics-based model of the lower extremity to study orthopaedic surgical procedures. IEEE Trans Biomed Eng. 1990; 37(8):757-67.

(2) Schutte1993Muscle, based on the model described in Schutte et al, 1993..

Schutte, L.M., Rodgers, M.M., Zajac, F.E., Glaser, R.M., 1993. Improving the efficacy of electrical stimulation-induced leg cycle ergometry: an analysis based on a dynamic musculoskeletal model. IEEE Transaction on Rehabilitation Engineering 1,109–125.

(3) Thelen2003Muscle, based on the model described in Thelen, 2003.

Thelen DG. Adjustment of muscle mechanics model parameters to simulate dynamic contractions in older adults. J Biomech Eng. 2003; 125(1):70-7.

Also, check out Section 4.4 of the OpenSim Developer's Guide to learn how you can use the OpenSim API to create a custom muscle model.

Q: What anthropometric database is used for the model scaling?

A: OpenSim does not use a database for scaling. The model is scaled based on measurements of experimental markers. Check out Chapter 14 of the OpenSim User's Guide for more details on scaling.

Q: When you are scaling the generic model to match the subject, how do you account for the difference in bone length, like, if someone has a proportionally shorter tibia?

A: Scaling in OpenSim scales each body segment independently based on measurements of markers placed on that segment. Check out Chapter 14 of the OpenSim User's Guide for more details on scaling.

Q: Getting back to the muscle force question, are the muscle forces not scaled based on the subject's weight (compared to the generic model weight)?

A: No, the scale tool in OpenSim does not automatically scale muscle forces based on the geometric-based scaling (i.e., scaling based on distance measurments between markers) or the mass scaling. However, you can scale muscle forces in the model based manually if you have a criterion for doing this.

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ABOUT RUNNING SIMULATION

Q: Would you tell us more about how you modeled the ground interaction?

A: In the induced acceleration analysis used in this study of running, we modeled foot-floor interaction with a set of kinematic constraints we call rolling without slipping. This custom constraint does a good job of reproducing the experimentally measured ground reaction forces and moments. However, this is not a contact model that could be used in a forward simulation, as the constraints are applied based on the measured location of the center of pressure. But, OpenSim does have contact models, such as the Hunt-Crossley and Elastic Foundation models, that can be used to model contact for forward simulations.

Q: What marker set did you use for this project?

A: For this study we used a marker set based on principles described in Kadaba et al., 1990.

Kadaba MP, Ramakrishnan HK, Wootten ME. Measurement of lower extremity kinematics during level walking. J Orthop Res. 1990, 8(3):383-92.

Q: Was the generic model strong enough to run, or did you have to increase the muscle strength?

A: Yes, the model used (which was based on the example model called gait2392 in OpenSim) was strong enough to run. However, other researchers have noticed that the "strength" (i.e., optimal force) of the muscles has to be increased for movements with higher forces and accelerations, like running and cutting, or for pathological gaits, such as crouch gait.

Q: Have you measured surface EMGs? If yes, have you approximated some of muscle EMGs from other muscles sEMGs since we cannot measure all muscles surface EMGs?

A: Yes, for this study we measured surface EMG signals for 8 muscles, and we compared to 12 muscles from speed-matched data from the literature (Cappellini et al., 2006). However, CMC does not know about the EMG recordings a priori and predicts muscle excitations/activations based on an optimization criterion of minimizing the sum of squares of muscle activation. We then compare these predictions to what can be measured. But, our model represents 76 muscles, so we have to make the assumption the other predicted muscle activations are reasonable if we match the 12 we can record with EMG.

Cappellini G et al. Motor patterns in human walking and running. J Neurophysiol. 2006; 95(6):3426-37.

Q: Did you try to simulate running also with static optimization?

A: Yes, and while the predicted forces were similar, preliminary static optimization results did not match experimental data very well, especially at foot strike when rapid increases in ground reaction forces are observed. While some researchers have suggested that static optimization might be used to predict muscle forces during walking, I am skeptical of using static optimization for running. For example, if a forward simulation is created with results from Static Optimization, the simulated motion will not match the observed motion recorded in the lab. That is why CMC was implemented, as it uses a PD tracking controller in conjunction with Static Optimization to predict muscle excitations/activations that will generate the observed motion in a forward simulation.

Q: Were torques used to drive the arm action? How big were they?

A: Yes, for this simulation of running, the arms were driven by torque actuators, and the shoulder was modeled as a simple ball-and-socket joint. Shoulder "flexion" torques were the largest torque with a peak near 15 N-m. Elbow extension torques were the second largest with peaks near 7 N-m.

Q: Did you use a 1 degree of freedom (dof) knee?

A: The model does have a 1 dof knee, but it is not a pure pin or revolute joint, but has translations coupled with rotation to better describe real knee motion. Check out this paper by Ajay Seth for a detailed description of the knee model:

Seth A, Sherman M, Eastman P, Delp S. Minimal formulation of joint motion for biomechanisms. Nonlinear Dyn. 2010; 62(1):291-303.

Q: Are the contributions of individual muscles to propulsion and support necessarily additive, or might there be complex interactions (not accounted for by the present analysis)?

A: Yes, assuming the rigid-body dynamics framework used by many researchers to study biomechanics, the sum of accelerations due to forces from muscles, gravity, and velocity effects, should equal the measured acceleration of body mass center. This concept, sometimes referred to as 'superposition', is true because the equations of motion for a rigid-body, musculoskeletal model is a linear system of equations. I actually like the explanation of superposition in this Wikipedia article:

http://en.wikipedia.org/wiki/Superposition_principle

Q: Did you filter the input data (e.g. ground reaction forces) or the outputs (muscle forces)?

A: Yes, for the running study we filtered the measured marker data and ground reaction forces both at 20 Hz with a low pass FIR filter.

Q: Which was the muscle most responsible to propulsion?

A: For this simulation, gastrocnemius and soleus (the largest ankle plantarflexors) made the largest contributions to propulsion (i.e., forward acceleration of the body mass center) during mid-to-late stance.