

# EMG-INFORMED COMPUTED MUSCLE CONTROL FOR DYNAMIC SIMULATIONS OF MOVEMENT

<sup>1</sup>Emel Demircan, <sup>1,2</sup>Jason Wheeler, <sup>1</sup>F. Clay Anderson, <sup>1</sup>Thor Besier and <sup>1</sup>Scott Delp

<sup>1</sup>Stanford University; email: [emeld@stanford.edu](mailto:emeld@stanford.edu)

<sup>2</sup>Sandia National Laboratories

## INTRODUCTION

Computed Muscle Control (CMC) is an efficient method for estimating muscle activations and forces from kinematic and ground reaction force data [1]. However, it can fail to replicate some muscle activation characteristics found in electromyographic (EMG) recordings. For instance, muscles often activate in anticipation of events such as heel strike, and these anticipatory responses are not predicted by CMC. Also, when joint accelerations are high, for instance at the ankle during heel strike or toe-off, CMC will often predict co-contraction strategies to track the kinematics when gravity or inertia were actually providing the necessary forces. Previous efforts to reconcile these differences have attempted to implement constraints on muscle activations based on recorded EMG data [2]. This can cause simulations to fail if the constraint criteria cannot be met or can result in unwanted effects on unconstrained muscles. We present here a modified version of CMC that better reproduces measured EMG data without constraining muscle activations.

## METHODS

Conventional CMC estimates muscle forces using an optimization criteria that minimizes muscle stress. In this solution kinematics are treated as constraints. We modified the CMC minimization function  $P$  by adding a term related to the difference between the muscle excitation  $x$  and the filtered EMG data  $x_{emg}$  for some muscles, specifically

$$P = \sum_{i=1}^{n_m} \sigma_i^2 + \sum_{k=1}^{n_e} w_k * f(x_k - x_{emg_k}) ,$$

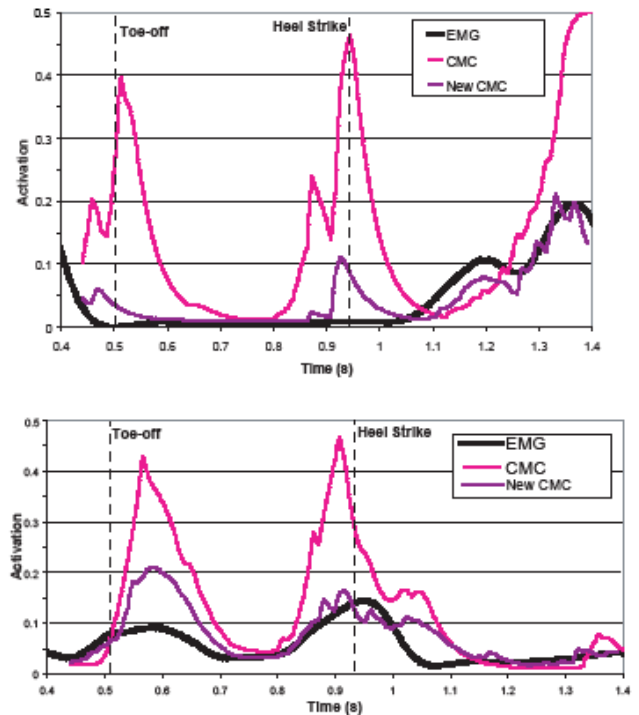
where  $n_m$  is the number of muscles in the simulation,  $\sigma$  is the muscle stress,  $n_e$  is the number of muscles with EMG data,  $w$  is a weight and  $f$  can be any function. The first term in  $P$  is used for conventional CMC. The second term is added to track EMG data for a subset of muscles. Kinematics are still treated as constraints. When no EMG data are supplied, this reverts to conventional CMC.

Muscle forces were estimated using conventional and EMG-informed CMC for one male subject walking at 1.75 m/s. Marker, force plate, and EMG data were recorded simultaneously using an 8-camera Vicon system (OMG plc, Oxford UK). Inverse kinematics and residual reduction algorithms for approximately one gait cycle were performed in OpenSim [3] using a scaled lower limb model [4]. Joint kinematics and kinetics were then used to estimate muscle forces using both the conventional CMC and EMG-informed CMC algorithms. EMG data were processed by high-pass filtering to remove motion artifacts, full-wave rectifying and then low-pass filtering at 6 Hz to generate a linear envelope. These data were then normalized to a maximum isometric muscle contraction. For the purpose of testing EMG data were tracked for tibialis anterior and medial gastrocnemius as these were observed to deviate from EMG data with conventional

CMC, particularly at heel strike and toe-off. In the EMG-informed we used the square of the difference between the desired and actual excitation.

## RESULTS AND DISCUSSION

Figure 1 shows the activations from both simulations, along with filtered EMG data for the medial gastrocnemius (top) and tibialis anterior (bottom).



**Figure 1:** Conventional and modified CMC simulation results along with filtered EMG data for medial gastrocnemius (top) and tibialis anterior (bottom).

In the original CMC simulation, the ankle muscles are active around heel strike and toe-off, likely due to the high joint accelerations and kinematic constraints, while the EMG data shows the muscles are only slightly activated. Muscle forces more closely matched EMG data with the EMG-informed algorithm in all cases compared to conventional CMC. Interestingly, because this was an agonist/antagonist pair, when only a single muscle was tracked, predictions for both muscles were improved. These results indicate that EMG-informed CMC can be used to improve dynamic simulations to better match experimental data.

## REFERENCES

1. Thelen DG, et al. *J Biomech.* **36**:321-328, 2003.
2. Liu MQ, et al. *J Biomech.* In press.
3. Delp SL, et al. *TBME.* **55**:1940-1950, 2007.
4. Delp SL, et al. *IEEE Transactions on Biomedical Engineering.* **37**:757-767, 1990.