# A biomechanical model for the validation of modular control in balance

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***Abstract*— Recent research on neuromuscular organization in humans suggests the adoption from the nervous system of a modular control strategy to control the execution of mediolateral postural sway movements. However, the functional validity and the contribution of each module to the final movement is not so clear. In this study we use a musculoskeletal simulation platform to observe the functional contribute of each module to the execution of postural sway movements. The results from the simulation provide important indications for the implementation of biomimetic neuroprostetic controllers.**

## I. Introduction

Accordingly to the hypothesis of modular organization of the central nervous system (CNS), spatiotemporal activations of muscles can be described with the combination of a lower dimensional set of motor modules also known as muscle synergies [1]. In our recent study [2] we extracted muscle synergies on healthy subjects during the execution of postural sway movement in the mediolateral (ML) direction. We found that in each subject, two modules were sufficient to describe the EMG activity of 8 muscles in one leg. This observation suggested the possibility to use these modules for the implementation of a neuroprosthetic controller for the rehabilitation of postural control [3].

However, these modules could not contain all the essential informations for the correct realization of the task. The limited number of muscles considered in the analysis could not be enough to reproduce the task neither with the original signal. Eventually, even the variability in the EMG signals not represented by the modules (corresponding to the 25%), could still have a fundamental role in the execution of the task as well.

Simulation offers a means of integrating experimental data, anatomical models, and dynamic principles to thoroughly validate the functional meaning and potentialities of synergies, representing a virtual testbed for the application of modular control with FES.

In the present study we used a simulation platform including an OpenSim and MATLAB interface [4] to perform forward dynamic simulations to validate the motor modules extracted in [2] by answering the following questions: i) Is it possible to generate stable postural sway movements using only the muscles considered by the study? ii) What is the contribution of each synergy to CoM displacement?

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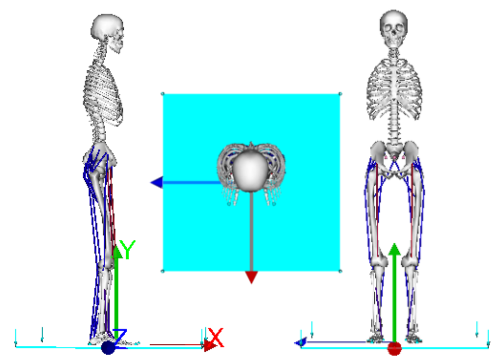



Fig. 1: Initial position of the model.

## II. Materials and Methods

### *Musculoskeletal Model and Platform Dynamics*

A three-dimensional musculoskeletal model with 24 muscle-tendon actuators and 14 DOF was created in OpenSim software. The model was scaled to represent the average size subjects using previously collected anthropometric data. The 8 muscles were selected to match the experiment on healthy subjects described in [2]. These muscles are gluteus maximus (GMAX1,2,3), gluteus medius (GMED1,2,3), tensor fascia latae (TFL), rectus femoris (RF), biceps femoris (BF), gastrocnemius lateral (GAS), soleus (SOL), and tibialis anterior (TA). Ground contact points in the feet have been modeled with 5 free-to-move contact points for each foot.

As initial conditions, the model was kept in stable bipedal standing position, with the vertical projection of the center of mass (CoM) in the middle of the support surface (Fig. 1).

### *Muscle-set validation*

Computed muscle simulation (CMC) [5] was used to track the CoM. CMC uses desired kinematics and ground reaction forces to calculate the required muscle activity. The desired trajectories for CoM were defined using a sinsoidal function of frequency f=0.5 Hz.

Pelvis residuals shown in the equation of the motion ($F = M * A + residuals$) are due to the errors between experimental and simulation kinematics and we tried to reduce the residuals to make more realistic simulations. Supplementary torques (reserves actuators) were added to the articulations of each joint to compensate the work of the missing muscles when needed.

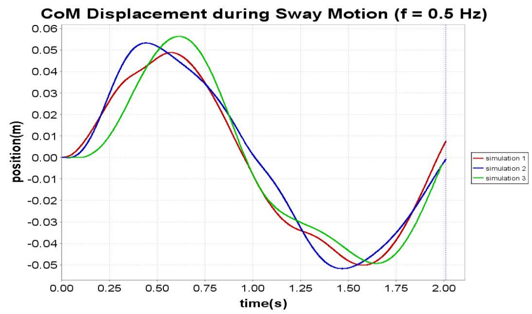



Fig. 2: Simulation results from CMC over a sway cycle (f = 0.5 Hz). The difference on the simulations 1-3 is the result of the difference between the CMC controller joint tracking target weights.

*Modules dynamical effects*

2 modules extracted from each of the 8 subjects studied in [2] while performing ML postural sway movements at the frequency of $0.5$ Hz were used. For each one of these modules a simulation has been set up, where only the selected module was activated with a constant activation signal of $0.75$. CoM displacement in the three directions were recorded for the first 200 ms. The absence of an active postural control makes the model fall uncontrolled after this period (see Fig. 3b).

## III. Results

*Muscle-set validation*

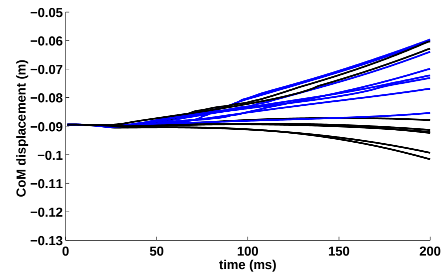
The model has been able to repeatedly complete the sway cycle for each selected frequency, by using the available muscles 2. Both residuals and reserves were kept low in the model. Low pelvis residuals ($< 0.8N$) are an indication of the bounty of the simulation, while values of reserves in the articulation, varying between $21N$ and $-9N$, are compatible with the amount of force that could have been generated from the missing muscles. This indicates that the missing muscles are needed for the stabilization of the movement but not necessary for the execution of the swing in the ML direction.

*Modules dynamical effects*

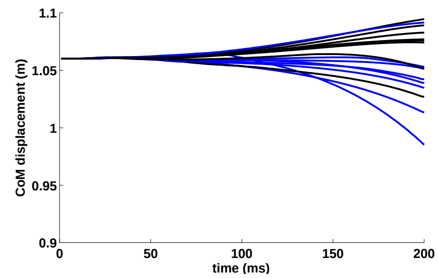
The activation of each module in simulation was capable to generate an observable displacement of the CoM in a specific direction. In particular, from 3c we can appreciate that module 1 generates a larger displacement (equivalent to higher forces) in the ML directions, for all subjects, while the effects of module 2 are not so evident. For what concerns AP direction, in all except one cases module 1 moves the CoM forward, and module 2 backwards.

## IV. Conclusions

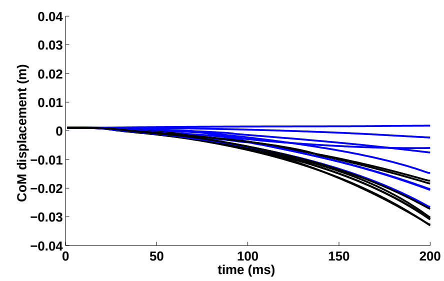
Firstly, we demonstrated that the 8 muscles considered in this study have the potentials to generate ML swing movements. Secondly, the action of each module has been observed. Module 1 provides an impulse in both the opposite lateral side and the backward direction, while module 2 generates an impulse in the frontal direction but has a trascurable effect in the ML direction. In healthy subjects the AP contribute is probably compensated by the remaining muscles not considered in this study. However, an impaired subject stimulated with FES using these patterns of activations could not have the ability nor the time to react, so this effect should be taken into account for the design of novel biomimetic neuroprostetic controllers.




(a) AP displacement.




(b) Vertical displacement.




(c) ML displacement.

Fig. 3: CoM displacement along the three axes. Black lines represent the first module for each of the 8 subjects. Blue lines the second module.

## References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