DOES MASS INFLUENCE PREDICTED MUSCLE ACTIVATIONS IN UPPER LIMB ISOMETRIC TASKS?

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Introduction

Sensitivity analyses have explored the precision of a model's muscle parameters and bone placement required for accurate gait analysis [1, 2], but few studies explore the mass parameter. Mass scaling is considered an essential step to improve prediction accuracy of biomechanical variables, such as muscle activations, estimated from models and simulations [3] because the mass parameter defines the weight of a model's rigid bodies and weight is known to vary across people. Understanding the extent to which predicted activations are sensitive to mass changes in upper limb models is important to identify 1) the required accuracy of subject's weight and 2) shortcomings of current models and their predicted activations.

In this study, we characterize how model mass influences simulations of upper limb isometric tasks. We specifically examine how the mass parameter influences predicted muscle activations when interacting with maximum isometric force (F_{max}) and optimal fiber length (OFL), as these parameters are often scaled when adjusting model size and strength. We evaluate if the mass parameter's influence increases with proximal upper limb tasks, as segment mass increases from distal to proximal. Lateral pinch, wrist extension, and elbow flexion, were chosen as representative isometric tasks at the hand, wrist, and elbow.

Methods

Six hundred unique parameter sets were generated by adjusting F_{max}, OFL, and mass to determine how mass interacts with muscle parameters to influence muscle activation. Two datasets, with 100 parameter sets each, were generated: (1) the F_{max} dataset varied F_{max} from -30% to +20%, and (2) the OFL dataset varied OFL from -10% to +20%. The mass of the two datasets was then changed by -25%, 0%, and +25%. The ranges for mass, F_{max}, and OFL were determined based on reported values for hypertrophy, atrophy, osteoporosis, and osteopetrosis [4,5].

Computed muscle control was performed for 1,800 simulations in OpenSim 4.1 to estimate muscle activation. For these simulations, each parameter set was applied to a full arm model [6] and a thumb model [7]. The thumb model was used to simulate a 40 N lateral pinch. Isometric wrist extension was performed with a 100 N target force at the third metacarpal, and isometric elbow flexion was performed with a 200 N target force at the distal radius. Gravity was set to 9.81 m/s^2 and directed inferiorly for all simulations. The selected target forces were half the baseline model's maximum force for each task.

OpenSim predicts normalized muscle activations, so all activations are values between 0 and 1. Because consistent activations were generated throughout each isometric task, the average muscle activation across task was calculated. A one-way ANOVA was performed in Python to identify significant differences in muscle activation for simulations of different mass in isolation within the OFL or F_{max} datasets.

Results and Discussion

Across simulations with different masses, muscle activations did not exhibit physiological changes even in the presence of statistical significance (Fig. 1). Significant differences in muscle activations were only when mass was varied in the OFL dataset. For lateral pinch a single muscle had significant ($p<0.05$) differences in the activation, while isometric wrist extension and isometric elbow flexion had 3 and 5 muscles with significant differences, respectively. This statistical significance did not translate into physical differences as there were not substantial changes in activation. For example, the largest activation range between models with the same OFL percent change was only 0.0236. This means for two models on opposite extremes of mass scaling, their predict activations were within 0.025 of each other.

These simulations suggest that changes in mass do not meaningfully alter predicted activations for isometric upper limb tasks. It was originally hypothesized that increased mass would require more activation to achieve target forces since isometric tasks oppose gravity. It is believed that mass scaling did not affect predicted activations because either 1) the bone masses are mostly under 1 kg, so a 25% change does not generate large weight differences, or 2) the isometric tasks rely less on inertial terms, which is seen by similar trends across tasks even as inertia increases from the hand to the forearm. In developing subject-specific OpenSim models for isometric upper limb tasks it may be appropriate to forgo customizing bone segment masses.

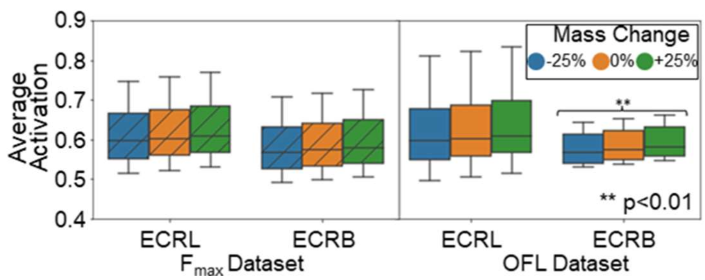

Figure 1: Representative average muscle activation from isometric wrist extension simulations showing changes in activation due to mass.

Significance

This work shows that when performing OpenSim simulations of isometric upper limb tasks mass scaling will not influence predicted muscle activations in a physiologically significant manner. The study is currently limited by having only simulated static isometric tasks, and mass may have greater influence in tasks with high speeds or large ranges of motions.

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