Finding patterns in the noise: a method for control parameter reduction for predictive neuromuscular simulations

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Summary

Older adults exhibit a relatively lower neuromuscular capacity that affects their ability to move under different conditions. While predictive neuromusculoskeletal simulation presents a means to study compensation strategies, biologically-inspired control models suffer from the curse of dimensionality, making it difficult to assess the importance of and realism of each control parameter. In this study, we conducted numerous sit-to-walk simulations using models that exhibit different levels of age-related decline in capacity. We determined a minimal subset of reflex control parameters needed to predict sit-to-walk compensation strategies.

Introduction

Standing up from a chair is approximately performed over 60 times daily and becomes increasingly challenging with age. Predictive neuromusculoskeletal simulations can offer valuable insights into how neuromuscular capacity, reinforcement, sensory integration, and adaptation interact during this movement. For this purpose, a validated planar neuromusculoskeletal model with reflex-based muscle control was previously developed to simulate sit-to-walk transitions, using a biologically inspired control architecture [1].

While the framework successfully simulated sit-to-walk adaptations under varying conditions (e.g., seat height, foot placement), reduced muscular/neural capacity, and altered movement objectives (e.g., pain) [2], its main limitation is the large number of model parameters, requiring reoptimization for each condition—something humans neither can nor need to do in reality. To address this, we are developing a more advanced high-level controller with fewer control parameters, without losing the biologically inspired reflex-based control architecture. This study marks the first step in that process, aiming to reduce requisite control parameters and move toward a more generalized robust control framework.

Methods

We began with a validated planar musculoskeletal model (11 DOF, 20 muscles) and a reflex-based control framework consisting of a two-phase stand-up controller and a gait controller[1]. Using this model, we systematically simulated 729 conditions by combining three seat heights with 243 muscular capacities varying maximum isometric force of muscle groups (100%, 87.5%, and 75%) to reflect age-related declines in four key muscle groups: hip extensors, knee extensors, knee flexors, and plantarflexors. In each condition, the optimization adapted reflex gains accordingly. Of the simulations generated, outcomes were classified based on simulation duration and distance into three classes: Success (147) where the model completed the task over a duration of 6s and greater than 3m, Intermediate (53) where the model completed the 6s with distance less than 3 m, and Failure (529) where the model fell and did not complete the 6s.

Using a decision tree, we mapped from conditions to each class. Since this mapping was able to predict classes correctly, we proposed the existence of a minimal optimized reflex parameter set that would map to our classes. To ensure optimality, our optimizer, CMA-ES, requires multiple runs in parallel. As these parallel simulations are in progress at this time, we focused on the conditions in the Success class since they represented optimized cases. We used Multi-Task Lasso parameter selection to determine a linear model with a reduced set of reflex parameters.

Results and Discussion

The linear model required a reduced set of 108 of the 551 reflex parameters, to map conditions of the Success class. The reduced feature set associated with our stand-up controller is illustrated in Figure 1.

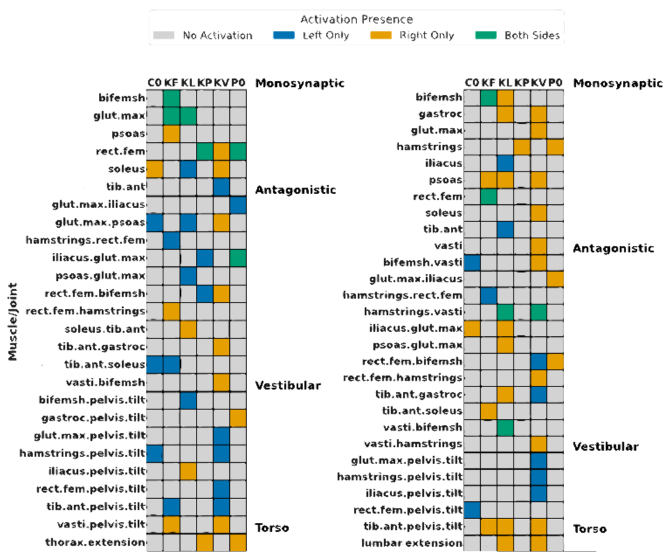

Figure 1: Reduced parameter set for controllers RF1 and RF2.

Conclusions

In this study, we reduced the necessary number of control parameters to perform sit-to-walk behaviors using a reflex-based controller from 551 to 108. Future work will evaluate controller robustness across different conditions.

Acknowledgments

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References

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[2] Van der Kruk, E. et al. (2024). *PLoS one*, **19**(6)