Towards Simulation-Based Exoskeleton Control Design & Optimization

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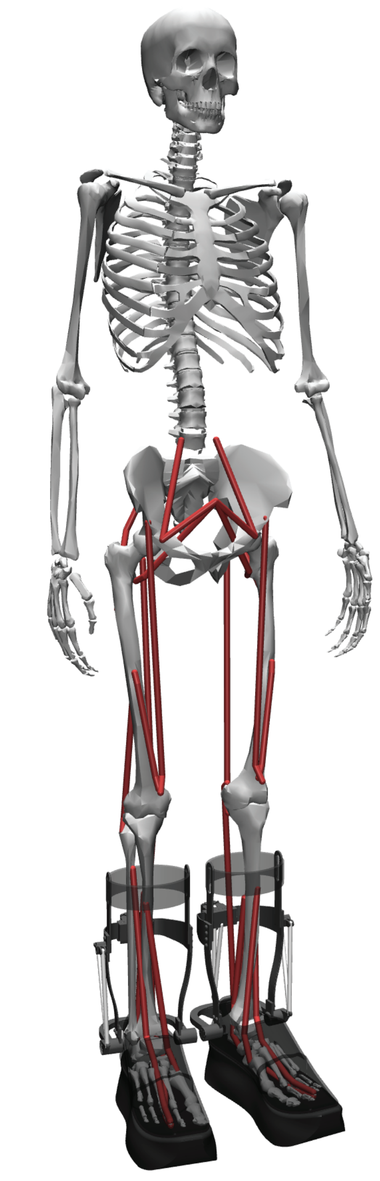
We leveraged neuromechanical simulations of an ankle exoskeleton to systematically evaluate whether the conventional **4-parameter phase-based spline controller** is optimal or if alternative parameter structures can achieve greater **metabolic cost reductions**.

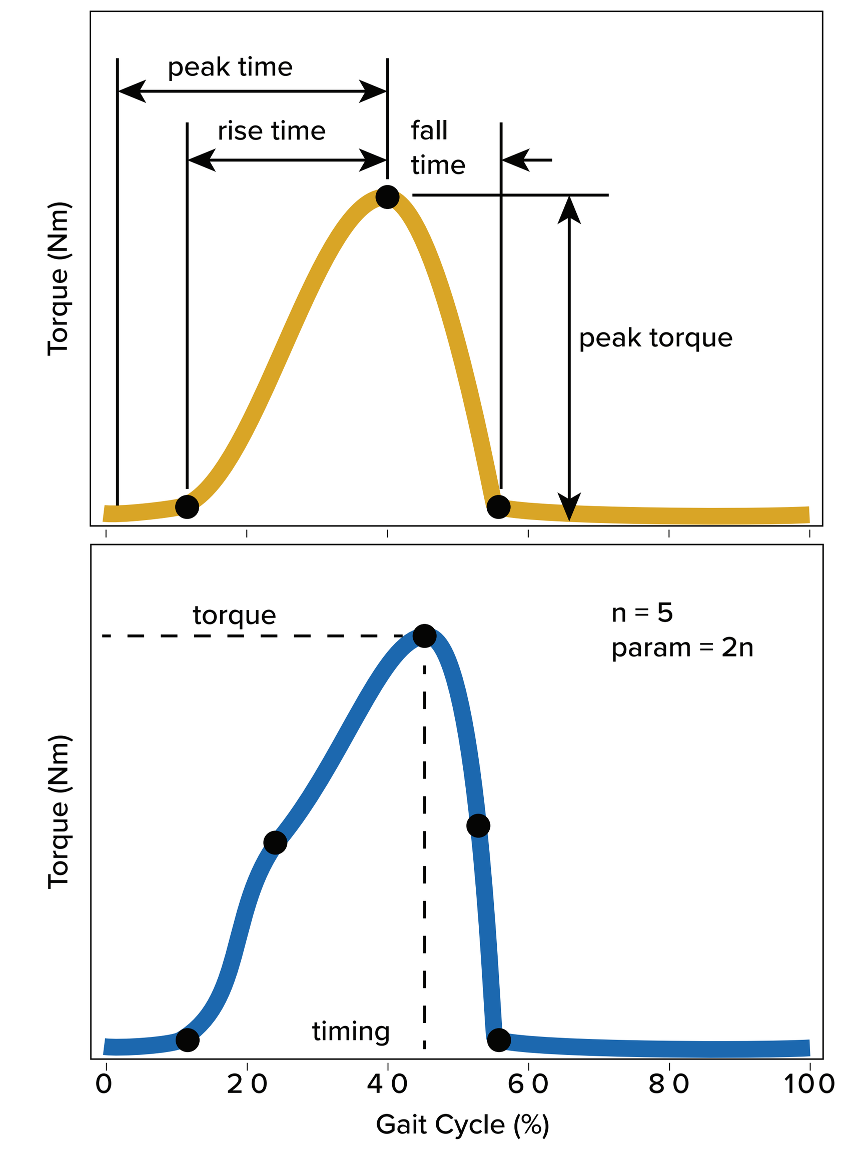
- Previous studies have demonstrated up to 40 ± 8% metabolic cost reduction with ankle exoskeletons[1]
- Neuromechanical simulations provide a scalable alternative for optimizing control parameters, allowing for various exoskeleton controllers and predictions on how human musculoskeletal dynamics would adapt[2]
- Thus, we reduce the need for extensive human subject testing and providing insights into the balance between controller flexibility, and the relationship between control complexity and cost of transport.

1Poggensee KL, Collins SH., Science Robotics, (2021),
[2]S. Song and H. Geyer, The Journal of Physiology, (2015)

NEUMOVE Northeastern University ASB American Society of Biomechanics FOUNDED IN 1977

Model, Control, and Optimization



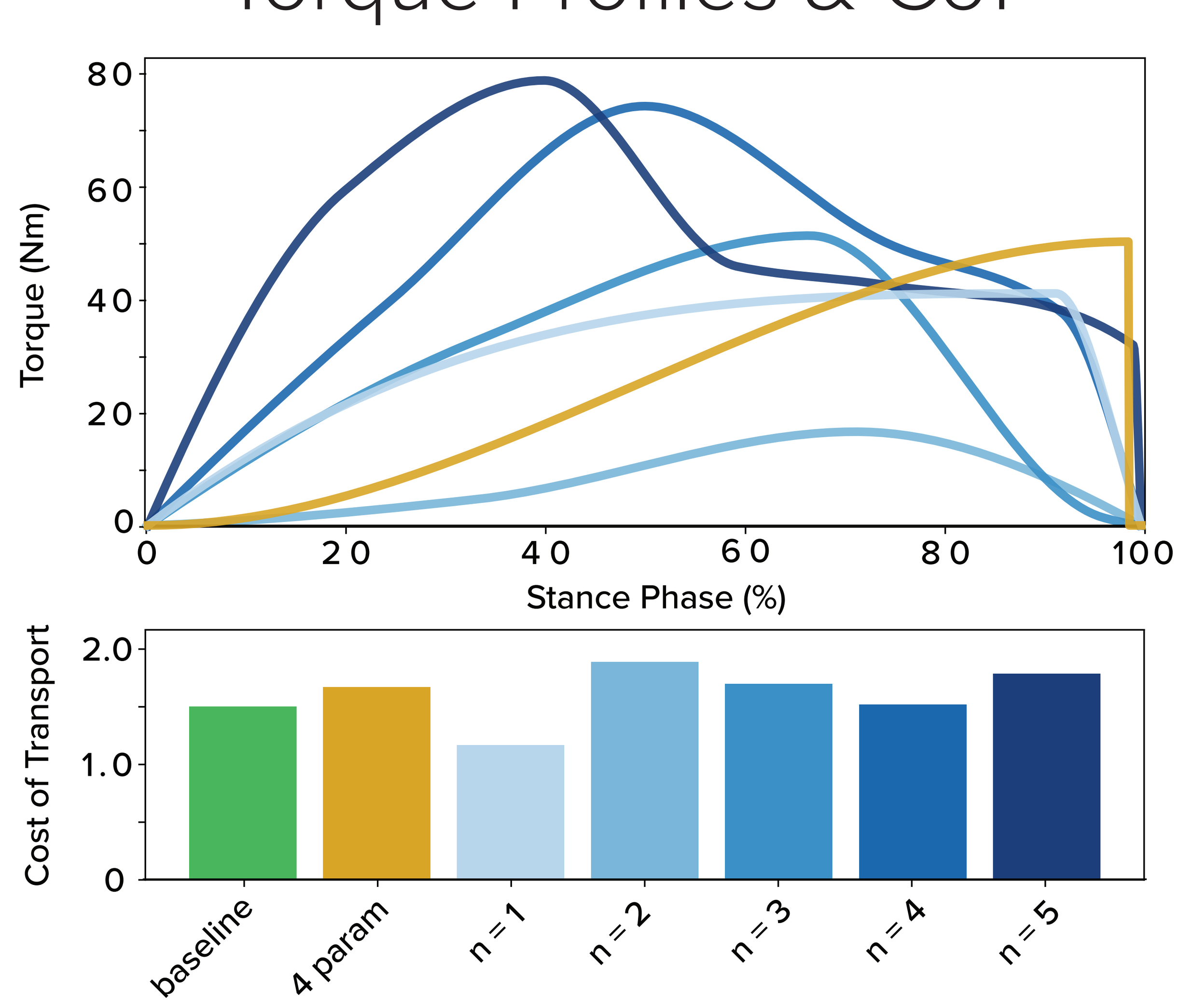


- 22 musculotendon actuators with 51 neural control parameters
- *MyoAssist* Humotech model with ideal actuators at ankle
- *4-parameter phase-based spline:* rise time, peak time, fall time, and peak torque
- *N-point spline:* n points, 2 × n parameters (timing & magnitude)
- Reflex-based controller optimization using CMA-ES optimizer and sequentially optimized cost function structure.

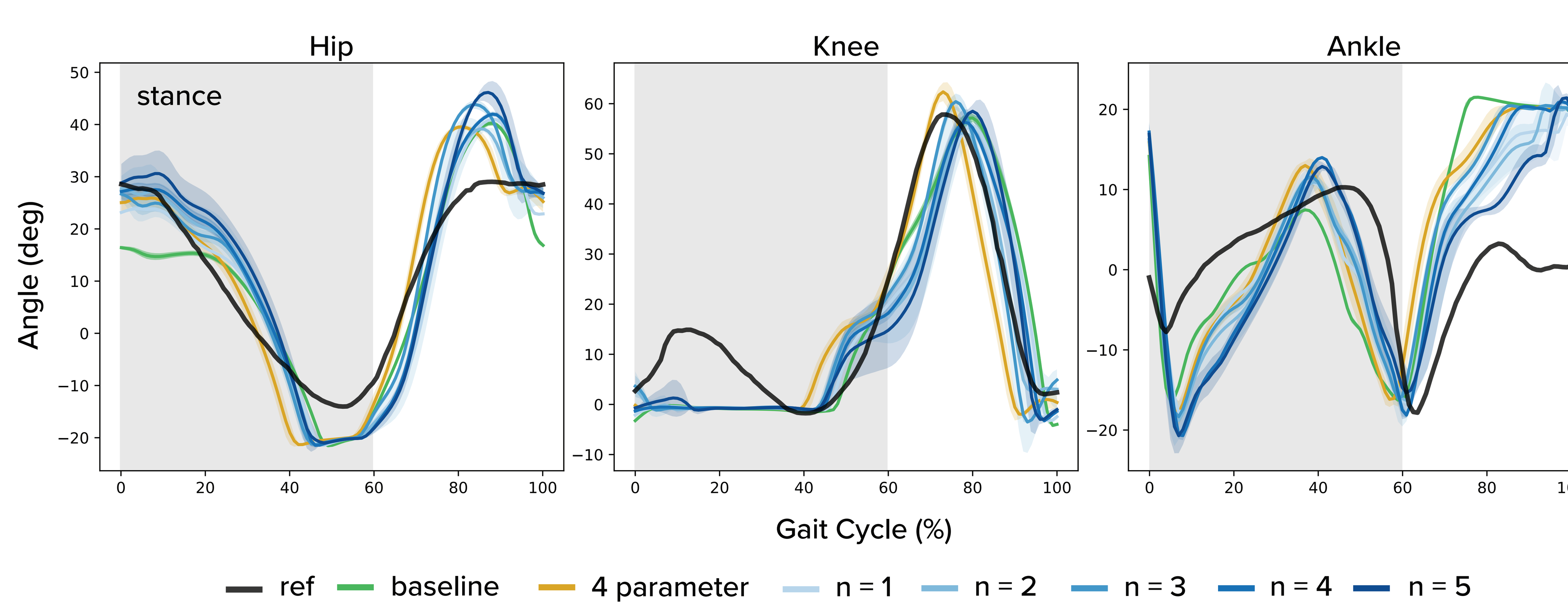
final cost: $J_{\text{effort}} = \frac{1}{d}\int_{t_0}^{t_f} \sum_{i=1}^{N_{\text{musc}}} a_i^2(t)\,dt, \qquad d = \left\| x(t_f) - x(t_0) \right\|_2$

Preliminary Optimized Control, Cost of Transport, and Kinematics

Torque Profiles & CoT



Kinematics



Discussion

Using neuromechanical simulations and optimization reduces dependence on **extensive human subject testing** while maintaining biological realism through the *MyoAssist* **Controller Optimization framework**. Here we systematically compared the **4-parameter spline** control against **N-point spline** alternatives (n = 1 - 5) and a baseline condition (exo off).

MyoAssist