EMG-driven Neuromuscular Model for Hip Exoskeleton Control Can Adapt Across Simulated Walking Modes

Benjamin A. Shafer[1,2], Lena H. Ting[3], Aaron J. Young[1,2], and Gregory S. Sawicki[1-4]

[1]George W. Woodruff School of Mechanical Engineering*, [2]Institute for Robotics and Intelligent Machines*, [3]Wallace H. Coulter Department of Biomedical Engineering*,** and [4]School of Biological Sciences*

*Georgia Institute of Technology and **Emory University

Motivation

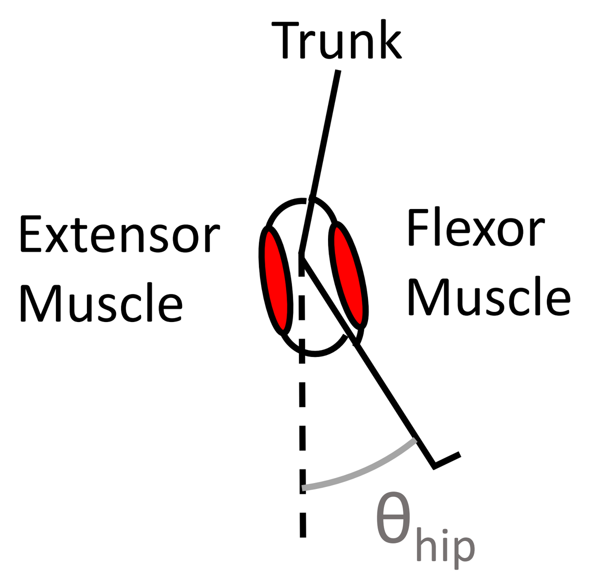
How can we find optimal exoskeleton control while avoiding "brute-force" methods?

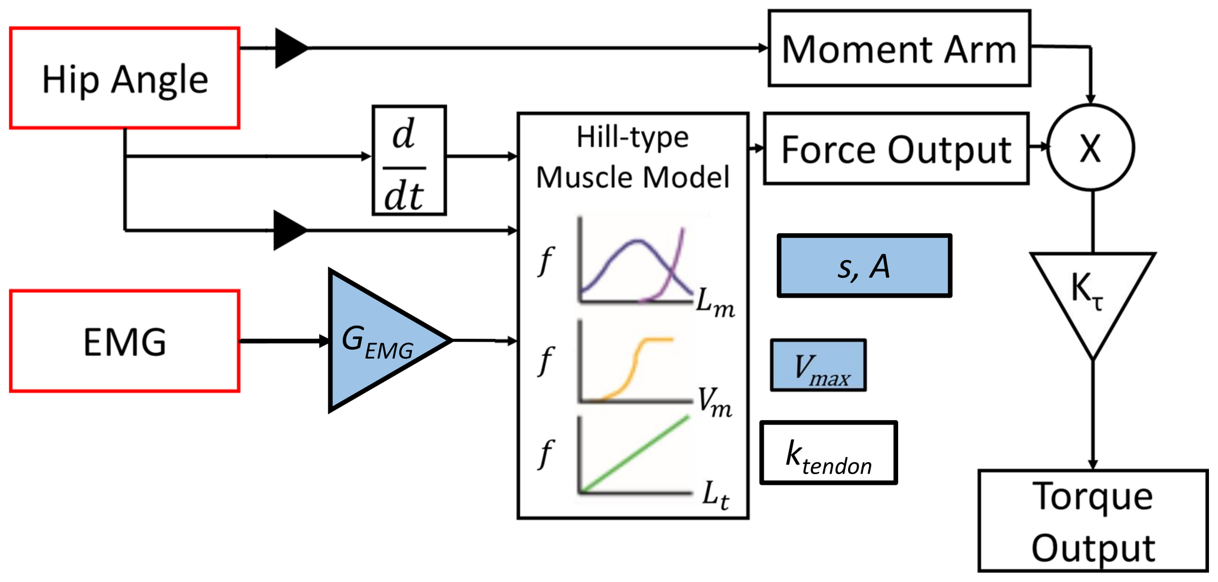
- Do not know *optimal assistance* profiles across all modes (gait, speed, slope, etc.)[1]
- Human-in-the-Loop optimizations can take up to *an hour* per locomotion mode per control scheme[1]
- Need a controller that *adapts* across modes

What is the best control scheme for each locomotion mode?

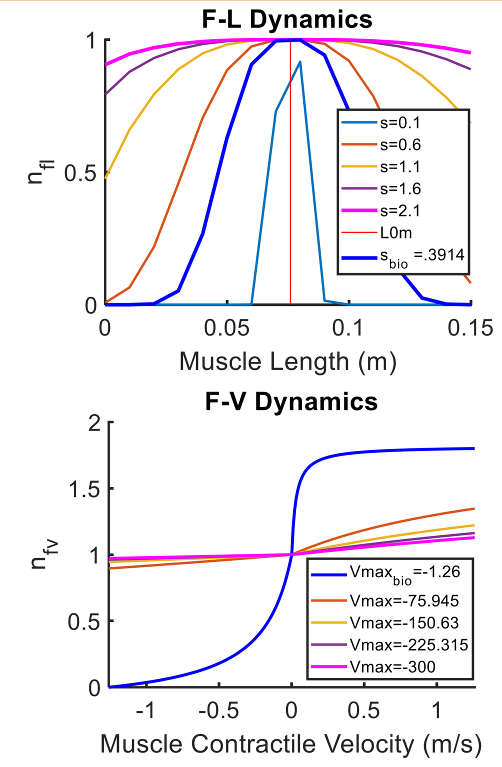
- Biological moments, EMG, and kinematics change with mechanical demands across modes[2-4]

Methods





A: Quasi MTU Stiffness



Experiment 1 (n = 1)

- Train model parameters to match biological moment at level ground at 1.25 m/s
- Vary mode (hip angle and EMGs) and measure model torque without changing parameters

Experiment 2 (n = 1)

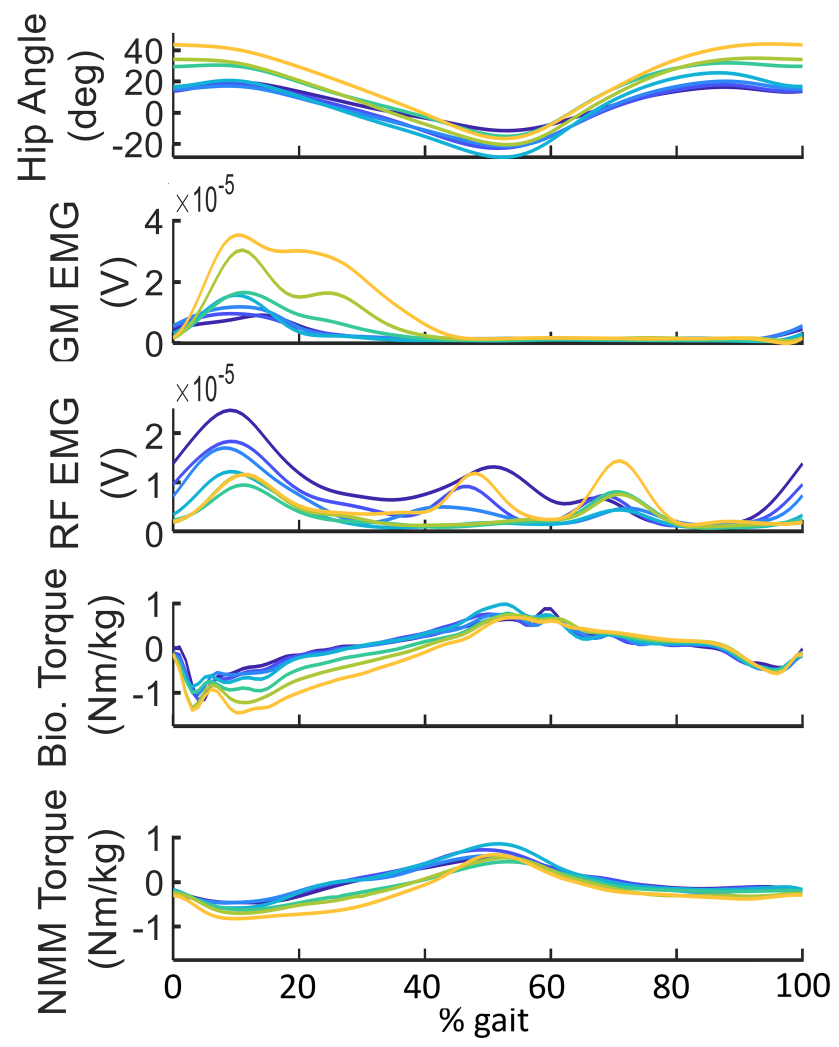
- Train model parameters at all available walking and running modes
- Examine control parameters for motor-like or passive/physiological properties

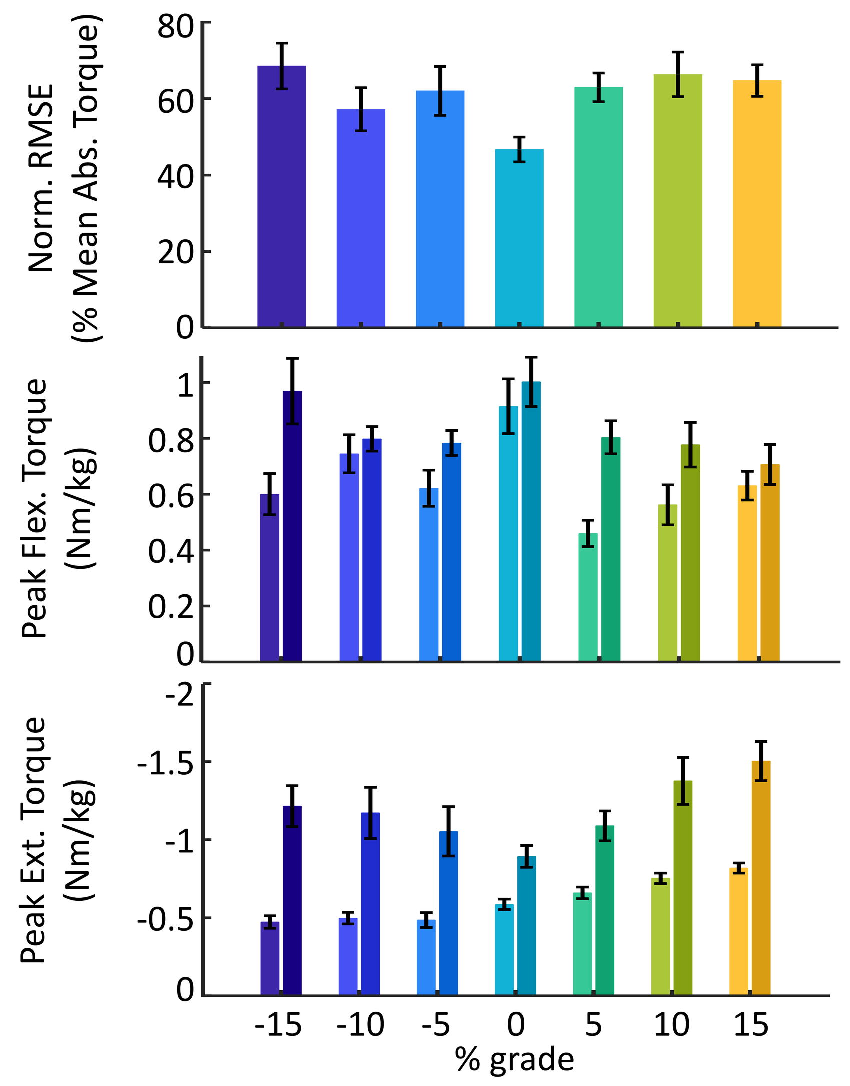
Hypotheses

1. **NMM with parameters optimized at level ground walking will track biological torques across grades**
2. **Optimal Extension NMM will favor more myoelectric control (*motor-like assistance*) with increasing incline while flexion will be more passive/biological**

Results

Experiment 1





- Model optimized at flat-ground adapts to declines in with similar accuracy without re-tuning
- NMM Flexion peak torque was highest at level
- NMM Extension torque increased with incline

Experiment 2

- Extension NMM was more motor-like with walking vs running (G_{EMG})
- Flexion NMM was less motor-like than Extension for walking modes (G_{EMG})
- Flexion NMM "s" for walking and running modes was relatively consistent

Extension

Grade (deg)	G_{EMG} W 1.25	G_{EMG} W 2.0	G_{EMG} R 2.0	G_{EMG} R 3.25	s (% max) W 1.25	s (% max) W 2.0	s (% max) R 2.0	s (% max) R 3.25	V_{max} (% max) W 1.25	V_{max} (% max) W 2.0	V_{max} (% max) R 2.0	V_{max} (% max) R 3.25
15	0.8	0.7	0.5		0.6	0.9	0.1		0.2	0.5	0.4	
10	0.8	0.8	0.5	0.5	0.7	1.0	0.9	0.0	0.4	0.6	1.0	0.8
5	0.8	0.8	0.6	0.4	0.5	1.0	0.7	0.0	0.0	0.6	0.4	0.7
0	0.9	0.9	0.6	0.4	1.0	0.2	1.0	0.1	0.0	0.0	0.6	0.8
-5	0.9	0.7	0.7	0.4	1.0	0.9	0.0	0.0	0.3	0.0	0.8	0.7
-10	0.9	0.6	0.7	0.2	1.0	1.0	0.0	0.0	0.0	0.0	0.8	0.4
-15	0.8	0.6	0.6		0.1	1.0	0.0		0.0	0.1	0.2	

Flexion

Grade (deg)	G_{EMG} W 1.25	G_{EMG} W 2.0	G_{EMG} R 2.0	G_{EMG} R 3.25	s (% max) W 1.25	s (% max) W 2.0	s (% max) R 2.0	s (% max) R 3.25	V_{max} (% max) W 1.25	V_{max} (% max) W 2.0	V_{max} (% max) R 2.0	V_{max} (% max) R 3.25
15	0.6	0.7	0.6		0.1	0.2	0.1		0.2	0.3	0.2	
10	0.6	0.7	0.4	0.7	0.1	0.2	0.1	0.1	0.3	0.5	0.7	0.6
5	0.5	0.5	0.6	0.7	0.1	0.2	0.1	0.1	0.1	0.6	0.2	0.3
0	0.5	0.5	0.6	0.6	0.1	0.1	0.2	0.2	0.4	0.6	0.4	0.7
-5	0.5	0.5	0.6	0.6	0.1	0.1	0.1	0.5	0.4	0.1	0.3	0.4
-10	0.5	0.6	0.6	0.6	0.1	0.1	0.1	0.2	0.6	0.2	0.4	0.1
-15	0.3	0.6	0.6		0.1	0.1	0.1		0.6	0.2	0.1	

(Colour scale 0–1; NaN cells shown in black.)

Discussion

- NMM increased extension torques with increased grade like biological trend
- Need to find optimization mode with best tracking across modes
- Optimal control schemes may differ between walking/running, and extension/flexion

Acknowledgements

This work was funded by NSF Research Traineeship Award #1545287, DoD Grant #GR10003831, and Lockheed Martin Corp.

References

[1]Zhang et al. (2017)
[2]Wall-Scheffler et al. (2011)
[3]Farris and Sawicki (2011)
[4]Franz and Kram (2012)
[5]Montgomery and Grabowski (2018)