Syracuse University

Targeting the Soleus and Quadriceps Muscles Using Powered Robotic Rehabilitation Devices and Neuromuscular Control

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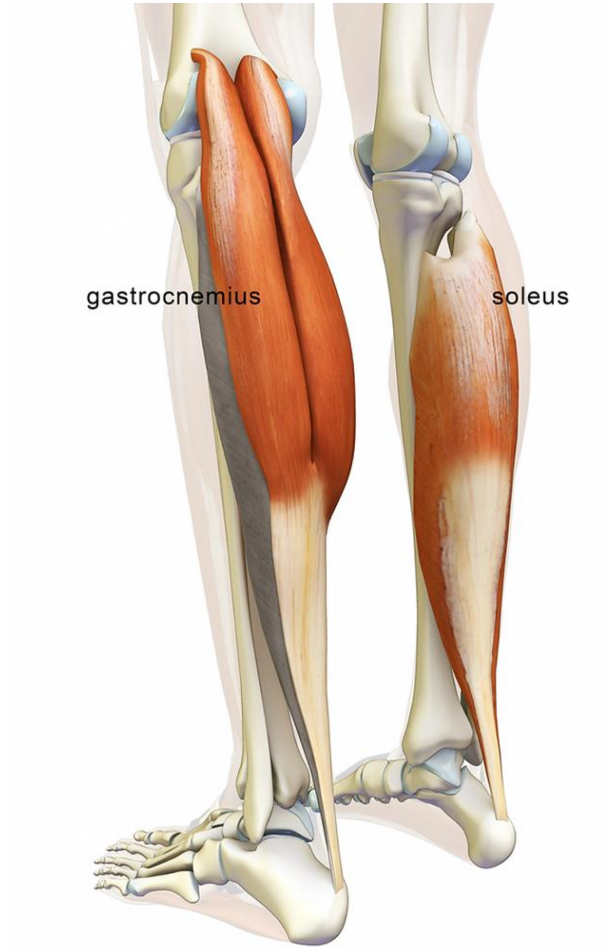
Motivation

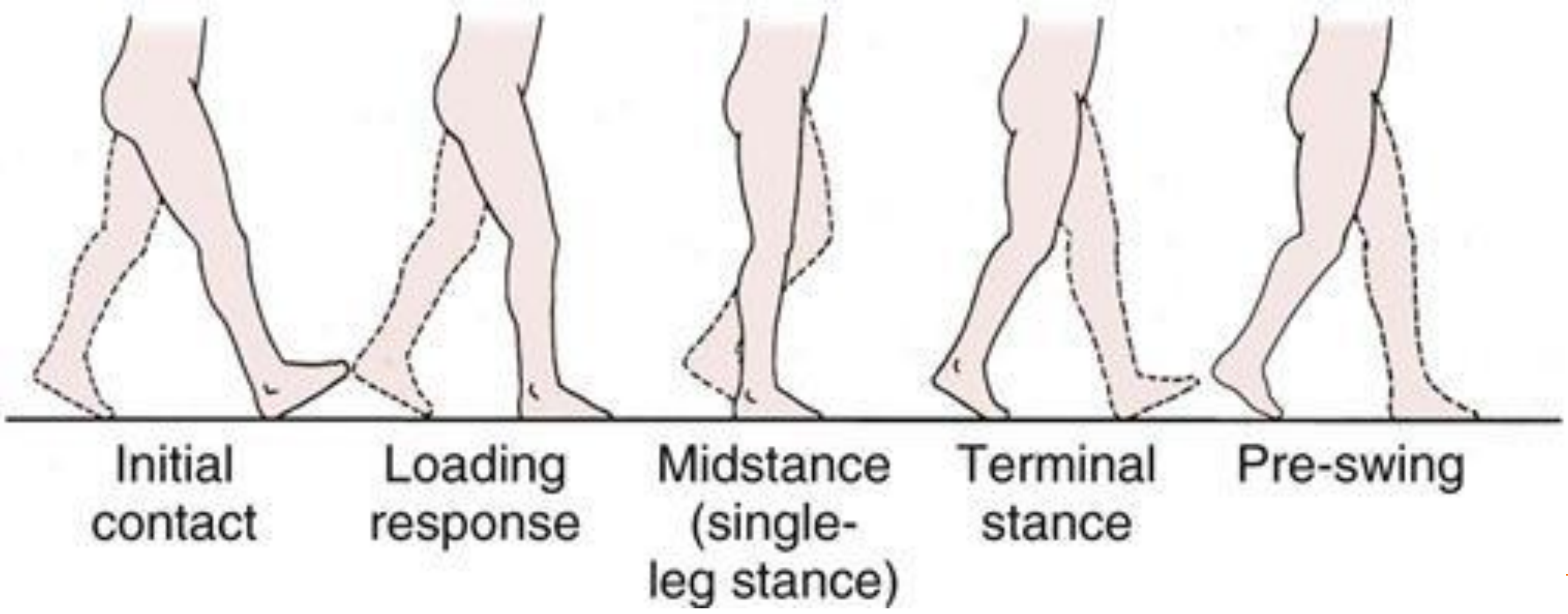
- Individuals with neurological disorders (NDs) experience partial or total loss of motor and sensory function
- Significantly impacts an individual’s independence and quality of life
- Around 800,000 people in the U.S. have a stroke each year

Gait Training for Soleus Muscle Rehabilitation



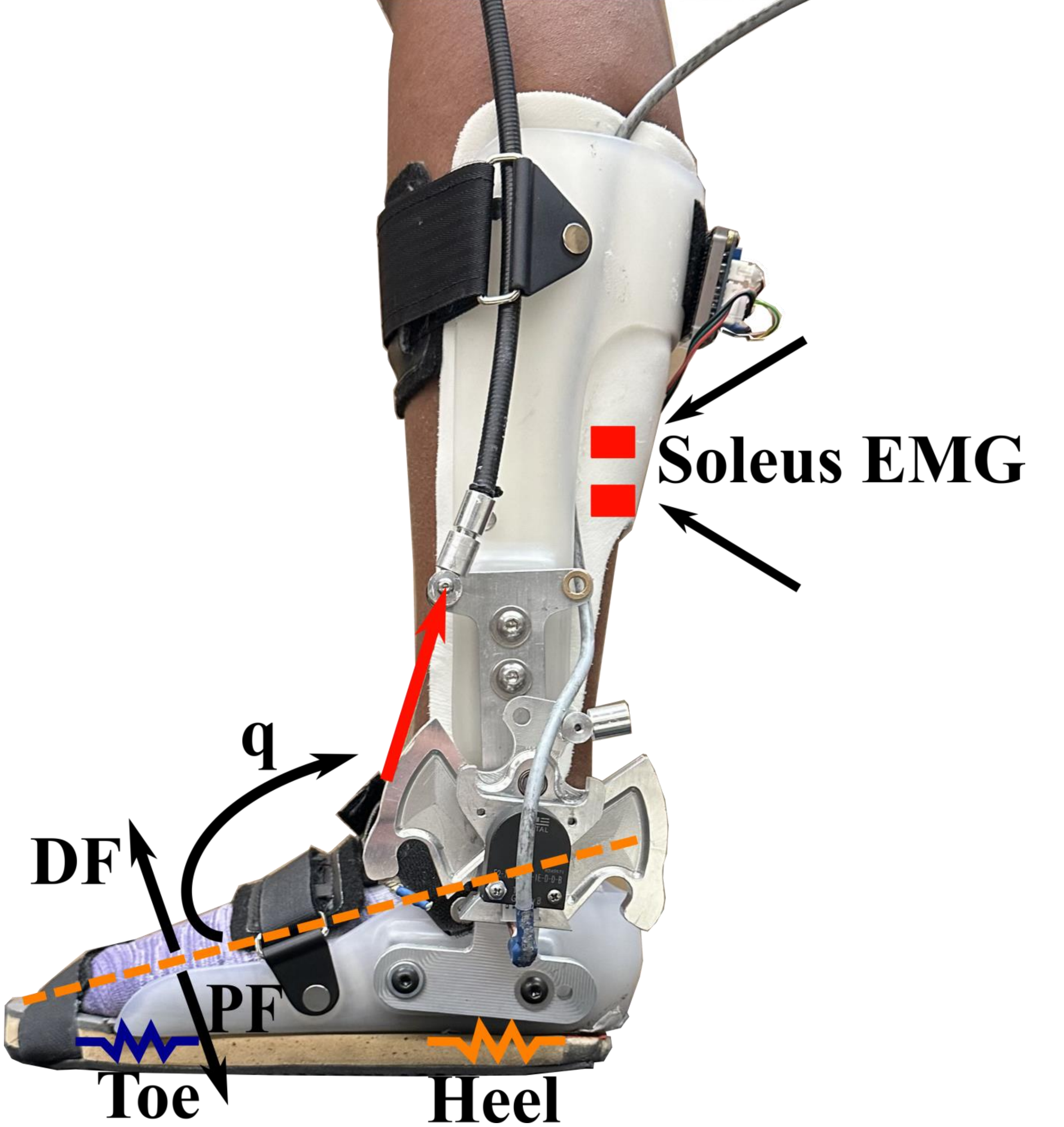
Soleus Muscle Rehabilitation

- In the mid-late stance phase, soleus muscle triggers propulsion and force generation
- With stroke, the soleus muscle activation patterns and propulsion are diminished

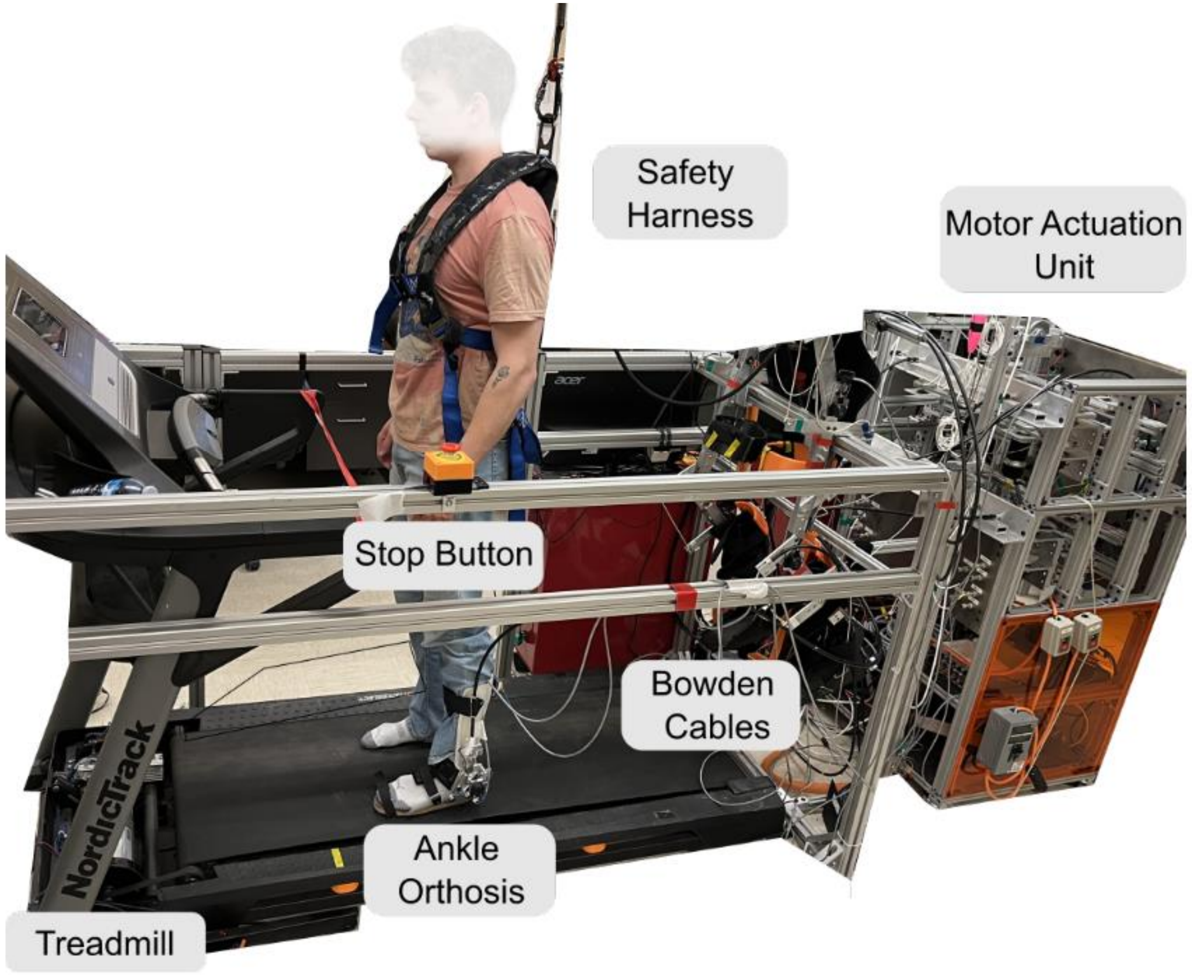


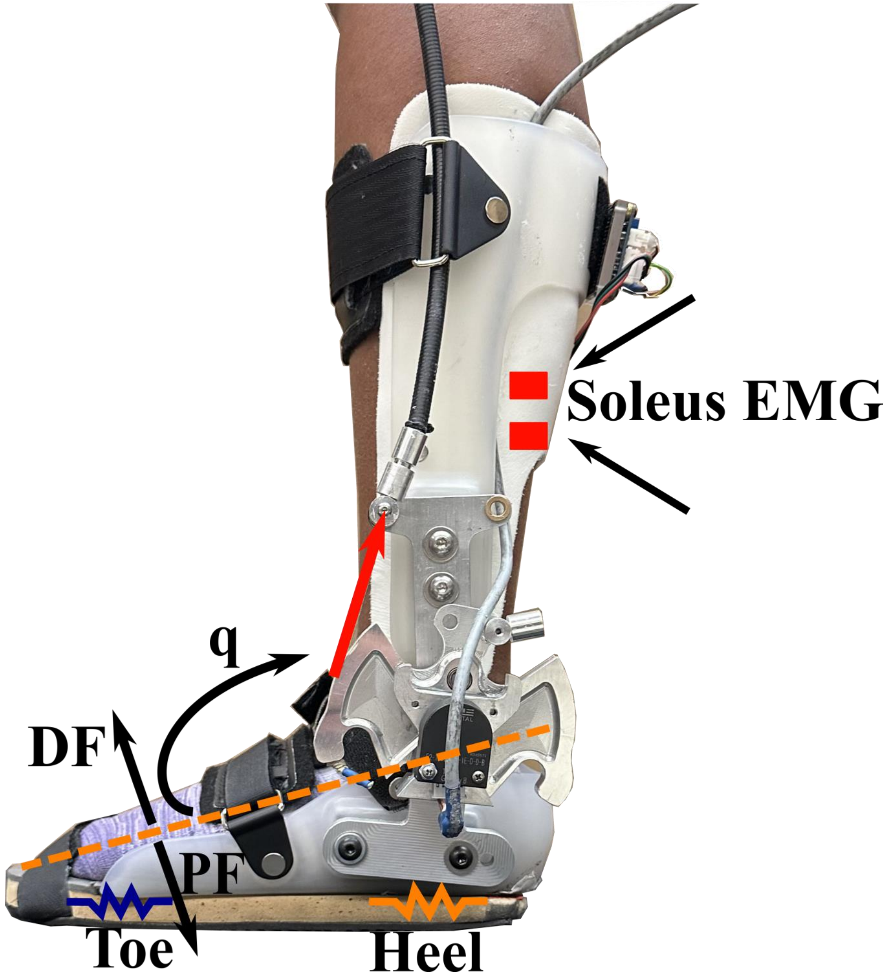
Extremum Seeking Control for Ankle Perturbation Trajectory Generation

Tulsky, ER, Rubino, N, Carter, J, Thompson, A, Duenas, V. (Under Review). “Extremum Seeking Control of a Robotic Ankle-Foot Orthosis Targeting the Soleus Muscle Activation During Walking”, CCTA, Newcastle, England.



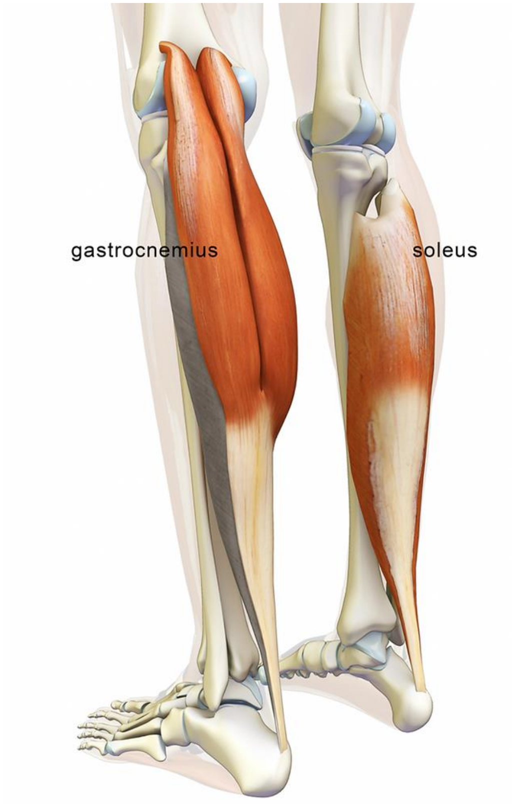
Ankle Orthosis Setup



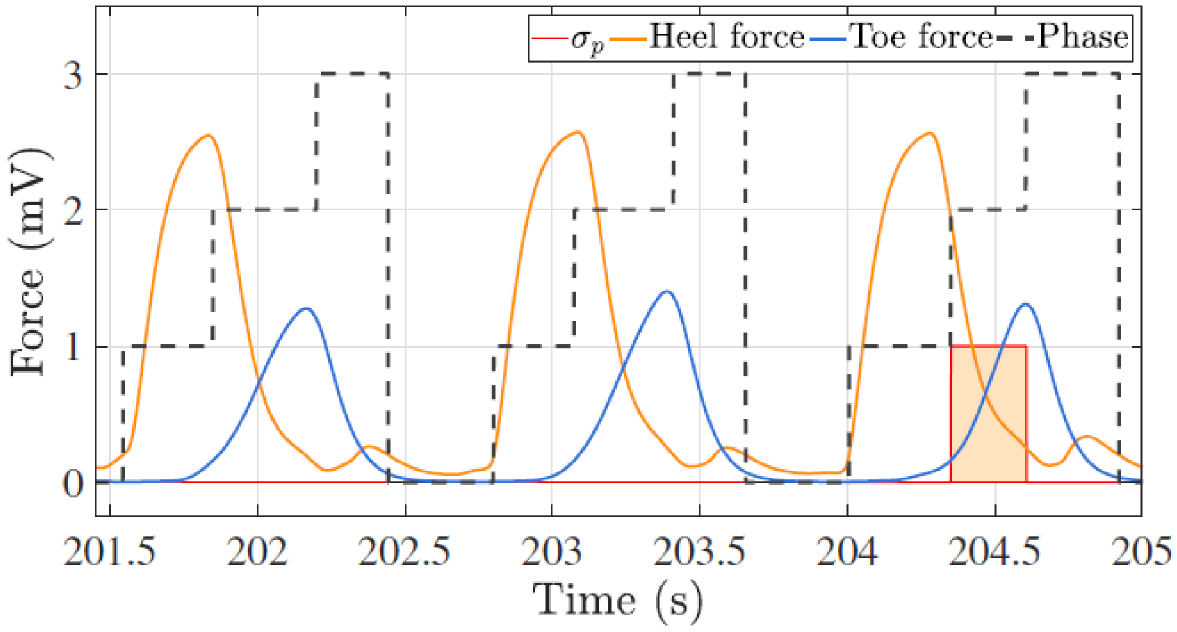


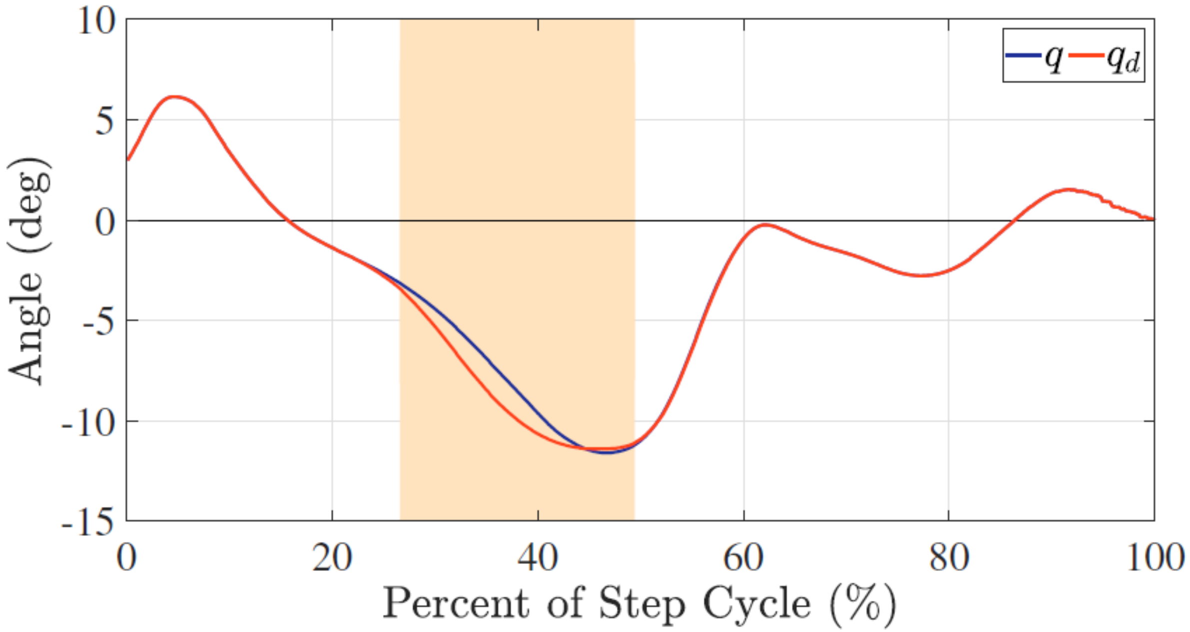
Perturbation

- Applied force on muscle that elicits response



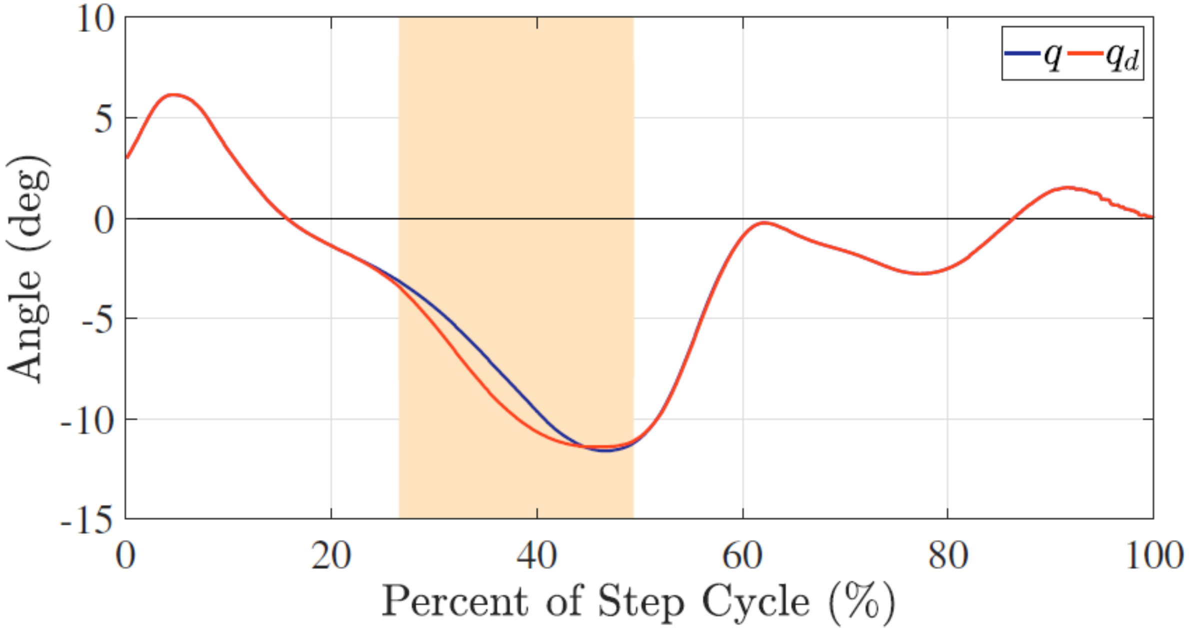
Gait Phase Detection



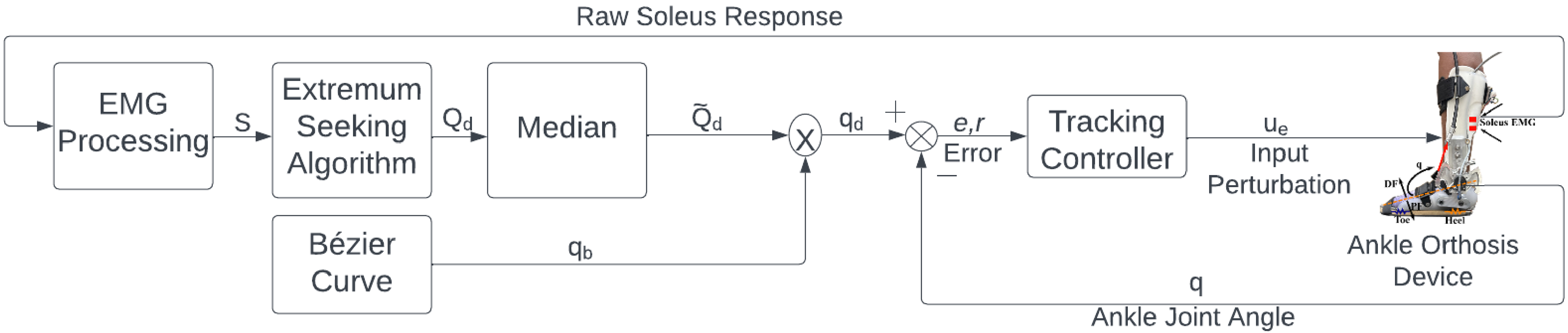


Extremum Seeking Control

- Leverages an unknown input-output map
- Adaptive method to characterize the unknown ankle angle to soleus muscle activation map



Block Diagram of Ankle Orthosis System



$$e(t) = q_d(t) - q(t)$$

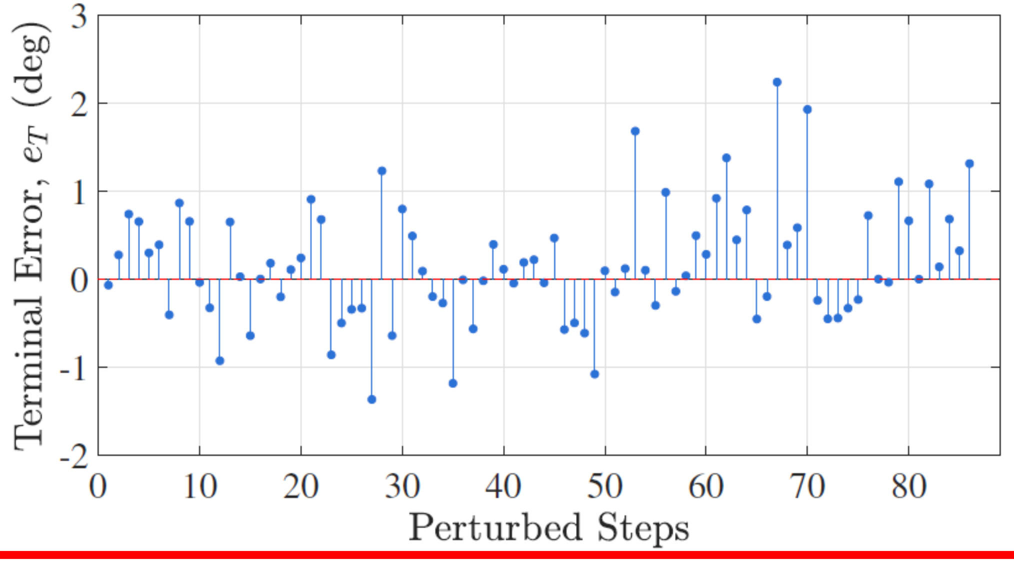
$$r(t) = \dot{e}(t) + \alpha e(t)$$

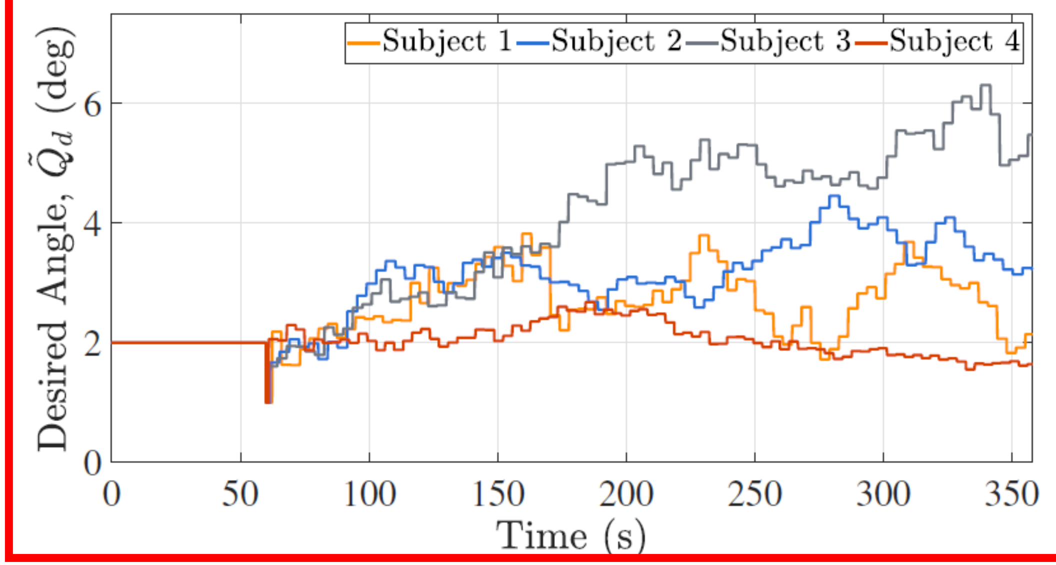
Approach

- 4 able bodied individuals
  - 360 second walking experiment
- Perturbations applied every third walking step
- Treadmill walking at a comfortable 1 m/s
- Participants instructed to follow metronome

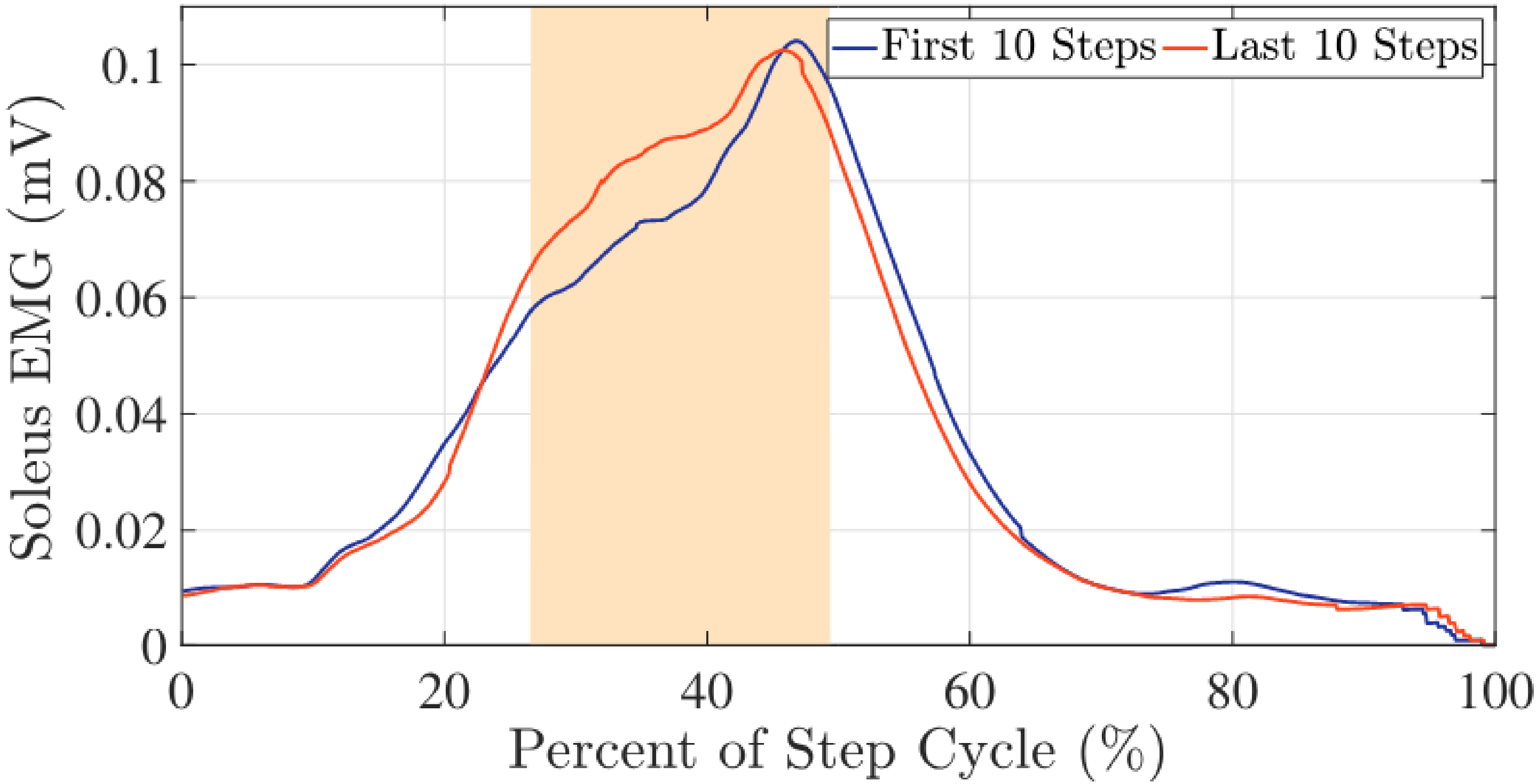
Results

	Avg. Terminal Error $\bar{e}_T$ (deg)	Avg. Desired Angle $\bar{Q}_d$ (deg)	Percent Terminal Error $\%e_T$	First 10 Steps $\bar{S}$ (mV)	Last 10 Steps $\bar{S}$ (mV)
Subject 1	0.52 ± 0.66	5.40 ± 1.07	9.98 ± 12.68	0.0816 ± 0.0089	0.0878 ± 0.0070
Subject 2	0.89 ± 0.52	6.37 ± 1.19	13.95 ± 8.19	0.0670 ± 0.0056	0.0672 ± 0.0101
Subject 3	1.82 ± 1.08	8.37 ± 2.50	20.92 ± 12.60	0.0684 ± 0.0012	0.0695 ± 0.0095
Subject 4	0.50 ± 0.61	4.09 ± 0.55	12.59 ± 15.47	0.0161 ± 0.0012	0.0091 ± 0.0011
Mean (S1-S4)	0.93	6.06	14.36	0.0582	0.0584
STD* (S1-S4)	0.71	1.83	12.23	0.0042	0.0069





Average Soleus Muscle Response as a Function of the Step Cycle



Conclusions

- An ESC algorithm updates ankle perturbations to evoke increments in activity of the soleus muscle during treadmill walking
- Suitable tracking performance leveraging the terminal error (error at the peak dorsiflexion angle)
- Preliminary evidence supports muscle activity differences between beginning and ending perturbed steps
- Future work includes the implementation in stroke survivors during walking

Influence of Vibration Stimuli on the Quadriceps Femoris Muscles During FES-Induced Cycling

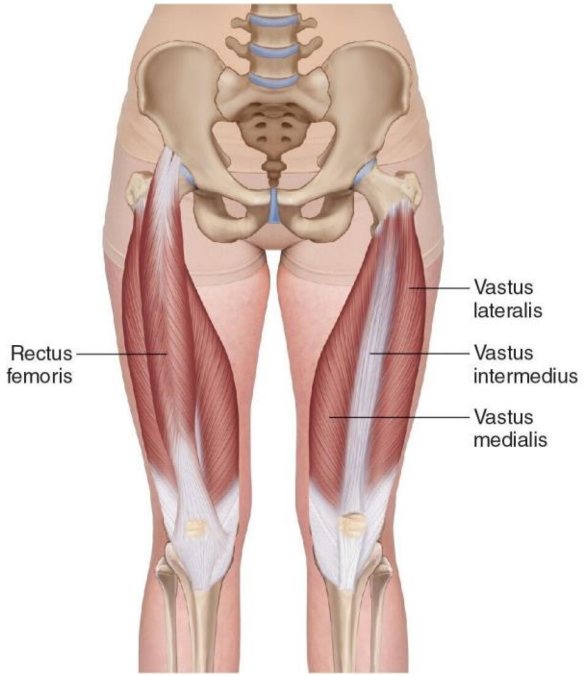
Tulsky, ER, Casas, J, Cheng-Hao, C, Brose, S, Duenas, V. (September, 2021). “Influence of Vibration Stimuli Applied on the Quadriceps Femoris Muscles During Functional Electrical Stimulation Induced Cycling”, International Functional Electrical Stimulation Society, Rovinj, Croatia (Online).

Motivation

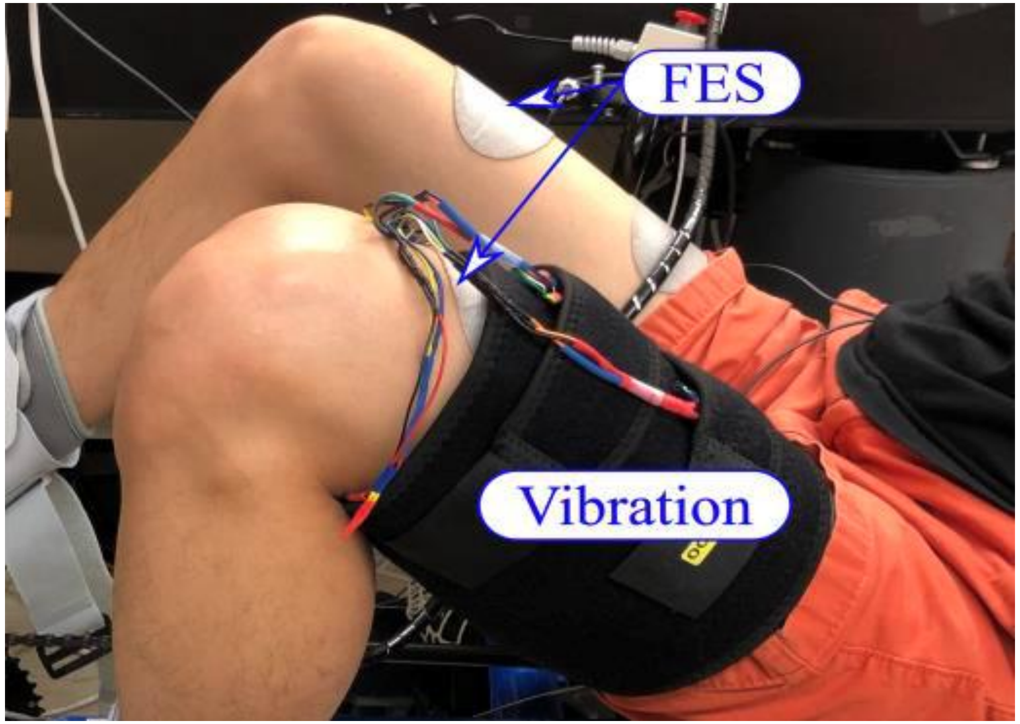
- FES induce controlled muscle contractions and facilitate pedaling a cycle
- FES-cycling has restrictions
  - Muscular fatigue develops more rapidly using FES
  - Spasticity from SCI individuals limit duration
- **Explore the impact of mechanical vibration during FES contractions**

Quadriceps Rehabilitation

- Responsible for majority of force in cycling exercise
- Contains the largest muscle mass



FES-Cycling Setup



Approach

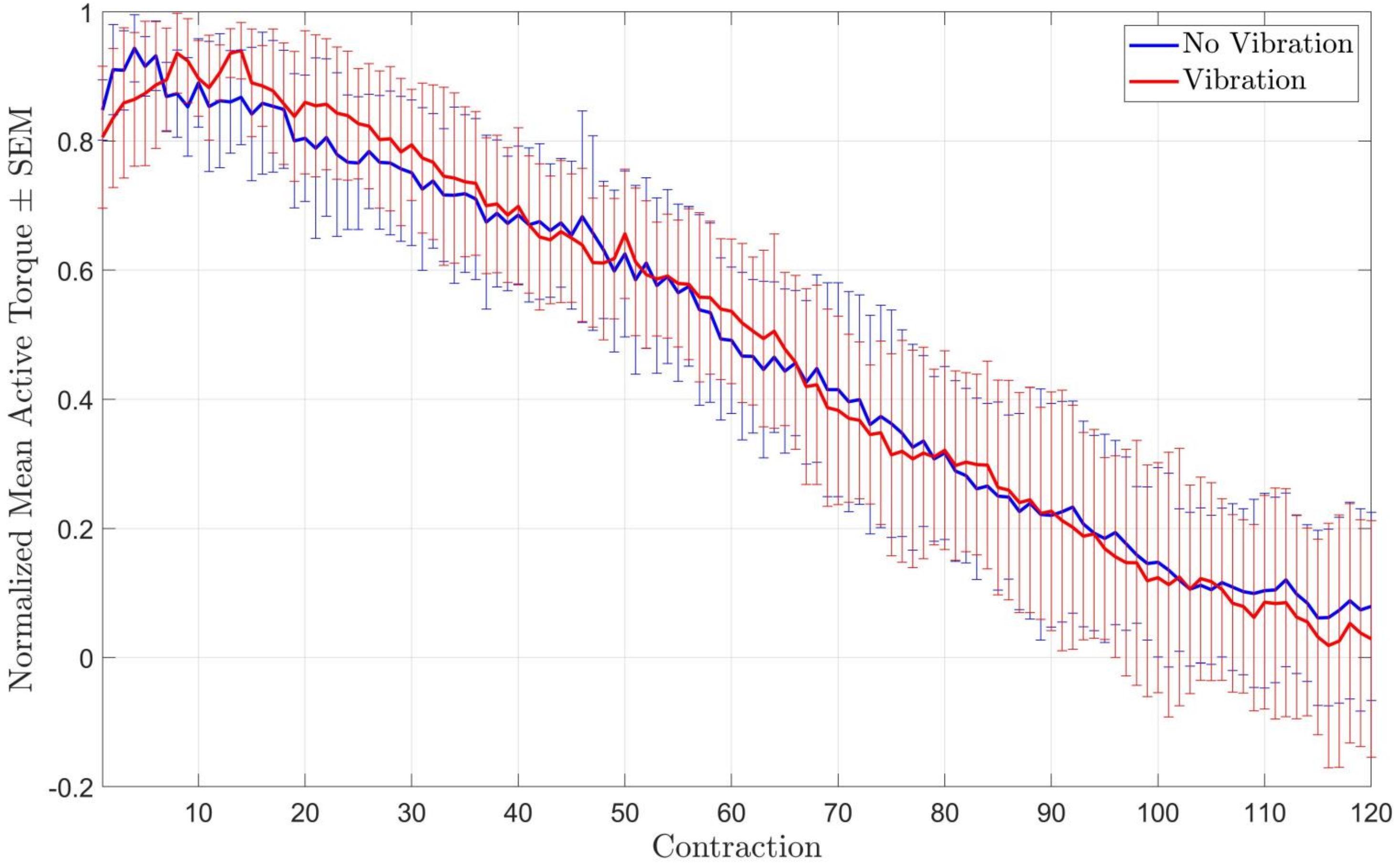
- 4 able bodied individuals
- Two trials of FES-cycling experiments at 65 rpm cadence for 180 seconds
  - Without vibratory stimuli
  - With vibratory stimuli on quadricep

Results

- For sample fatigue rate for all participants was 5.23% greater for trials with vibration stimuli

Subject	Pulse Width	Avg. Active Torque		Fatigue Time		Fatigue Rate	
		no vib.	vib	no vib.	vib	no vib.	vib
Subject 1	75	0.49	0.57	42	55	-9.4	-9.4
Subject 2	80	0.45	0.39	41	41	-9.5	-11.3
Subject 3	80	0.53	0.50	28	33	-5.8	-7.2
Subject 4	90	0.57	0.53	35	33	-7.2	-6.3
Q1		**0.39**	**0.48**	**29.5**	**31.5**	**-9.4**	**-9.4**
Median		**0.44**	**0.51**	**43.0**	**37.0**	**-8.8**	**-7.0**
Q3		**0.39**	**0.55**	**52.5**	**52.5**	**-7.3**	**-6.2**

Mean Active Torque for All Participants Over Number of Contractions



Conclusions

- Preliminary study on FES-cycling with vibrational stimuli
- Future Work
  - Recruit more participants
  - Study people with spinal cord injuries
  - Further investigate optimal vibration patterns, vibrational frequency, and number of vibrational motors on the muscles.

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Questions and Discussion