P3-C-38

FES Control for Restoring Complex Functional Hindlimb Movements in the Rat

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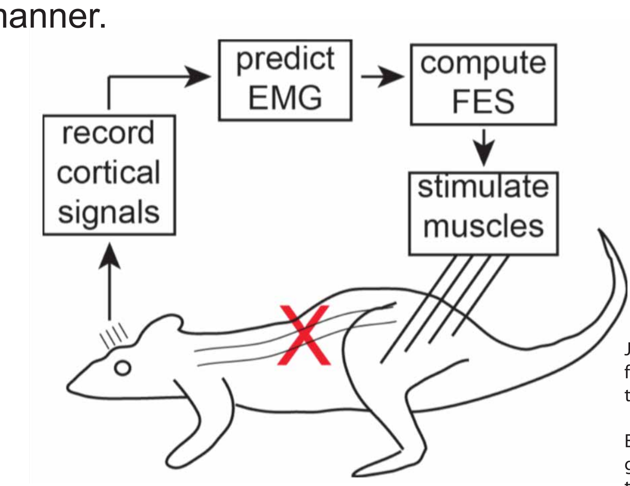
Introduction

Cortically-controlled functional electrical stimulation (FES) offers a means to restore voluntary motion following spinal cord injury (SCI). We have previously demonstrated the ability to make an anesthetized rat support itself in a stance position, and to produce a range of endpoint forces using FES (Jarc et al 2013). In addition, we have restored grasp during peripheral nerve block in monkeys using cortically-controlled FES (Ethier et al 2012). We are working to achieve cortically-controlled FES in rats to restore gait following actual SCI.

Here we show the ability to modulate FES intensity and achieve functional movements of a rat's hindlimb in an open-loop model. By modulating certain stimulation parameters, we can alter the characteristics of the functional movement in a predictable manner.



Jarc AM, Berniker M, Tresch MC (2013) FES control of isometric forces in the rat hindlimb using many muscles. IEEE Transactions on Biomedical Engineering 60.5: 1422-1430

Ethier C, Oby ER, Bauman MJ, Miller LE (2012) Restoration of grasp following paralysis through brain-controlled stimulation of muscles. Nature 485:368-371

Experimental Setup

We implanted silver wire electrodes in ten muscles of the hindlimb of the rat.

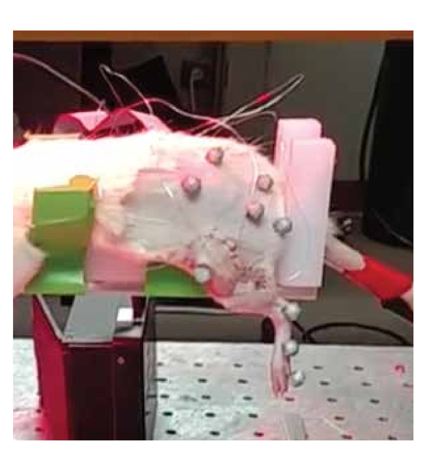
We suspended the rat on a platform with the hindlimb free to move in space. We stimulated these electrodes using a stimulator from Ripple with currents based on EMG activity recorded previously from a rat walking on a treadmill.

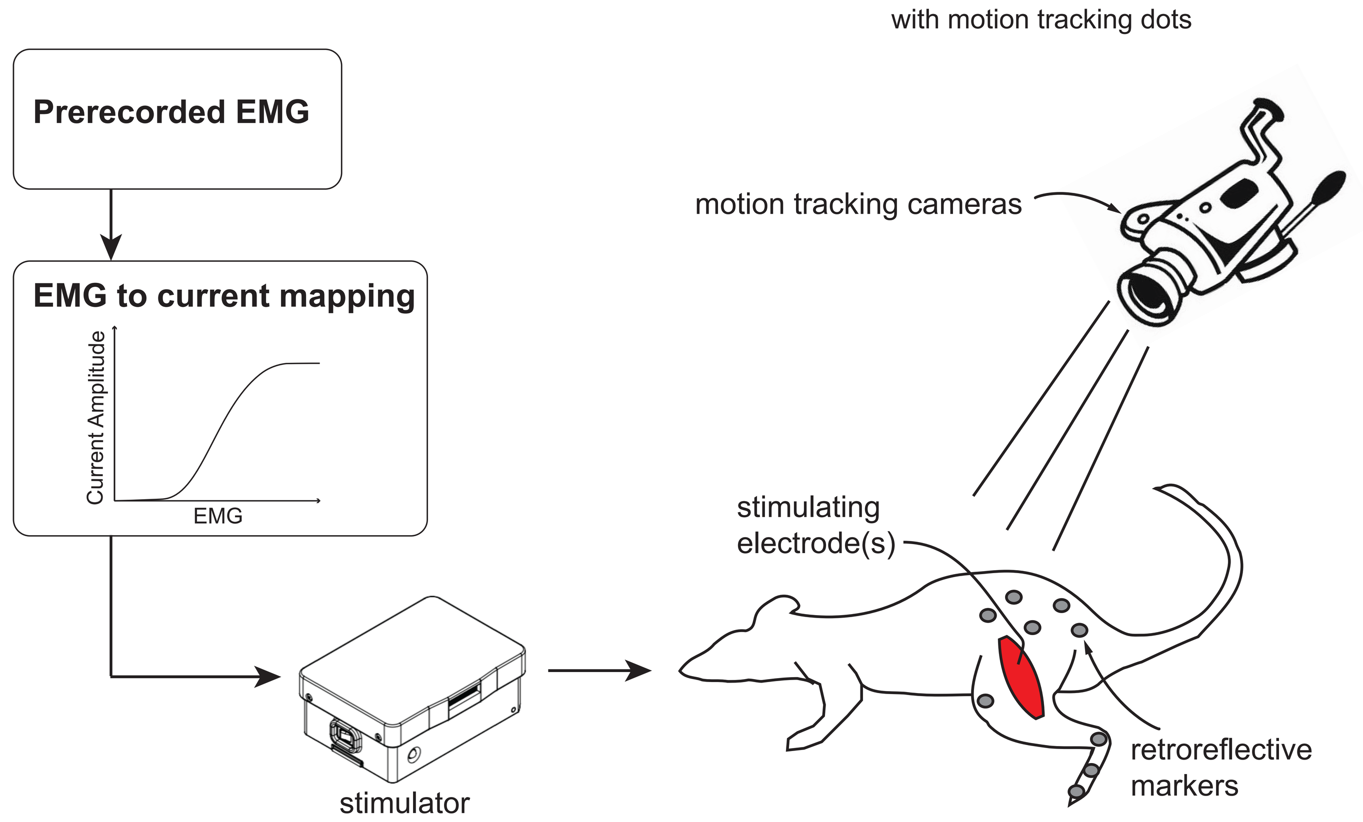
We placed retroreflective markers at 9 points on the hindlimb and recorded kinematics with a Vicon motion tracking system.

Muscles Implanted
Gluteus Superficialis (GS)
Vastus Lateralis (VL)
Biceps Femoris Anterior (BFa)
Biceps Femoris Posterior (BFp)
Lateral Gastrocnemius (LG)
Tibialis Anterior (TA)
Iliopsoas (IP)
Rectus Femoris (RF)
Semimembranosus (SM)
Semitendinosus (ST)

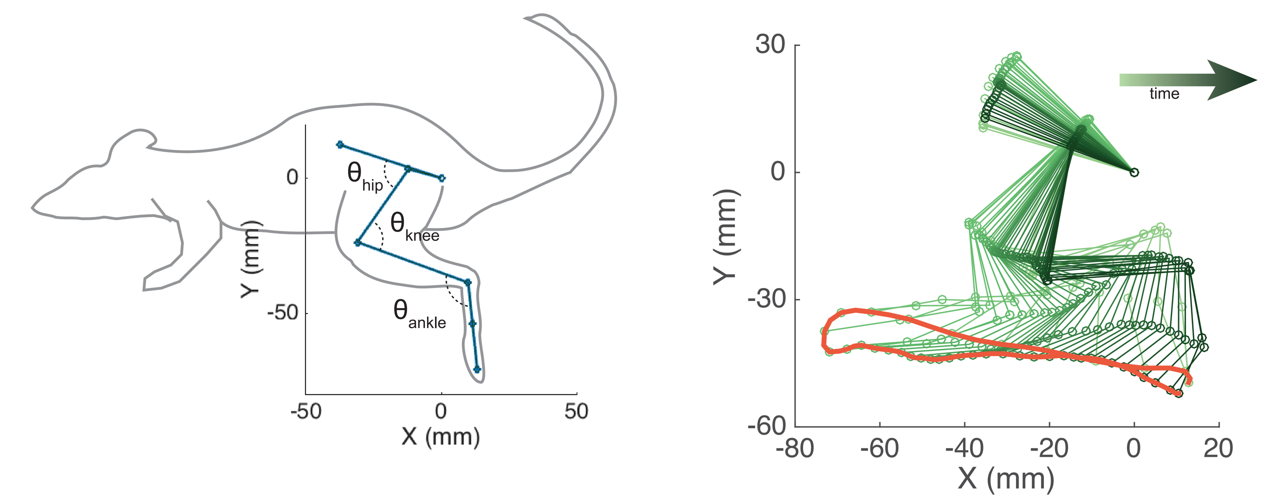

Stimulation electrode


Implanted electrodes


Rat on stimulation platform, with motion tracking dots

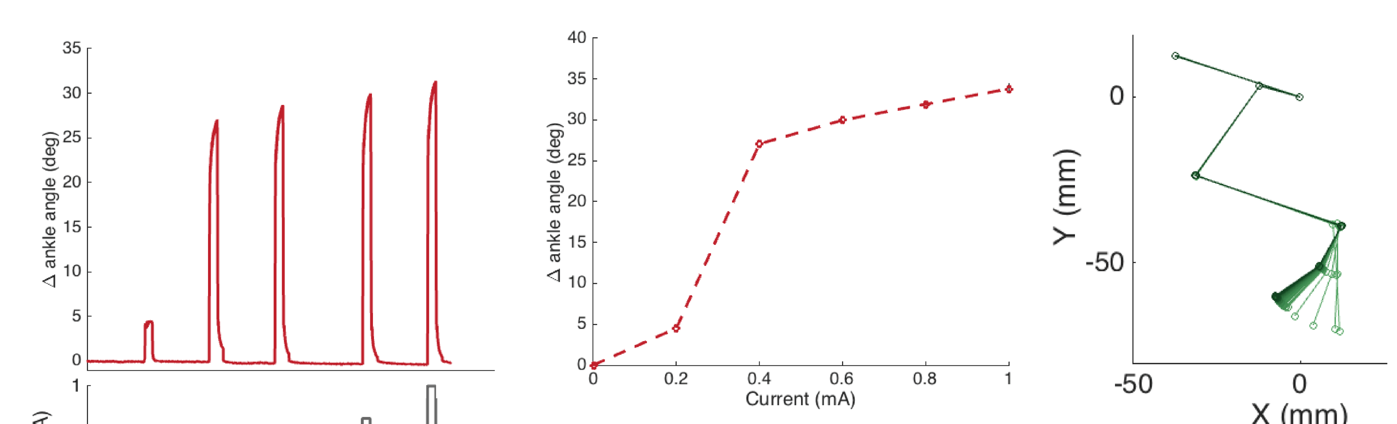


Kinematics of Treadmill Walking



Data for this figure courtesy of Cristiano Alessandro

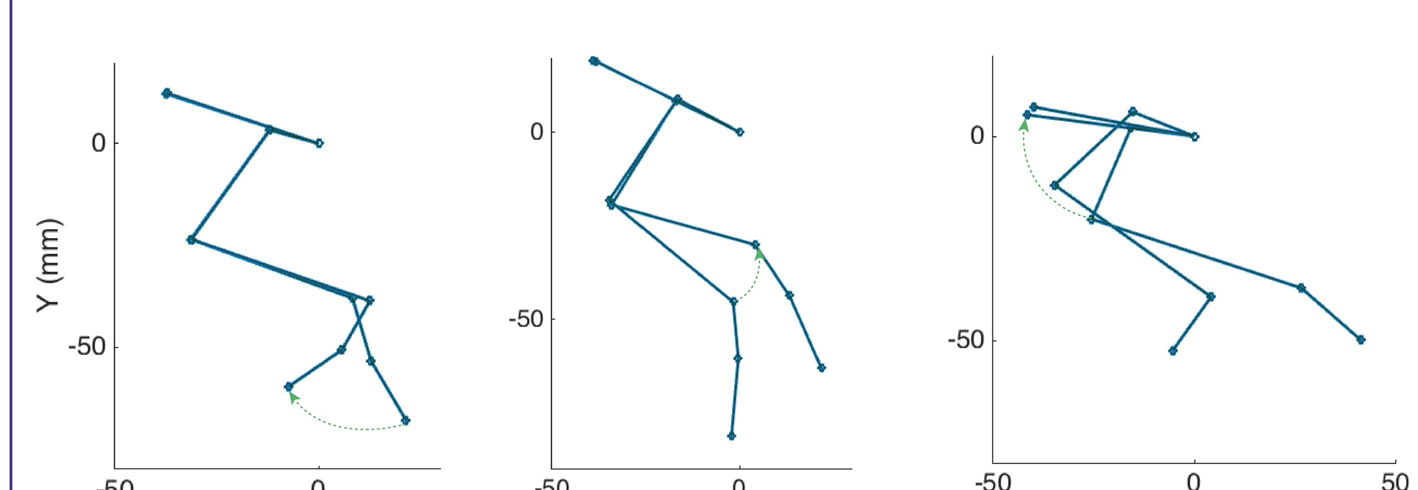
FES of Individual Muscles



- Recruitment curve for tibialis anterior (TA) from a resting position.
- Used for converting EMG to stimulation current.

Joint Angle Ranges

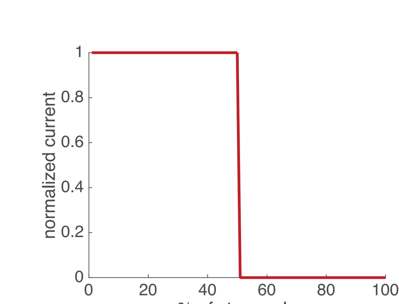
- We achieved maximum ranges of motion that were similar to those seen during treadmill walking. The limb was not under load, so the posture of the hindlimb was slightly changed.



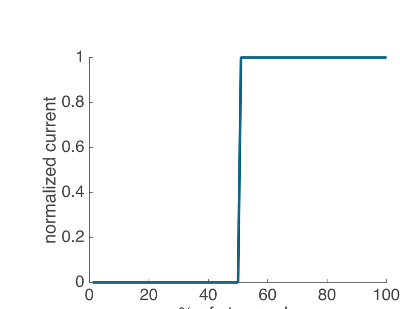
$Ankle_{max}$ = 132°, $Ankle_{min}$ = 62°
$Knee_{max}$ = 89°, $Knee_{min}$ = 68°
Hip_{max} = 73°, Hip_{min} = 49°

Simplified Control

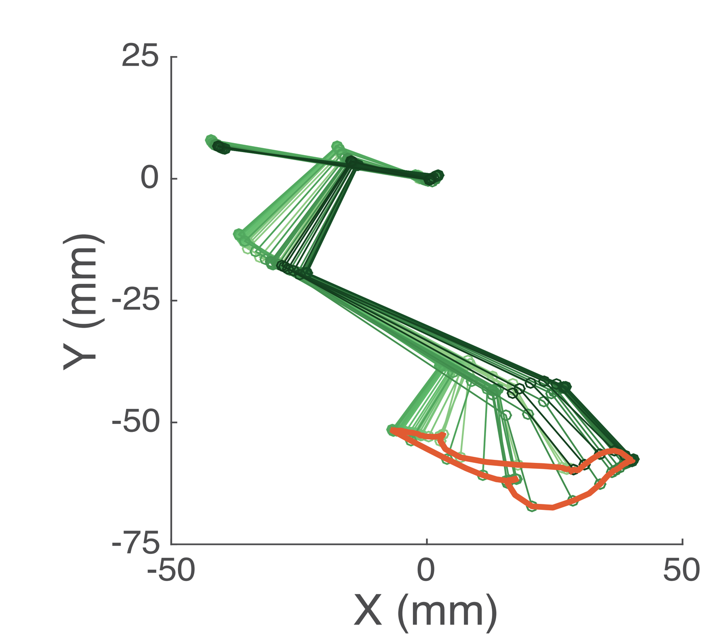
In early experiments, we demonstrated a full range of hindlimb motion using alternating stimulation of several flexor and extensor muscles, each for equal time periods, to produce stepping movements.



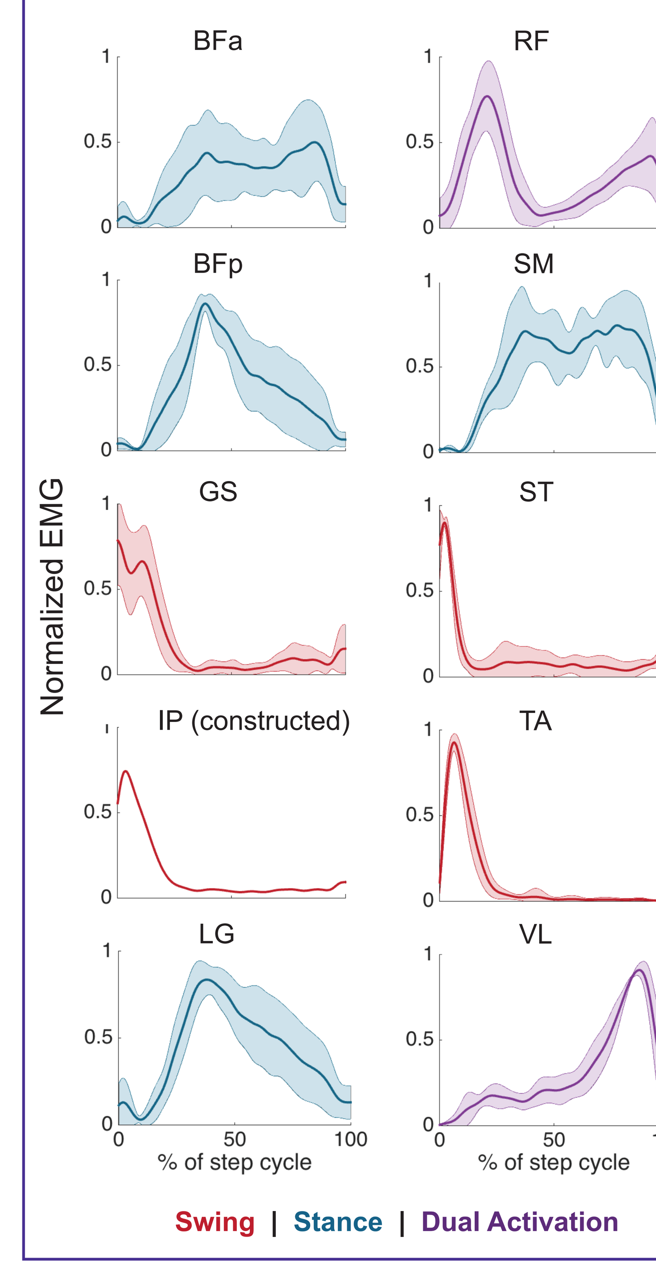
Flexor Stimulation: IP, TA

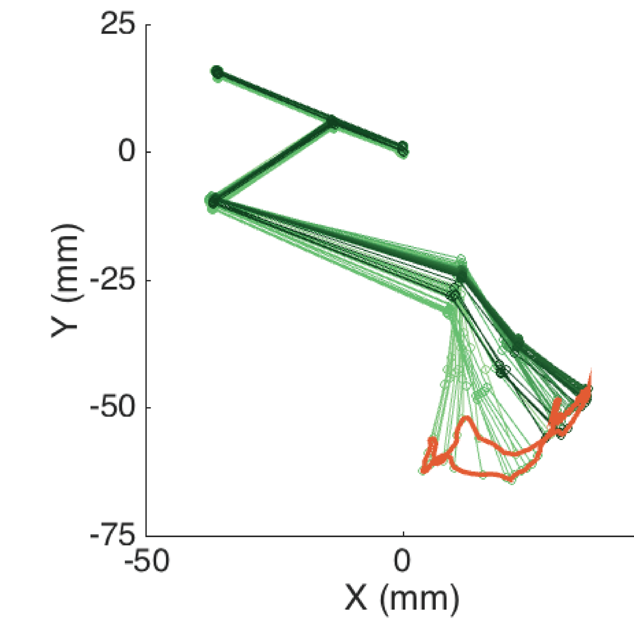


Extensor Stimulation: VL, SM, LG



EMG-based Control

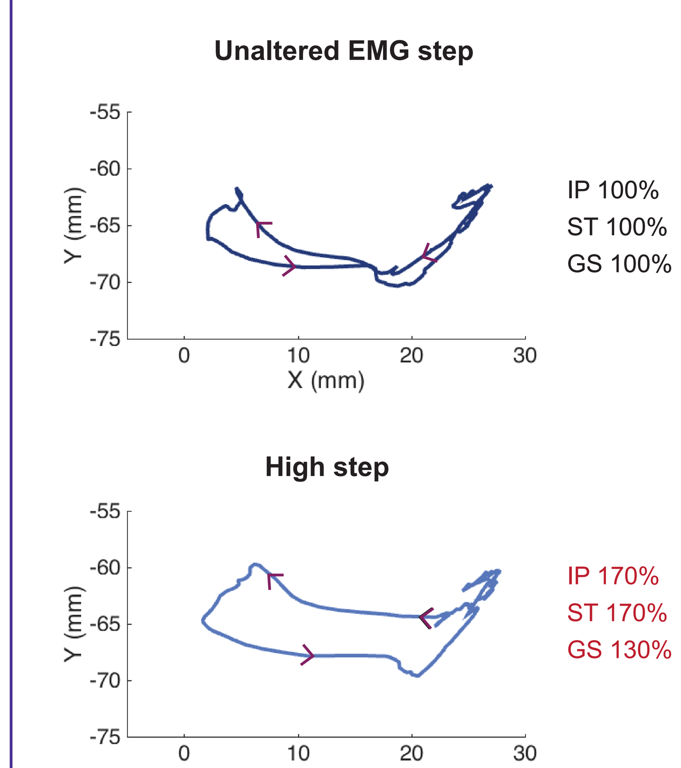




Convert EMGs to FES commands:
- Normalize
- Filter
- Average
- Scale limits

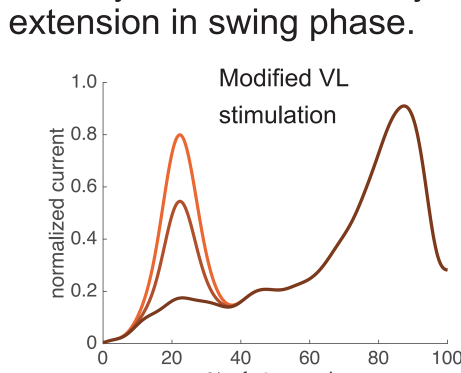
Control runs in MATLAB at 20 Hz.

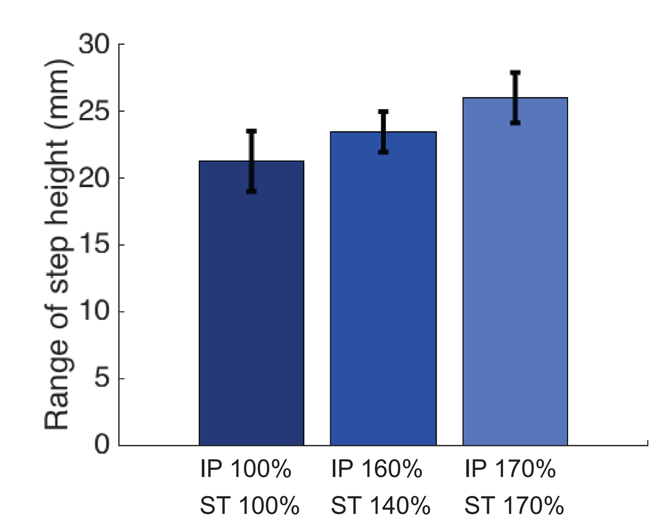
Control of Functional Parameters

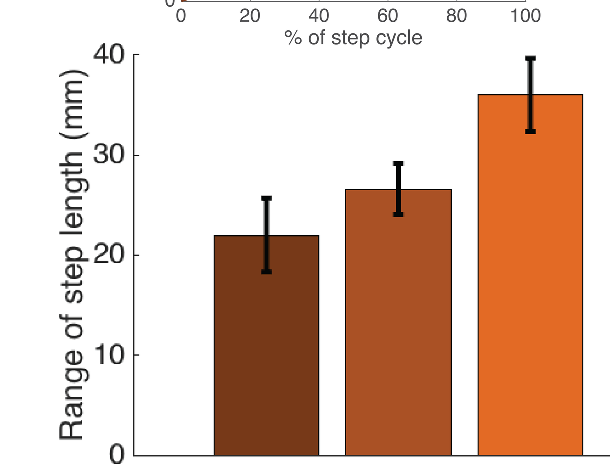


Height
- Increased amplitude of individual muscles in the step cycle relative to other muscles in order to determine key muscles needed to control step height.
- Increased relative current amplitude of several of those key muscles simultaneously to give an overall step height increase.

Length
- Added early burst of VL activity to increase knee extension in swing phase.







Conclusions & Future Directions

We can generate functional hindlimb movements in a rat using EMG-based FES. We would like to increase the range of motion evoked by EMG-controlled stimulation, particularly at the hip joint, as well as to refine control of the leg. Ultimately, we will use the control principles derived from the pre-recorded EMG in a cortically-controlled neuroprosthesis.

Acknowledgments
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