**Muscle Synergy Analysis of tSCS-Assisted Balance Training with a Robotic STAND Trainer**

Tara H. Kimiavi, Robert M. Carrera, Sunil K. Agrawal

Robotics and Rehabilitation Laboratory, Department of Mechanical Engineering, Columbia University

**Introduction:** Muscle synergy analysis is often used as an outcome measurement for task performance1 to investigate how the central nervous system coordinates movement in healthy individuals and in subjects with neuromuscular impairments2. Transcutaneous spinal cord stimulation (tSCS) is a validated rehabilitation technique used to facilitate greater locomotor function in post-spinal cord injury (SCI) patients 3-4. When combined with functional training tasks, tSCS has also been shown to facilitate greater balance control in patients with SCI4. combination of tSCS and functional balance training with the robotic STAND trainer5 may facilitate balance restoration and the formation of more complex muscle synergies for patients with spinal cord injury. The objective of this project is to facilitate balance restoration in patients with severe spinal cord injury using the STAND trainer and transcutaneous spinal cord stimulation while developing an advanced electromyographic filtering and  muscle synergy analysis toolbox in MATLAB for experimental use.

**Methods:** A single able-bodied subject completed two excursion postural lean trials in the STAND trainer with and without tSCS assistance. Each excursion trial consisted of moving the trunk in 8 different lean directions while keeping the feet firmly planted onto the ground to form a “postural star”. Under the tSCS condition, electrical stimulation was provided bilaterally at the anterior superior iliac spine (ASIS) and between T12-L1 on the lower spine. Electromyographic (EMG) signals were collected bilaterally from the soleus (SOL), tibialis anterior (TA), lateral gastrocnemius (GA), rectus femoris (RF), biceps femoris (BF), gluteus medius (GM), rectus abdominis (ABD), and erector spinae (ES). Unwanted frequency components created by tSCS were removed using an open-source ACSR filter8. EMG signals were then Hampel filtered, bandpass filtered between 20-400Hz, rectified, and lowpass filtered at 40Hz to create a linear envelope 9. For each excursion direction under each trial, EMG envelopes were time-interpolated to 200 time points 10 and concatenated into an “all-task” EMG matrix for input into the nonnegative matrix factorization (NMF) algorithm. NMF is a dimensionality reduction algorithm frequently used for muscle synergy analysis11-14. The algorithm assumes that a muscle activation pattern M can be decomposed into a linear combination of basis synergy vectors W and their corresponding activation coefficients C, as shown:

M = c1W1 + c2W2 + c3W3 …. cnWn (1) 11

Where the nth synergy has a fixed muscle composition Wn and can be described by the synergy activation Cn under a given time. Variance accounted for (VAF) between the reconstructed matrix and the input matrix determined the number of synergies that could reasonably represent each dataset (overall VAF > 90, muscle VAF > 75)12. To determine similarity of muscle synergies across directions and conditions, extracted synergies were compared using correlation coefficients, in which a pair of synergies were considered similar if r > 0.623 11-13.

**Results:** Results from the NMF reconstruction identified nine synergies (VAF = 93.3) responsible for movements in all directions under the tSCS condition and seven synergies (VAF = 91.4) under the ntSCS condition. Four synergies were found to be extremely similar (r > 0.9)11 between the tSCS and the no tSCS reconstructions. When comparing synergy activation coefficients between the ntSCS and tSCS conditions, no significant similarities were found, regardless of similarity of muscle synergy vectors for those activations.

**Conclusions:** Balance training with the robotic STAND trainer and transcutaneous spinal cord stimulation may impact muscle synergy complexity. For an able-bodied subject, an increase in muscle synergies (+2) was found when training with tSCS assistance. This analysis pipeline outlines a potential rehabilitative protocol and functional outcome measure for introducing balance restoration in spinal cord injury patients.

**Acknowledgements:** I would like to thank Dr. Sunil Agrawal and all members of the ROAR lab for their guidance.

**References:**