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

Tara H. Kimiavi, Robert M. Carrera, Sunil K. Agrawal
Robotics and Rehabilitation Laboratory, Department of Mechanical Engineering, Columbia University

Abstract

Background: Muscle synergy analysis is often used as an outcome measure for task performance, as muscle synergies serve as the basis for low-level neuromuscular control. For patients with spinal cord injury (SCI), combining transcutaneous spinal cord stimulation (tSCS) with the ROAR robotic STAND trainer may facilitate functional balance restoration.

Experiment: Muscle activation data from a single healthy subject while training with tSCS and the STAND trainer was input into a nonnegative matrix factorization (NMF) muscle synergy analysis algorithm in MATLAB.

Results: Results show increased muscular complexity during postural excursion tasks with tSCS (nSyn = 7 for ntSCS, nSyn = 9 for tSCS). Four synergy pairs were identified as similar (r > 0.9) between tSCS and ntSCS conditions.

Conclusions: Muscle synergy analysis is a potential tool for evaluating outcome measures with the STAND trainer. Future directions include training with SCI subjects and performing group synergy analysis.

Objectives

1. Facilitate **balance restoration in patients with spinal cord injury** using the STAND trainer and transcutaneous spinal cord stimulation.
2. Develop an advanced **electromyographic filtering and muscle synergy analysis pipeline** in MATLAB for experimental use.

Materials and Methods

A single able-bodied subject completed two "postural star" excursion trials in the STAND trainer with and without tSCS assistance, given at both ASIS and T12.

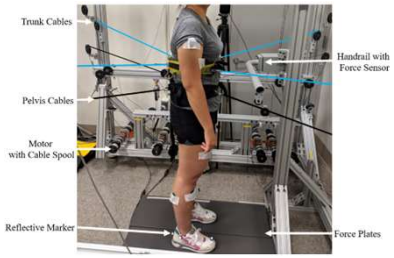

Figure 1: *STAND Trainer Setup (courtesy of Tatiana Luna)*

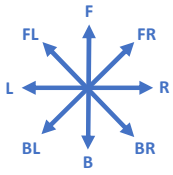

Figure 2: *Postural Star Directions.*

EMG signals were collected bilaterally from the soleus (SOL), tibialis anterior (TA), gastrocnemius (GA), rectus femoris (RF), biceps femoris (BF), gluteus medius (GM), and erector spinae (ES), then processed:

The NMF algorithm is a dimensionality reduction algorithm frequently used for muscle synergy analysis [3-6] and 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:

$$M = c_1W_1 + c_2W_2 + c_3W_3 \ldots . c_nW_n \ (1)$$ [7]

Where the *n*th synergy has fixed muscle composition W_n and can be described by the synergy activation C_n under a given time period.

Results

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].

I. Synergy Reconstructions

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 no tSCS condition.

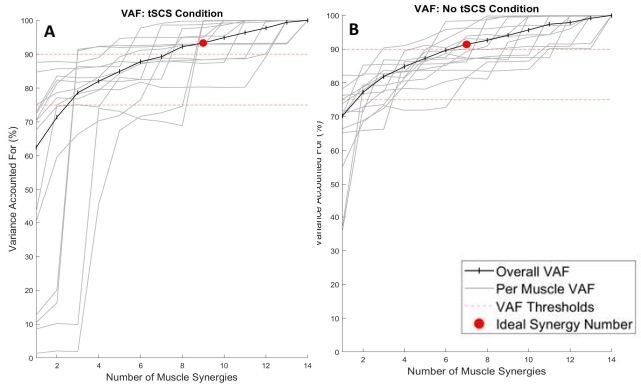

Figure 3A/3B: Reconstruction Quality. Overall (Black) and per-muscle (Grey) VAF results compared between tSCS (3A) and no tSCS (3B) reconstruction conditions.

II. Synergy Similarities

Four synergies were found to be extremely similar (r > 0.9) between the tSCS and no tSCS reconstructions.

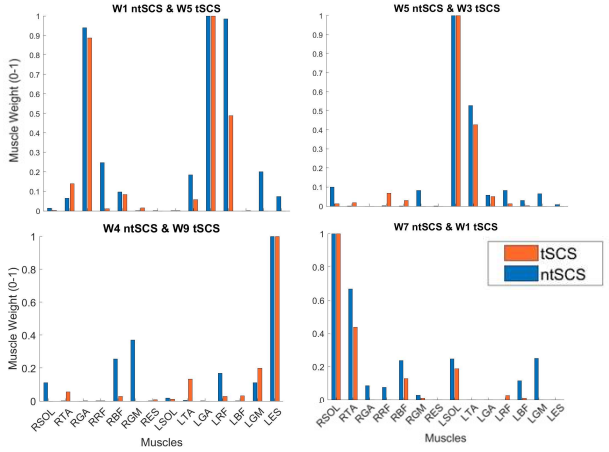

Figure 4: Similar Synergies. tSCS (Orange) and non-tSCS (Blue) grouped synergy pairs.

Results

1. III. Synergy Activations

Although synergy weights between the tSCS and ntSCS conditions were found to be extremely correlated, under these same groupings, activation coefficients under all directions were not similar.

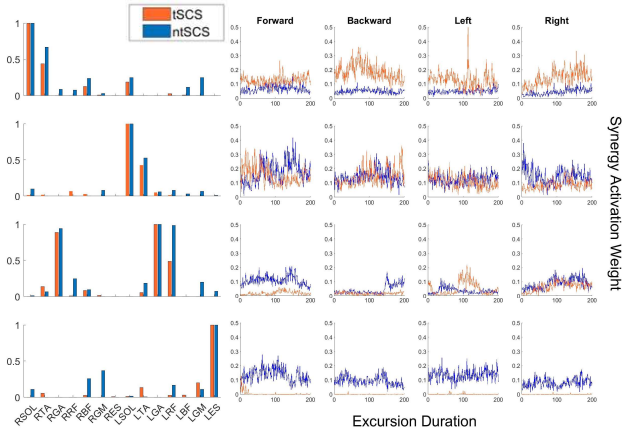

Figure 5A/5B: Synergy Activations for Paired Synergies. A) Similar synergies from nTSCS and tSCS conditions grouped together. B) Activation coefficients for similar synergies under the forwards, backwards, left, and right excursion lean directions.

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.
- Similar muscle synergies are used when training with and without tSCS assistance.
- There is a potential rehabilitative protocol and functional outcome analysis method for introducing and evaluating balance restoration procedures in spinal cord injury patients

References & Acknowledgements

I would like to thank Dr. Sunil Agrawal and all members of the ROAR lab for their guidance this summer.

ROAR LAB