**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 tSCS, nSyn = 9 for isCS). 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 neuromuscular control. For patients with SCI, combining tSCS and the STAND trainer may facilitate functional balance restoration.

**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.

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:

![Image 1: STAND Trainer Setup (courtesy of Tatiana Luna)](image)

The NMF algorithm is a dimensionality reduction algorithm frequently used for muscle synergy analysis 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:

\[ M = c_1 W_1 + c_2 W_2 + c_3 W_3 + \ldots + c_n W_n \]  

Where the nth synergy has fixed muscle composition Wn and can be described by the synergy activation Cn under a given time period.

**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.

**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). 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.  

1. **Synergy Reconstructions**

   Results from the NMF reconstruction identified nine synergies (VAF = 93.3) responsible for movements in all directions under the isCS condition and seven synergies (VAF = 91.4) under the no isCS condition.

2. **Synergy Similarities**

   Four synergies were found to be extremely similar (r > 0.9) between the tSCS and isCS reconstructions.

3. **Synergy Activations**

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

**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**

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**Figure 1:** Postural Star Directions.

**Figure 2:** STAND Trainer Setup (courtesy of Tatiana Luna).

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

**Figure 4:** Similar Synergies. A) ISCS (Orange) and non-ISCS (Blue) grouped synergy pairs. B) Activation coefficients for similar synergies under the forwards, backwards, left, and right excursion lean directions.

**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.