Functional Electrical Stimulation (FES) and Transcutaneous Spinal Cord Stimulation (tSCS): Better Together?

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INTRODUCTION

Aim: Determine whether delivering *FES and tSCS* "*together*" produces contractions that are *"better*" for rehabilitation than those produced by *FES* alone.

Hypothesis: *FES+tSCS* will produce larger contractions and H-reflexes than *FES* alone.

Functional electrical stimulation (FES*) and transcutaneous spinal cord stimulation (tSCS)

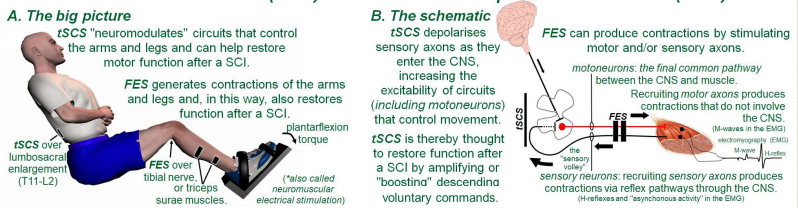

Figure 1: The "sensory vollies" produced during *FES* and *tSCS* share neural circuits and we expect that their effects will interact and influence FES-evoked contractions. This could have benefits for when *FES* and *tSCS* are used together for rehabilitation.

Rationale: We propose that ***if* tSCS "boosts" or amplifies voluntary commands after a SCI by increasing the excitability of spinal circuits (*including motoneurons*)**, as is generally accepted, ***then* tSCS will also amplify contractions produced via reflex paths during FES.**

Predictions: 1a. H-reflexes evoked by single pulses will increase as soon as *tSCS* is turned on.
1b. H-reflexes evoked by single pulses will increase in amplitude as *tSCS* intensity increases.

2a. H-reflexes during 20 Hz trains of *FES* will be larger when *tSCS* is "on" than "off".
2b. H-reflexes during 20 Hz trains of *FES* will increase in amplitude as *tSCS* intensity increases.

3a. Torque during 20 Hz trains of *FES* will be larger when *tSCS* is "on" than "off".
3b. Torque during 20 Hz trains of *FES* will increase as *tSCS* intensity increases.

METHODS

Figure 2: An exemplary participant in the Biodex.

Participants: Four participants (ages 23-59, 1 woman) with no history of neuromuscular injury or disease took part in a single 2-3 hour session.

Protocol: M-waves, H-reflexes and torque were compared when *FES* was delivered over the tibial nerve with and without *tSCS*. Two intensities of *FES* and three intensities of *tSCS* were tested.

Torque: Isometric plantarflexion torque about the ankle joint was recorded while participants sat in a Biodex System II dynamometer (ankle ~90°, knee ~120°).

Functional electrical stimulation (FES)
Stimulus pulses: 1 ms monophasic pulses over tibial nerve at 20 Hz (Digitimer, DS7AH)

Two FES intensities
Low: threshold for M-wave or H-reflex, contractions of ~5% MVC at 20 Hz.
Medium: above M-wave and H-reflex threshold, contractions ~15% MVC at 20 Hz.

Electromyography (EMG): recorded from right soleus (Digitimer, Neurolog).

Figure 3: *FES* stimulating and recording configuration.

Transcutaneous spinal cord stimulation (tSCS)
Stimulus pulses: 1 ms biphasic pulses at 30 Hz. Cathode over T11-L1 at site with lowest threshold for a dorsal root reflex (DRR thresh) in soleus (Digitimer, DS8R).

Three tSCS intensities
Low: 0.7x DRR Thresh
Medium: 0.9x DRR Thresh
High: 1.3x DRR Thresh

Return electrodes (anodes) over iliac crests.

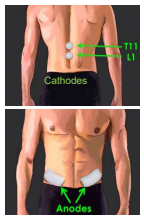

Figure 4: tSCS electrode configuration. (from Barss et al., *J. Clin Med* 2022)

METHODS

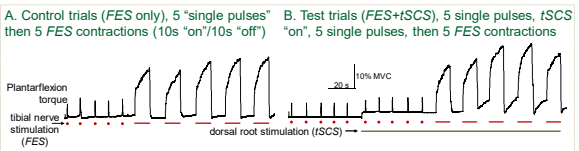

Figure 5. Experimental protocol. Trials were conducted in pairs of control trials and test trials conducted at the same FES intensity.

DATA ANALYSES:
Torque: Torque over 1s intervals at the beginning and end of each contraction was averaged together to provide a measure of the amplitude of each contraction. Torque was normalized to each participants maximum voluntary contraction (MVC).

M-waves and H-reflexes: Responses were measured peak-to-peak and normalised to each participants maximal M-wave (M_{max}).

Statistical analyses were not performed due to the low sample size.

RESULTS
Single Subject data

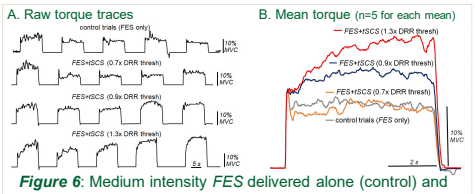

Figure 6: Medium intensity *FES* delivered alone (control) and during three intensities of *tSCS* in a single participant.

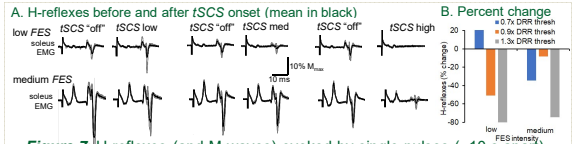

Figure 7: H-reflexes (and M-waves) evoked by single pulses (~10 s apart) immediately before and after *tSCS* was turned on in a single participant.

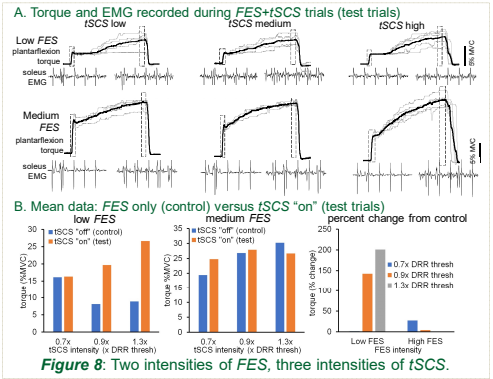

Figure 8: Two intensities of *FES*, three intensities of *tSCS*.

RESULTS
Group data

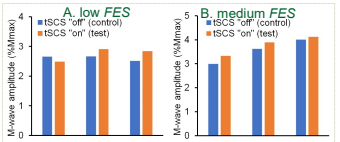

Figure 9. Mean M-waves during *FES*.

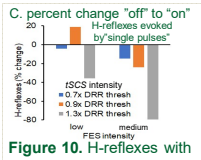

Figure 10. H-reflexes with *tSCS* "off" and "on".

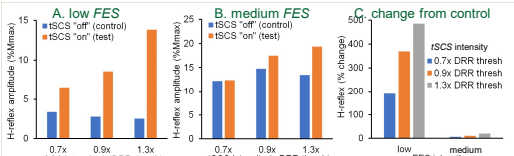

Figure 11. Mean H-reflexes during *FES* with percent change.

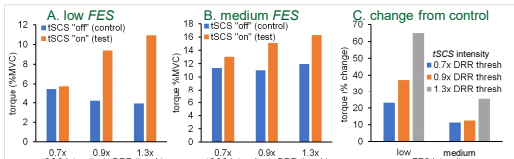

Figure 12. Mean torque during *FES* with percent change.

CONCLUSIONS & IMPLICATIONS

SUMMARY

1. When *tSCS* was turned on, H-reflexes were not immediately larger, instead they appeared to progressively decrease in amplitude as *tSCS* intensity increased.
2. During *FES* trains, H-reflexes did appear to get progressively larger as *tSCS* intensity increased, This effect was much greater during low *FES*.
3. During *FES* trains, torque did appear to increase as *tSCS* intensity increased and the effect was greater for low *FES*.

CONCLUSION

tSCS may increase the excitability of neural circuits and amplify the "reflexive" component of FES-evoked contractions.

POTENTIAL IMPLICATIONS

If *FES+tSCS* produces larger contractions than *FES* alone, we propose the contractions would also be more fatigue-resistant, due to synaptic recruitment in the spinal cord; both outcomes would be beneficial for rehabilitation.

FES+tSCS may also hold promise for neuromodulation, as their impact on CNS circuits may be additive. Further, *FES* of specific nerves or muscles may focus or augment neuromodulation to specific motor pools or pathways.

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