Multi-channel functional electrical stimulation: how many channels are optimal to reduce contraction fatigability?

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Introduction

Contraction fatigability limits the benefits of FES-based programs.

Delivering FES at relatively low frequencies (e.g. 20 Hz) can reduce fatigability, by lowering motor unit discharge rates closer to their natural range (5-25 Hz).

However, FES at low frequencies is not optimal for generating contractions of sufficient amplitude for FES programs. Thus, when selecting FES frequency, there is a trade off between contraction fatigability and contraction amplitude.

Multi-channel FES, in which stimulus pulses are rotated between electrodes ("channels") over a muscle or muscle group can reduce fatigability. The idea is that during multi-channel FES different motor units are recruited by each site and this reduces contraction fatigability by reducing motor unit firing rates.

Purpose

The present study was designed to characterise the relationship between the **number of FES "channels"** and **1) contraction fatigability**, **2) discomfort** and **3) the relationship between stimulation frequency and torque** when FES is delivered to generate isometric contractions of the quadriceps muscles.

Hypothesis

There will be significantly less contraction fatigability (decline in torque over time) as the number of stimulation channels increases.

Methods

Participants and General Setup

FIGURE 1. Subject position in Biodex Dynamometer to measure isometric knee extension. (*www.biodex.com)*

- n=15 participants, 5 women, 10 men; 28.5 ± 12.0 years, no history of neuromuscular injury or disease
- 4 (~1 hr) sessions each, different FES in each session (random order)
- seated in a Biodex dynamometer to measure isometric knee extension torque of the right leg

"Traditional" and Multi-channel FES

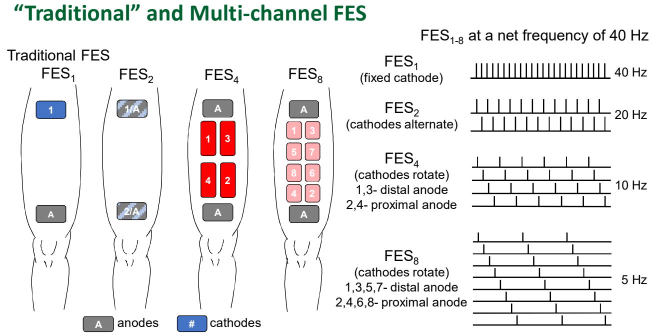
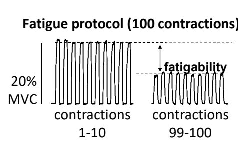


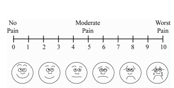
FIGURE 2. Electrode placements (left) and stimulation sequencing (right) for the four types of FES. "Traditional" FES (FES_1): cathode proximal, anode distal. FES_2: anode and cathode alternate (with every other pulse) between proximal and distal. FES_4 and FES_8: cathode rotates through numbered electrodes, proximal cathodes referenced to distal anodes, distal cathodes references to proximal anodes.

Outcomes

Contraction fatigability: Assessed as the decline in torque during a "fatigue protocol" (100 contractions, 1 s "on"/1 s "off", net frequency 40 Hz). Initial contraction amplitude, 20% of a maximum voluntary contraction (MVC). Peak torque binned over 10 successive contractions.



Discomfort: Assessed using a **visual analogue scale** (VAS) at the beginning, middle and end of the fatigue protocol.



Relationship between torque and frequency: Before each fatigue protocol, two trains of one type of FES were delivered at each of 6 frequencies (20, 40, 60, 80 ,100, 120 Hz) in random order. Stimulation intensity was set to generate contractions of 20% MVC at 40 Hz (same as fatigue protocol). A **modulation index** was calculated as the **torque at 100 Hz – torque at 20 Hz** for each type of FES. **Participants rated discomfort** using the VAS for each FES type and frequency.

Results

Single participant: contraction fatigability

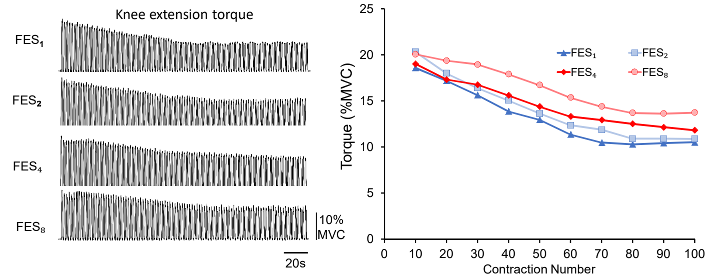


FIGURE 3. Examples of torque recorded from one participant during fatigue protocols using each type of FES (left panels) and "binned" data from that participant (right panel).

Group Data (n=15)

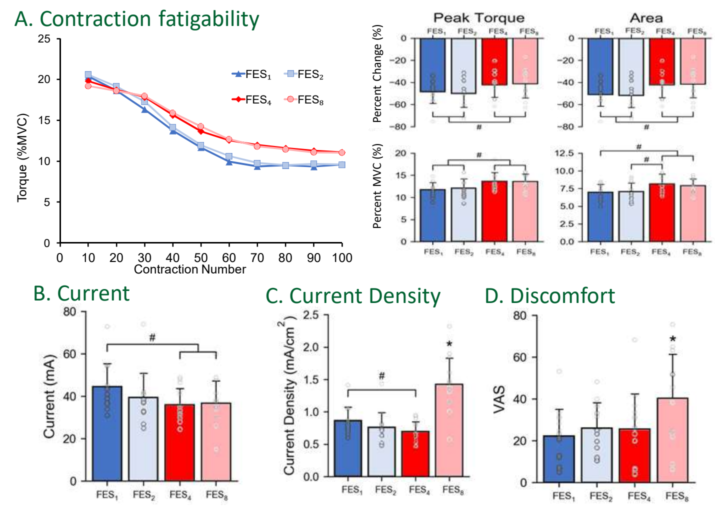


FIGURE 4. Contraction fatigability, current, current density and discomfort across the group of 15 participants. (#) denotes significant differences, and (*) denotes significant differences from all other FES types.

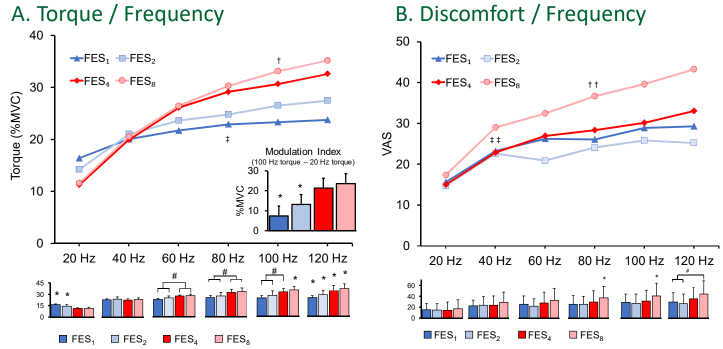


FIGURE 5. Relationships between torque and frequency (panel A) and discomfort and frequency (panel B) for the group of 15 participants. In the upper panels, (‡) is the point where FES_1 and FES_2 are not different from 120Hz. (††) is the point where FES_8 is not different than 120Hz. (‡‡) is the point where FES_4 is not different than 120Hz. (†) is the point where FES_4 and FES_8 are not different than 120Hz. In the lower panels, (#) denotes significant differences, and (*) denotes significant differences from all other FES types.

Conclusions

FES_4 and FES_8 reduced contraction fatigability compared to FES_1 and FES_2. FES_8 produced the most discomfort, likely due to the small electrodes and high current densities. FES_4 and FES_8 generated more torque than FES_1 and FES_2 at all frequencies above 40 Hz.

By lowering motor unit discharge rates, multi-channel FES reduces contraction fatigability and shifts motor units leftward on the torque/frequency curve, generating larger contractions by increasing the range over which frequency can modulate torque.

Based on these data, **we recommend FES_4 (at 80-100 Hz) for minimising contraction fatigability and discomfort while maximising contraction amplitude.**

Further optimisation of electrode orientations, stimulation parameters and sequencing will likely improve the extent to which **multi-channel FES can address the trade-off between contraction fatigability and contraction amplitude during FES**.

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