Assessment of Motor Units' Recruitment/Derecruitment Discharge Rate after Phase-Dependent Peripheral Electrical Stimulation

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***Abstract*— Peripheral electrical stimulation (PES) has been shown to boost activity-dependent neural plasticity by recruiting afferent fibers in conjunction with physiological activity. This study aimed to explore the acute changes in motor unit (MU) recruitment and derecruitment discharge rate (DR) following a 20-minute PES session in healthy volunteers. High-density electromyography decomposition from flexor carpi radialis was used to identify MU DR patterns before and after PES. Recruitment and derecruitment DRs were increased when PES was delivered in-phase with muscle contraction. These results expand our knowledge on the effects of PES as a neural rehabilitation tool to treat motor disorders.**

I. Introduction

PERIPHERAL electrical stimulation (PES) of afferent pathways is a widely used technique to promote neural plasticity in various neurological conditions, including pathological tremor, stroke or spinal cord injury. However, the exact mechanisms underlying these neural adaptations, particularly in the upper limb, remain a topic of ongoing research. We have previously shown that phase-dependent PES of the radial nerve, synchronised with flexor (FCR) or extensor carpi radialis (ECR) activity, produced distinct short-term modulatory effects on disynaptic group I inhibition [1]. Here, we explored the acute changes in the recruitment and derecruitment discharge rate (DR) after two different PES sessions in healthy volunteers, providing new insights into the neural drive changes and supporting evidence of phase-dependent PES-induced neuroplasticity.

II. Materials and Methods

A. Subjects

Eight healthy volunteers (3 females, 5 males; 27.6 ± 6 years; one left-handed) participated in the study. The CSIC Ethics Committee approved all procedures (code 122/2023), and all subjects signed a written informed consent according to the Declaration of Helsinki. Each participant completed two sessions: one with stimulation synchronized with muscle activity (in-phase) and the other with stimulation synchronized with the muscle activity of the antagonist (out-of-phase). Each participant was randomly assigned a session order and sessions were conducted in different weeks.

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B. Experimental procedure

Participants were seated upright with their dominant arm resting on a custom platform and the forearm between total pronation and supination. The shoulder and elbow joints were kept at approximately 45 and 120 degrees, respectively (see Fig. 1).

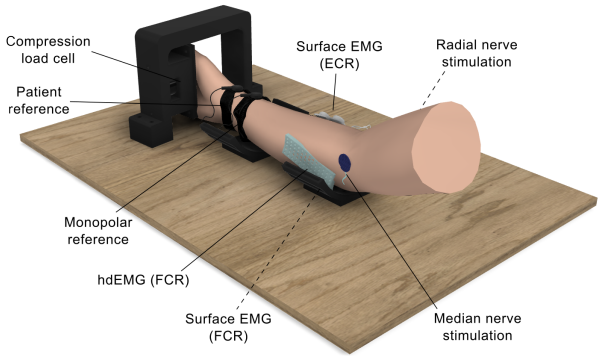

Fig. 1. Experimental setup.

Each of the two experimental sessions consisted of four series of isometric wrist flexions followed by PES, and concluded with another four series of isometric wrist flexions.

High-density electromyography (hdEMG) signals were recorded from the FCR. The skin was abrased and an adhesive grid of 64 electrodes (13×5, 8 mm of inter-electrode distance) (OT Bioelettronica, Italy) was placed centered over the FCR. The grid was secured with tape and an elastic band. HdEMG signals were recorded in monopolar derivation at 2,048 Hz with a bioelectric amplifier (Quattrocento; OT Bioelettronica, Italy) using a wet wristband as reference.

Participants were initially asked to perform two 5-second maximum voluntary contraction (MVC) wrist flexions, with a 2-minute rest between trials. The force exerted was measured by a compression load cell (model FC22; Measurement Specialties, USA) and displayed to the subject for visual feedback during the isometric wrist flexions. Each participant performed four trapezoidal contractions, consisting of a linear ramp up at 4%/second, a plateau at 20% MVC for 30 seconds, and a ramp down at 4%/second. Trials were alternated with 1-minute rests.

PES was delivered through surface electrodes (Ø 3.2 cm) (ValuTrode Cloth; Axelgaard Manufacturing, Denmark) placed at the cubital fossa and radial groove to stimulate the median and radial nerves, respectively, with a common anode at the olecranon (5×5 cm). Stimulation was guided by bipolar surface EMG on the FCR and ECR muscles

(Ag/AgCl, 2.2×2.2 cm) (NeuroPlus; Vermed, USA) according to the Selective and Adaptive Timely Stimulation strategy described in Pascual-Valdunciel *et al.* (2021) [2]. EMG recording (2,000 Hz of sampling frequency) and stimulation (100 Hz, biphasic 400 µs pulse width) were managed by a custom EMG amplifier with an integrated voltage-controlled stimulator (EAST; OT Bioelettronica, Italy). Stimulation amplitude was always just below motor threshold (MT). For 20 minutes, participants simulated flexion-extension wrist tremor while stimulation was delivered in-phase (median nerve stimulation when FCR was active and radial nerve stimulation when ECR was active) or out-of-phase (median stimulation when ECR is active and radial stimulation when FCR is active). Lastly, the four trapezoidal contractions were repeated post-intervention.

C. Data analysis

Raw monopolar hdEMG signals were digitally band-pass filtered with a second-order Butterworth filter (20-500 Hz) and power line interference was removed with a notch filter. Channels with low signal-to-noise ratio or artifacts were removed after visual inspection. Motor units (MUs) were extracted by an open-source fast independent component analysis algorithm [3]. Automatically detected MUs were checked for duplicates, and spike trains were manually edited to identify false positives and negatives. Only MUs with a pulse-to-noise ratio above 29 dB were used for further analysis.

By using the pre- and post-intervention trials with the greatest number of identified MUs, a percentage of the original MUs were tracked after the intervention. MUs with highly similar action potential waveforms (cross-correlation ≥ 0.7) were classified as belonging to the same MU.

From the edited discharge patterns, the characteristics of the tracked MUs were identified [4]. The DR at recruitment and derecruitment stages was calculated by averaging the intervals of four consecutive discharges at the start and end of the contraction. Post-intervention values were normalized to pre-intervention values and expressed as a percentage for each tracked MU.

D. Statistical analysis

Statistically significant differences in the DR during recruitment and derecruitment phases were assessed between the times of assessment (pre and post) and among the groups (in-phase and out-of-phase). Data normality was evaluated with the Shapiro-Wilk test. When normality was satisfied, two-tailed paired t-tests assessed post-intervention differences; otherwise, Wilcoxon signed-rank tests were used. For unpaired samples, independent samples t-tests and Mann-Whitney U test were employed. A significance level $p < 0.05$ was used.

III. Results

After the in-phase and out-of-phase strategies, 63% and 73% of the identified MUs were successfully tracked, respectively.

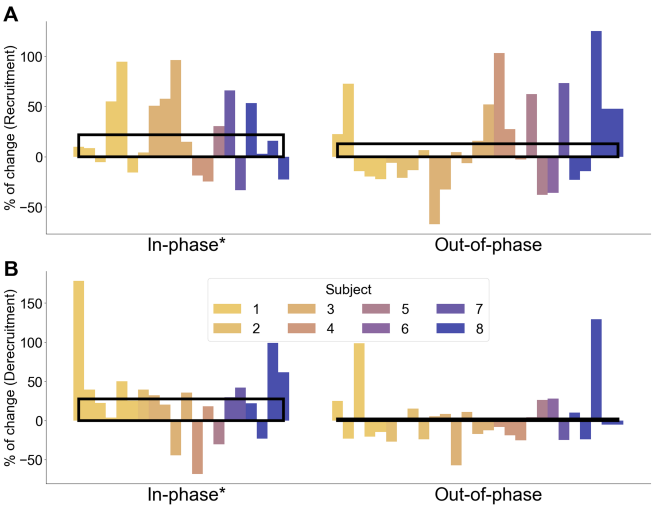

Fig. 2. Percentage of change of the DR after in-phase and out-of-phase strategies at the (A) recruitment and (B) derecruitment phases.

During the recruitment stage, there was a statistically significant increment of 21.97% ($p = 0.02$) in the DR of the tracked MUs after the in-phase intervention, and a 12.74% increment ($p = 0.17$) after the out-of-phase intervention.

Regarding the derecruitment phase, the DR of tracked MUs also experienced a statistically significant increase 27.64% ($p = 0.03$) in the in-phase group, whereas the DR after the out-of-phase intervention remained almost unchanged, with an average increase of 2.02% ($p = 0.56$).

No statistically significant differences were found between in-phase and out-of-phase groups during the recruitment ($p = 0.47$) or derecuitment ($p = 0.06$) stages (see Fig. 2).

IV. Discussion and Conclusion

This study provides further evidence that PES, specifically below MT, induces phase-dependent neural plasticity. This can potentially enhance functional recovery in various neurological conditions. The observed increase in DR during recruitment and derecruitment after PES in-phase with muscle activity aligns with previous findings of enhanced corticospinal excitability [1]. Part of our future work will include similar analysis in a bigger sample of subjects in order to confirm these preliminary findings.

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