

This is the peer-reviewed version of the following article:

Popović-Maneski, L., Topalović, I., 2019. EMG Map for Designing the Electrode Shape for Functional Electrical Therapy of Upper Extremities, in: Masia, L., Micera, S., Akay, M., Pons, J.L. (Eds.), *Converging Clinical and Engineering Research on Neurorehabilitation III, Biosystems & Biorobotics*. Springer International Publishing, pp. 1003–1007, http://dx.doi.org/10.1007/978-3-030-01845-0_201.



This work is licensed under a [Creative Commons Attribution Non Commercial No Derivatives 4.0](https://creativecommons.org/licenses/by-nc-nd/4.0/) license

EMG Map for Designing the Electrode Shape for Functional Electrical Therapy of Upper Extremities

Lana Popović Maneski, Ivan Topalović

Abstract: Achieving the functional grasp by electrical stimulation using surface electrodes is a demanding task. The innervations of muscles come via ulnar, radial and median nerves. The anatomy of nerve branches connecting various muscles in the forearm differs significantly between individuals. We hypothesize that the anatomical differences between the paretic and nonparetic arms are minimal. Based on this assumption we developed a method where the differences of muscle activities (EMG) between the healthy and paretic arms recorded by the 24-contact electrode within an array define the target zones to be stimulated on the affected forearm. We used special electrode where magnetic contacts allow simple change of the stimulation pads. The examiner positions the magnetic contact on the pads where the EMG differences are maximal. The stimulator delivers asynchronous stimulation to the selected pads. We proved that the method is working in stroke patients by measuring joint angles and the grasping force.

Key words: EMG map, Functional Electrical Stimulation, Multipad electrode, Stroke, Reaching and grasping

I. INTRODUCTION

THE problem of selective activation and the possible solution to use multipad electrodes for control of the grasping was addressed by Nathan [1]. Nathan provided detailed maps for the stimulation of forearm muscles indicating significant inter-subject variability.

The research headed by ETH Zurich resulted in a comprehensive analysis of the effects of the size of individual pads and their position when activated by electrical stimulation [2].

The Actitrode[®] system [3] was the starting point for the development of the asynchronous distributed functional electrical stimulation [4-6]. The testing of the automatic procedures showed that it is not simple enough to be used in the daily clinical use. Popović-Maneski et al. [7] introduced the method presented here.

The use of the electrode array has another important feature: it facilitates the prolongation of the continuous stimulation of a particular muscle by postponing the fatigue

The work on this project was partly supported by the grants III 44008 and TR35003 from the Ministry of Education, Science and Technological development of Serbia and the project F 137 by the Serbian Academy of Sciences and Arts, Belgrade, Serbia.

Lana Popović-Maneski is Institute of Technical Sciences of Serbian Academy of Sciences and Arts, Belgrade (e-mail: lanapm13@gmail.com).

Ivan Topalović is with the Institute of Technical Sciences of Serbian Academy of Sciences and Arts, Belgrade (e-mail: topalovic_ivan@yahoo.com)

induced by electrical stimulation [8, 9].

II. METHODS AND MATERIAL

The hypothesis that we tested was that the mirror map of the EMG recorded from the nonparetic arm during a functional movement would be the target on the paretic arm. We generated the EMG map from the signals recorded with a 24-pad surface electrode connected to the digital amplifier Smarting [10, 11].

A. Subjects.

The criteria for the participation in the study were: compromised grasping, first-ever stroke, stable blood pressure and heart rhythm, no implanted stimulators, able to understand and follow instructions during the tests, receiving only conventional therapy. The protocol for the study was approved by ethics committee of the Clinic "Dr. Miroslav Zotović," Belgrade (N^o 03-580/1, 2015). Three, out of 12, randomly selected chronic stroke patients (upper extremity score FM scores over 80) participated after signing the consent form.

B. Instrumentation

Two sets of 24 circular conductive pads ($D = 0.8$ cm) printed on 6 cm x 15 cm nonconducting flexible sheets were connected to two 24-channel digital amplifiers (Smarting[®]). The 500 pps sampling rate range was applied because of the Bluetooth communication link limitations. The reference and ground electrodes (SG26, Bio-medical Instruments, MI, USA) were positioned over the bony portion of the elbow joint. EMG map was generated by cubic spline interpolation of 24 nodes on the paretic and nonparetic arm. These maps were projected on the computer screen to the examiner.

The kinematics was acquired by F35 single axis goniometers over the fingers (Biometrics Ltd, VA, USA) and SG65 and SA110A for the thumb and wrist rotations. The joint angle units were used for the signal conditioning. The analog signals were fed to the input of the NI USB 6216 A/D card (National Instruments, TX, USA). The dynamometer for the assessment of the grasping force was custom made device with four squeezable chambers instrumented with pressure sensors [12].

Two electronic stimulators with eight output channels generated compensated biphasic current controlled pulses [13]. The stimulator allows the control of frequency, pulse duration, pulse amplitude and pulse delay on each of the channels. The output leads had pins made out of rare earth magnets on their ends for the contacts with the electrodes.

An array (5 along the forearm and 8 circular to the forearm) magnetic metal pads (square, side 12 mm) covered with AG730 conductive gel were possible cathodes. Two oval anodes (Pals Plus electrode, 4 x 6 cm, Axelgaard Manufacturing Co) were positioned over the dorsal and volar sides above the wrist of the paretic arm. The examiner was positioning the leads from the stimulator to pads where the EMG differences between the nonparetic and paretic EMG maps were the largest.

III. RESULTS

We show only one example (Fig. 1): the pads and stimulation relative intensities used to stimulate prehension and grasp in one hemiplegic subject. The positions correspond to the zones in the EMG maps where the differences have been established. The examiner changed the position of contacts (maximum three contacts per electrode) by observing the differences in the EMG maps.

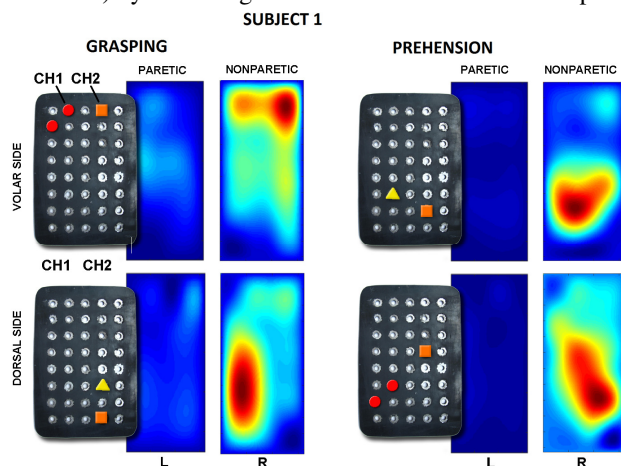


Fig. 1. EMG activity maps and stimulation zones in subject N° 1. Maximum current intensities are color-coded: red - high intensity \approx 24mA, orange - middle-intensity \approx 19mA, yellow - low-intensity \approx 14mA. The frequency of all channels was set to 30pps and the pulse duration to 350 μ s. Modified from [7]

IV. CONCLUSION

We developed a method for determination of the regions over the motor system that need to be stimulated for the selective functional activation of the hand based on the comparison between the nonparetic and paretic forearm EMG activities.

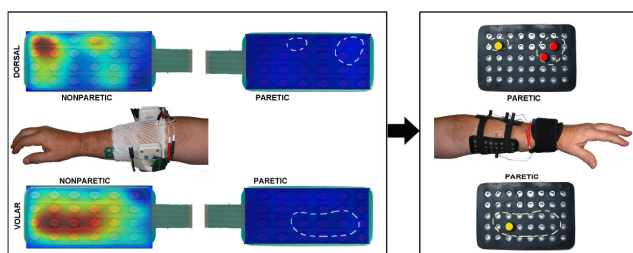


Fig. 2: The two-phase procedure for selective activation of target muscles: 1) mapping of EMG activity (top view) for nonparetic and paretic forearm muscles during hand opening (left panel), and 2) the zones where

significant differences are visible where the outputs from the stimulator should be connected. Color codes: red - high intensity, orange - middle intensity, yellow - low intensity). Modified from [7].

The actual implementation is foreseen as the two-phase operation (Fig. 2): 1) Multi-channel EMG recordings and data processing, and 2) Stimulation via electrode pads selected based on the position of significant differences in EMG maps from paretic and nonparetic forearms.

ACKNOWLEDGMENT

We thank the company "mBrainTrain," Belgrade for allowing us to use Smarting amplifiers and the company "Tecnalia Serbia," Belgrade for providing us with the array electrodes for EMG recordings. We thank clinicians from the Clinic for rehabilitation "Dr. Miroslav Zotović," Belgrade and Dejan B. Popović for the overall assistance.

REFERENCES

- [1] R. H. Nathan, "An FNS-based system for generating upper limb function in the C4 quadriplegic." *Medical and Biological Engineering and Computing* Vol. 27, 1989, pp. 549-556
- [2] A. Kuhn, T. Keller, S. Micera and M. Morari, "Array electrode design for transcutaneous electrical stimulation: A simulation study." *Medical engineering & physics*, Vol. 32, 2009, pp. 945-951
- [3] A. Popović Bijelić, G. Bijelić, N. Jorgovanović, D. Bojanić, M.B. Popović and D.B. Popović, "Multi Field Surface Electrode for Selective Electrical Stimulation." *Artificial Organs*, Vol. 29, 2005, pp. 448-452
- [4] D. B. Popović, M. B. Popović, "Automatic determination of the optimal shape of a surface electrode: Selective stimulation." *Journal of neuroscience methods*, Vol. 178, 2009, pp. 174-181
- [5] N. Malešević, L. Popović Maneski, V. Ilić, N. Jorgovanović, B. Bijelić, T. Keller and D.B. Popović, "A Multi-Pad Electrode based Functional Electrical Stimulation System for Restoration of Grasp" *J Neuro Eng Rehab* Vol. 9:66, 2012, doi: 10.1186/1743-0003-9-66;
- [6] L. Popović-Maneski, M. Kostić, T. Keller, S. Mitrović, Lj. Konstantinović and D. B. Popović, D.B. "Multi-pad electrode for effective grasping: Design". *IEEE Trans Neur Sys Reh Eng*, Vol. 21(4), 2013, pp. 648-654
- [7] L. Popović-Maneski, I. Topalović, N. Jovičić, S. Dedijer, Lj. Konstantinović and D. B. Popović, "Stimulation map for control of functional grasp based on multi-channel EMG recordings", *Medical Engineering & Physics*. Vol.38, 2016, pp. 1251-1259
- [8] L. Popović-Maneski, N. Malešević, A. Savić and D. B. Popović, "Spatially distributed asynchronous stimulation delays muscle fatigue." *Muscle & Nerve*, Vol. 48, 2013, pp. 930-937
- [9] R. Nguyen, K. Masani, S. Micera, M. Morari, and M.R. Popović, "Spatially Distributed Sequential Stimulation Reduces Fatigue in Paralyzed Triceps Surae Muscles: A Case Study." *Artificial Organs* Vol. 35, 2011, pp. 1174-11803
- [10] <http://www.mbraintrain.com/> last visited Mach 2018;
- [11] I. Topalović, M. Janković and D. B. Popović "Validation of the acquisition system Smarting for EMG recordings with electrode array." *Proc. 2nd IcETran*, Silver Lake, Serbia, June 6-9, 2015. ME11.3
- [12] L. Popović et al., Patent II-2014/0436 A1, <http://pub.zis.gov.rs>, last visited November 2017.
- [13] N. S. Jovičić, L. V. Saranovac, and D. B. Popović, "Wireless Distributed Functional Electrical Stimulation System." *J Neuro Eng Rehab* Vol. 9:54, 2012, doi:10.1186/1743-0003-9-54