
There may be differences between this version and the published version. You are advised to consult the publisher’s version if you wish to cite from it.

http://eprints.gla.ac.uk/143728/

Deposited on: 7 July 2017
Gait Analysis and Quantitative Drug Effect Evaluation in Parkinson Disease by Jointly EEG-EMG Monitoring

D. De Venuto\textsuperscript{1}, V.F. Annese\textsuperscript{2}, G. Defazio\textsuperscript{3}, V.L. Gallo\textsuperscript{1}, G. Mezzina\textsuperscript{1}

\textsuperscript{1} Dept. of Electrical and Information Engineering (DEI) Politecnico di Bari, Italy
\textsuperscript{2} School of Engineering, University of Glasgow, Glasgow G12 8LT, U.K
\textsuperscript{3} Department of Basic Science, Neuroscience and Sense Organs, “Aldo Moro” University of Bari, Italy

Abstract — This work addresses the rising need for a diagnostic tool for the evaluation of the effectiveness of a drug treatment in Parkinson disease, allowing the physician to monitor of the patient gait at home and to shape the treatment on the individual peculiarity. In aim, we present a cyber-physical system for real-time processing EEG and EMG signals. The wearable and wireless system extracts the following indexes: (i) typical activation and deactivation timing of single muscles and the duty cycle in a single step (ii) typical and maximum co-contractions, as well as number of co-contraction/s. The indexes are validated by using Movement Related Potentials (MRPs). The signal processing stage is implemented on Altera Cyclone V FPGA.

In the paper, we show in vivo measurements by comparing responses before and after the drug (Lodopa) treatment. The system quantifies the effect of the Lodopa treatment detecting: (i) a 17\% reduction in typical agonist-antagonist co-contractions time (ii) 23.6\% decrease in the maximum co-contraction time (iii) 33\% decrease in number of critical co-contraction. Brain implications shows a mean reduction of 5\% on the evaluated potentials.

Keywords—EEG, EMG, MRPs, Gait, FPGA, Parkinson disease, Lrovodopa administration

1. INTRODUCTION

Parkinson's disease (PD) is a long-term degenerative disorder of the central nervous system, resulting in motor impairment. Typically, the cardinal features of PD are resting tremor, rigidity, bradykinesia and gait disturbance followed by disequilibrium [1]. Nowadays, PD affects 1\% of the over 60 year-old population and the 4\% of those over 80: globally, about 7 million people [2]. In Parkinson's disease, certain nerve cells (neurons) in the brain gradually break down or die. Many of the symptoms are due to a loss of neurons that produce a chemical messenger in the brain called dopamine. When dopamine levels decrease, it causes abnormal brain activity, leading to signs of Parkinson's disease.

In order to make personalized medicine be successful, the major challenges to address are the development of accurate diagnostic tests that detect a pathology in its early stage and identify patients who can benefit from targeted therapies. Emerging new tools in PD analysis such as molecular imaging (PET/SPECT imaging) [4] and OMICS [5] have made it possible to customize the health care of individual PD patients, basing on a physiological and pathological knowledge of the subtype and the stage of the disease [3]. The Deep Brain Stimulation (DBS) is a promising surgical procedure for the treatment of advanced PD. The mechanism of DBS [6] is blocking abnormal neural signals, which lead to clinical symptoms of PD sending electrical impulses to specific brain regions. From the perspective of precision medicine, one of the key considerations in DBS is selecting the most effective target area individually for the specific patient. These types of prognostic approaches are highly accurate, but they still do not allow a real-time evaluation of the impact. Furthermore, DBS is an invasive technique suggested only in advanced PD patients due to the high cost of the operation and because of the need of change the implanted device every 10 years.

Instead, on the drug side, no significant progress has been achieved: the Levodopa, releasing dopamina, has remained the most effective treatment since 1960. Nevertheless, the scientific community has demonstrated a very high variability of the efficacy of a single treatment from one subject to the other [3]. Some patients also develop severe side effects that make, de facto, their situation even worse.

In the meantime, wearable sensor technology offers an encouraging solution to the above-mentioned challenge since it performs high degree of objectivity, sensitivity, good accuracy and real-time operability, allowing the monitoring during the everyday life with a discrete comfort degree. Interestingly wearable solutions have been proposed in literature aiming help patients with therapeutic administration, by using automatic assessment of gait analysis indexes. eGaIT system [7] and Parkinson’s Kinetigraph based (PKG) system [8] are some examples. Both evaluate the gyro and accelerometer responses, neglecting cortical and muscular implications, but translating a typical visual inspection in an unambiguous signal. Furthermore, classifications algorithms and evaluations are entrusted to computing units (i.e. PC) in post-processing (offline) mode. eGaIT [7] does not provide useful information about PD’s cardinal features (i.e. dyskinesia). Finally, PKG [8] excludes from the assessment the postural instability.

In this frame, we propose a gait cortico-muscular indexes evaluation platform for PD patients. The architecture - fully implemented on Altera Cyclone V FPGA - combines and processes in parallel both electromyographic (EMG) and electromyographic (EEG) bio-signals in order to define in real-time the modulation of ad hoc calculated indexes to characterize the gait. For instance, the monitoring of these quantitative parameters before and after a treatment allows verifying the degree of effectiveness of the treatment, which is dispensed to the patient. The here proposed Cyber-Physical System (CPS) is an improved version of the system implemented in [9]. Differently from [9], this CPS implements a novel stage for muscular indexes evaluation, allowing precise gait analysis. The platform has been tested on a Parkinson’s diseased (PD) patient before and after the Levodopa treatment.
This paper presents detailed results of the above-mentioned in vivo measurements, highlighting quantitative gait modification due to the effect of Levodopa. The structure of the paper is outlined in the following. Section II introduces the basic medical knowledge for gait analysis, focusing on both EEG and EMG evaluation. Section III outlines the CPS architecture and previous implemented EEG-EMG branches. Section IV introduces the new computing block for the patient muscular status evaluation and its implementation on FPGA. Section V presents experimental results. Section VI concludes the paper.

II. THE ARCHITECTURE BACKGROUND: PREVIOUS WORK

Exploiting the Cyber-Physical System (CPS) proposed in our previous works [9, 12-14], a new computing branch has been added to the overall architecture, aiming to extrapolate useful indexes related to abnormality in walking pattern, which are typical features of neurological patients as the ones with PD. Recognizing and quantifying the typical drift in gait alterations indexes (brain or muscular implications) allows to outline the positive/negative effects of a specific drug treatment, and thus makes possible to adjust the dose if needed.

The CPS consists of a wireless body area network (WBAN) linked to a gateway, which collects and on-line processes the EEGs and EMGs signals. The CPS calculates muscular activation and cortical implication flags, for the recognition of voluntary movements.

Medical Background

Before performing a voluntary movement, our brain activates a cerebral process dedicated to the ideation and activation of a proper muscles sequence stimulation. This brain process starts 1 second before the muscle activation. The occurrence of the EEG Movement Related Potentials (MRPs), before the EMG activation, shows the movement intentionality, as well as its magnitude returns an objective evaluation of the cerebral cortex implication in the specific movement [10]. As in [9], the implemented CPS focuses on three MRPs: Bereitschaftspotential (BP), μ and β rhythms. BP ranges in 2-5 Hz band reaching its magnitude peak about 200ms before the movement onset [10]. The μ-rhythm occupies the 7.5-12.5 Hz band (and primarily 9-11Hz), and can be defined as a kind of steady state of motion. μ -rhythm is suppressed after the motor action [10]. The β-rhythm ranges between 12.5 and 30 Hz. β-waves recorded in the motor cortex are associated with the muscle contractions that happen in isotonic movements. [10]. MRPs are more visible on the motor cortex. In parallel, EMG are processed in order to both evaluate the cortical implication and involuntary muscles cross-activation (dyskinesia). The single muscle parameters (activation and relaxation times) contribute to fill of the UPDRS scale in Section III and IV. They allow the evaluation of the bradykinesia degree (i.e. slowness or abnormal muscular hyperactivity). In addition, they allow to objectively assessing motor fluctuations in long period, which are linked to a wrong dose of drug, by using a set of muscle activation/relax timer (known in Section IV [11] as State ON-OFF).

III. THE CYBER PHYSICAL SYSTEM

Hardware. The system, outlined in Fig.1, uses 8 EMG electrodes and 8 EEG ones. The EEG electrodes are placed on Gastrocnemius, Tibialis, Rectus and Biceps Femoris of both the legs. The EMG electrodes, according to the international 10-20 system, cover the pre-motor cortex area with T5, T6, C3, C4, Cz, P3, P4 positions. O2 electrode is used for noise reduction. The EMG signals are sampled at 500Hz with 16bit resolution while EEG signals are sampled at 500Hz with 16bit resolution while EEG channels have the same sampling rate (500Hz) and 24bit resolution [12-14]. A wireless and wearable recording system collects both the signals and sends them to a gateway. The signal processing is performed in real-time on an FPGA.

Working Principle. The EMG electrode detects the movement, due to a muscle contraction (Trigger), and magnitude level overcomes a learned baseline (Edge Enable). The trigger enables the computing unit that operates a time-frequency analysis on the EEG data, in the 500ms preceding the movement. The EEG analysis consists of a MRPs detection by using thresholds based approach. The overlap of the dynamic thresholds detects three MRPs flags for each channel – 21 flags in total, identifying the voluntariness of the movement (see Fig. 1). Here we introduce in the FPGA, a novel computation block
with respect to [9, 12-14], the Muscular Index (MI) block, which follows the Trigger generator one (in orange in Fig. 1). It extracts in real time 36 MIs from EMG signals, supporting the cortical implication information.

**Algorithm.** The movement detection is entrusted to 1-bit trigger signals (one trigger for each muscle) obtained by dynamic-threshold approach [12]. The EMG is stored in an M samples shift-register (M = 512 -1s). The mean value of all register samples defines the global average (GA) and it is used as threshold. A second average is computed on the last N samples (with N<M). For this local averages (LA), our design adopts N = 128 samples (~250ms). Finally, the LA is compared with the GA threshold. Since the threshold is dynamically updated (as soon as an EMG sample arrives), the algorithm allows to follow the trend of the muscular tone continuing to work properly. The EMG trigger stays at high level until the local power is larger than the dynamic threshold. The EEG trigger signals (one trigger for each muscle) obtained by an on-chip Phase-Locked Loop (PLL) are temporized through a series of dedicated states. A comparator compares the powers calculated by the two blocks (G \( \text{Pwr} \) and L \( \text{Pwr} \)). L \( \text{Pwr} \) is also compared to a learned fixed threshold that prevents uncontrolled activation connected to noisy events (BL). The comparator provides a 1bit EMG Trigger, used both in the EEG and muscular computing.

**A. Previous FPGA Implementation: EEG-EMG Branches**

The global system clock is set to 8.19209MHz (signal 8 MHz CLK), obtained with an on-chip Phase-Locked Loop (PLL) from the embedded 50MHz oscillator. The global signals of the whole implementation are: Reset, an asynchronous reset, Enable, an enable signal which freezes the processing; 500Hz CLK, an input data clock signal from the EMG and EEG channels (500Hz frequency). 8 EMG and 7 EEG branches work in parallel on FPGA [9]. The following section briefly summarizes the FPGA implementation of the CPS [9] in order to help the understanding the operation of the MIs block.

**EEG Computing Branch.** Within the branch there is a 256 point 24 bit resolution FFT processor based on a butterfly structure. The 256 EEG samples to be transformed are dynamically stored in a 256 24bit words RAM addressed by a loop address counter. When EMG Trigger rises to ‘1’, the 256 samples stored into the RAM are passed the FFT block by temporizing through a series of dedicated states. A MRP Calculator interprets the FFT output data in order to extract the BP, \( \mu \) and \( \beta \) powers, in natural units (BP, MU, BETA signals). Finally, BP, \( \mu \) and \( \beta \) are compared to fixed thresholds related to the subject, preloaded on the FPGA [9].

**EMG Computing Branch.** As shown in Fig. 2, the EMG samples are squared and passed to two blocks named GA and LA FSM. The FSMs calculate the dynamic threshold (G \( \text{Pwr} \)) and the local power (L \( \text{Pwr} \)).

**IV. ARCHITECTURE IMPROVEMENT: THE MUSCULAR INDEXES**

The precision medicine has led to the demand for more objective and on-line assessments of the patient's muscular status. The objective knowledge and quantification of these parameters help identify the stage of the disease and allows to shape a particular treatment accordingly, on the basis of the specific needs. In order to provide quantitative parameters for the complete gait analysis and aiming to assess benefits and side effects of particular treatments (in our application: Levodopa administration), without post processing needs, an improvement on the system was needed.

Referring to the Fig. 1, the MIs branch concludes the EMG block operating after trigger generation through a set of time counter driven by the system clock. In particular, the system generates a first set of 1bit co-contraction signals. A co-contraction signal is obtained by the overlap of two muscle triggers that operate as agonist-antagonist couple (i.e. Left Rectus and Biceps Femoralis). On 8 coupled EMG, 4 co-contractions signals are extracted. The MIs block computes the co-contraction time (number of sample between positive and negative edge of the signal) providing a quantitative value with 2ms resolution time. The system extracts the HR, counting the co-contractions’ peaks during a second of acquisition (512 samples). Furthermore, the system derives three single muscle
contraction time, relaxation time and the step duty cycle. Specifically, the step duty cycle is defined as:

$$\text{DC}(\%) = \frac{\text{t}_{\text{con}}}{\text{t}_{\text{con}} + \text{t}_{\text{rel}}} \cdot 100$$

(1)

where $t_{\text{con}}$ and $t_{\text{rel}}$ are contraction and relaxation times on each muscle, respectively, $t_{\text{con}} + t_{\text{rel}}$ corresponds to the step time. Signal processing outcomes are stored (for post-processing operations necessity) and real-time displayed to the user (i.e. physician in outpatient applications or caregivers).

A. General features of FPGA Implementation

The architecture has been implemented on FPGA (Altera Cyclone V 5CSEMA5F31C6N) with the future goal of an ASIC implementation [15 - 19]. In our design, 16 bio-signals (8 EEG and 8 EMG channels) inputs and 57 outputs, have been used. The inputs, coming from signal conditioning circuits [17], are serially canalized on 16 FPGA GPIO ports. Finally, they are subjected to filtering and decimation. The 57 outputs, which are functionally distributed on the remaining available GPIO ports, consist of:

- 7 (motor- cortex channel) BP, $\mu$ and $\beta$ 1bit flags (21 parameters), already present in [7];
- 4 co-contraction 1bit signals, already present in [7].
- 4 co-contraction time values of 11 bit (2ms time resolution on a full scale of about 2s).
- 8 contraction and 8 relaxation times of 11 bit.
- 8 duty cycles with 7 bit (1% resolution).

The need for an immediate response, has led to the development of an interface that both the post-processing of the acquired data and the on-line evaluation of the MRPs and MIs (i.e. through a set of displays).

B. The MIs Computing Branch on FPGA

Fig. 3 schematically explain the operation process of a single MIs computing branch. Eight MIs branches are present in the architecture, one for each monitored muscle. It operates serially with the Trigger signal, and thus, when the Trigger goes '1' the Contraction Counter starts increasing its value by 1 bit, every time a 500Hz CLK positive edge occurs.

A similar operation is carried out on Relaxation Counter that is fed by the 'Trigger'. Since a clock of 500 Hz allows a resolution of 2ms, the counters are in “module 2” mode (outcomes are multiplied with decimal 2). When the step is ended, both the counter are ready for the output. Indeed, the loop counter does not reset the Contra Time because the Trigger signal work as count enable, allowing it to be available in parallel with Relax Time. A progressive bit sum realizes the Step Time. When the second Trigger positive edge arrives (that corresponds to the step time) all the MIs extracted until now are stored and then “popped out” by a 2 pulses based PIPO register, under the piloting of the 1 bit Reg EN. A delayed version (two 8MHz Clk pulses) of Reg EN resets Contraction and Relaxation Counters, in order to allow the data transfer before the asynchronous reset. In this way, all the useful values (Contra Time, Step Time) are simultaneously present downstream from the PIPO for the entire next step time.

C. Data Compressing and Output Management on FPGA

This approach isolates the counting section, generating a static calculation section for the DC. Here, the high level time (Contra Time) is first multiplied for 100 (decimal) and then divided by the entire step duration (Step Time). The quotient in output represents the integer value of the DC (7bit). The remain of the divider block is defined as a binary subtraction between Step Time and Contra Time. It is multiplied with 100 (decimal) and thus divided for the Step Time. If the quotient overcomes 50 (decimal) the DC is increased by one. This process halves the error. Agonist and Antagonist muscle triggers jointly contribute, through an AND gate, to generate the square co-contraction waveform. Similarly to Contraction/Relaxation Counters, the co-contractions time is evaluated (CoCon Time) and returns its value when the step - in which the co-contraction is contained - end.

Fig. 3. Schematic diagram of a single MIs branch
legs. The system exploits the Reg EN’ signals coming from each channel (used for the parallel output process, and thus, named Reg EN PO) in order to generate a square waveform, which increases a loop address counter (2 bit). It pilots both the 4x1 multiplexer block and the RAM address. A delayed version of the signal downstream the OR gate works as Write Enable (avoiding operation on RAM during addressing edge), and a shifted version of the signal is used as clock for the read operation (dotted temporal diagram). A similar system is used for the upper section, which is based on the biomechanical order: Right Rectus, Left Biceps, Left Rectus, and Right Biceps.

V. RESULTS

In this paper, we present a dataset including EEG/EMG and MIs obtained by a subject affected by Parkinson disease (PD), performing natural gait. The subject is asked to perform a natural and fluid walk in a straight path of 10m for 10 times (5 before and 5 after treatment) within a time range of 120 min, starting from the Levodopa administration. The duration of each gait was about 50 s, interspersed by 10 min. These clinical tests are performed in a controlled environment (local hospital), under the supervision of specialized staff. The assessment regards the short-time impacts of the Levodopa on the patient. The present section provides quantifications of the considered diagnostic indexes. We expect to find only the benefits, linked to the drug, by an assessment in the short time.

A. Cyber-Physical System Performance

The overall FPGA implementation uses 28967.5/32070 (90.3%) ALMs, 50177 ALUTs, 48020/64140 (74.9%) registers, 10.3% block memory of the available resources. Table I defines the resource utilization of the architecture. The first entity in the Table I summarizes the resources consumption of 8 EMG triggers and 4 Co-contraction signal generation. The second row quantify the MRPs calculation resources needs for 7 EEG. The third entity (Single Muscle Parameters) concerns the utilization concerns the extraction of Contra Time, Relax Time and DC for 8 EMG channels. The fourth subsystem is related to the extrapolation of CoCont Time and HR for 4 agonist-antagonist couples. The voice Single Muscle Out Management refers to the output data canalization in a single output pin with biomechanics timing, for lower and upper section (Section IV.C). The only MIs system uses 2784 logic elements out of 32070 available, 256/4065280 memory elements RAM and registers 944/64140.

B. Experimental Results in Gait Analysis

The parameters here reported and discussed are obtained considering the average on first 5 walks as “Before drug treatment” status (blue background in Table II), and the 5 final walks as “After drug treatment” status (red background in Table II). The results summarized in Table II quantify the muscular implications of the drug treatment in the short time. The Fig. 5 and Table II show:

1. The maximum co-contraction time is reduced of 23.6% after the treatment. Before the Levodopa administration PD subject had a maximum co-contraction of 840ms; after the application the maximum reaches 628ms on R. Rect-R. Bic.

2. The HR is, on average, reduced of 23.3% after the treatment. PD subject exhibits 1.92 co-contractions/s and 1.02 co-contractions/s respectively before and after the treatment. Co-contractions are less frequent in PD after the Levodopa. Dangerous co-contraction decrease is also highlighted in Fig. 5 with a red circle.

3. The co-contractions show a decrease of 53ms (average value on all the four muscles couples), here with greater incidence on the right leg (Δt=-51ms on R.Gast-R. Rect). The maximum reaches 628ms on R. Rect-R. Bic.

4. On single muscle, the duty cycles follow an opposite trend, showing an average increase of 2.25%. It represents an increase of the muscular activity during the step (i.e. due to the stretching in time of the contraction)

5. The contraction time on single muscle is reduced, on average, of 5.4% (576ms→544ms), similarly the relaxation is reduced of 18.8% (546ms→443ms). This behavior is linked to the loss of the slowness status. Indeed, step time after Levodopa is reduced of 100ms, starting from 1.2s.

During the gait, significant differences on MRPs were found, showing a reduction of intentionality in the phase of motor

### Table I. FPGA Resources Utilization

<table>
<thead>
<tr>
<th>SUB-SYSTEM</th>
<th>ALMs (TOT: 32070)</th>
<th>ALUTs (TOT: 64140)</th>
<th>Registers (TOT: 64140)</th>
<th>MEMORY BLOCK (BITS: 4065280)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMM Triggers Generation</td>
<td>1836.2 (5.7%)</td>
<td>3880</td>
<td>1432 (2.2%)</td>
<td>163840 (4.0%)</td>
</tr>
<tr>
<td>MRSs Calculator</td>
<td>23996 (74.8%)</td>
<td>40286</td>
<td>45227 (70.5%)</td>
<td>255164 (6.3%)</td>
</tr>
<tr>
<td>Single Muscle Parameters</td>
<td>2657.6 (8.3%)</td>
<td>5264</td>
<td>800 (1.3%)</td>
<td>0</td>
</tr>
<tr>
<td>Coupled Muscles Parameters</td>
<td>44 (0.14%)</td>
<td>48</td>
<td>120 (0.2%)</td>
<td>0</td>
</tr>
<tr>
<td>Single Muscle Out Management</td>
<td>73 (0.23%)</td>
<td>38</td>
<td>24 (0.04%)</td>
<td>256 (0.006%)</td>
</tr>
<tr>
<td>Total</td>
<td>28967.7 (90.3%)</td>
<td>50177</td>
<td>48020</td>
<td>174.9% 419260 (10.3%)</td>
</tr>
</tbody>
</table>

### Table II. MIs extracted by the CPS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>R RECT</th>
<th>L BICEP</th>
<th>R TIB</th>
<th>R GAST</th>
<th>L TIB</th>
<th>L GAST</th>
<th>R RECT</th>
<th>L BICEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coco Max (ms)</td>
<td>496</td>
<td>566</td>
<td>464</td>
<td>840</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coco Typ (ms)</td>
<td>418</td>
<td>396</td>
<td>516</td>
<td>628</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coco Tmp (ms)</td>
<td>312±88</td>
<td>221±90</td>
<td>176±72</td>
<td>334±186</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coco Tmp (ms)</td>
<td>382±90</td>
<td>170±60</td>
<td>272±150</td>
<td>256±150</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR</td>
<td>1.04 (25.244)</td>
<td>1.25 (30.244)</td>
<td>1.58 (38.244)</td>
<td>1.92 (46.244)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Coco/cont/s)</td>
<td>1.04 (52.50)</td>
<td>1.04 (52.50)</td>
<td>1.15 (55.50)</td>
<td>1.02 (51.50)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contra time (ms)</td>
<td>440±108</td>
<td>568±130</td>
<td>615±228</td>
<td>470±272</td>
<td>650±130</td>
<td>552±250</td>
<td>446±200</td>
<td>614±130</td>
</tr>
<tr>
<td>Relax time (ms)</td>
<td>558±204</td>
<td>708±422</td>
<td>570±94</td>
<td>494±126</td>
<td>716±390</td>
<td>512±266</td>
<td>588±70</td>
<td>222±120</td>
</tr>
<tr>
<td>DC(%)</td>
<td>44</td>
<td>49</td>
<td>50</td>
<td>46</td>
<td>50</td>
<td>57</td>
<td>45</td>
<td>60</td>
</tr>
</tbody>
</table>
administration. The system is made up by 8 EEG and 8 EMG modulation of the brain motor ideation, respecting expectations muscular implications during a movement. An FPGA (Altera in this work, a cyber-physical system for gait indexes extraction of the drug. The system is therefore highly sensitive to dosages. According to the dictates of precision medicine, this feature makes it a useful tool for treatments evaluation.

### Table III. MRPs EXTRACTED BY THE CPS

<table>
<thead>
<tr>
<th>MRPs</th>
<th>T3</th>
<th>P3</th>
<th>C3</th>
<th>CZ</th>
<th>C4</th>
<th>P4</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP (dBµ)</td>
<td>67.8±6.3</td>
<td>63.6±6.7</td>
<td>62.3±6.7</td>
<td>65.6±13</td>
<td>65.1±7.4</td>
<td>63.8±13</td>
<td>66.2±12</td>
</tr>
<tr>
<td>µ (dBµ)</td>
<td>49.2±2.3</td>
<td>50.1±2.9</td>
<td>49.0±2.4</td>
<td>47.9±9.1</td>
<td>47.0±9.0</td>
<td>52.3±9.5</td>
<td>49.0±9.0</td>
</tr>
<tr>
<td>β (dBµ)</td>
<td>48.5±2.3</td>
<td>48.9±2.9</td>
<td>48.6±2.7</td>
<td>48.3±2.7</td>
<td>46.6±3.0</td>
<td>49.6±2.7</td>
<td>48.3±3.0</td>
</tr>
</tbody>
</table>

Fig. 6. The MRPs modulation on midline electrode Cz before (blue) and after (red) the drug treatment.

### REFERENCES


