Using Upper Alpha Neurofeedback Training to Improve SMR Desynchronization

Eduardo López-Larraz, Carlos Escolano, Javier Minguez

***Abstract*— Desynchronization of sensorimotor rhythms (SMR) is a distinctive feature that provides a discriminative pattern for BCI operation. However, individuals such as BCI illiterates can not produce these discriminable patterns with sufficient reliability. Additionally, SMR desynchronization can become deteriorated or extinct in patients with spinal cord injury or a cerebrovascular accident. In all these situations BCI usage is compromised. This paper proposes an intervention based on neurofeedback training of the upper alpha band to improve SMR desynchronization. The feasibility of this intervention is demonstrated in a preliminary study in which five healthy subjects were trained to increase their upper alpha band power. Such increases produced higher SMR desynchronization and better discrimination between rest and execution states of a motor task.**

I. INTRODUCTION

Brain-computer interfaces (BCIs) have recently emerged as a technology to translate user intentions into commands. Many of the BCIs developed to date are based on the decoding of motor intentions using the activity of the motor cortex. Thus, the application of BCI technology requires the user to be able to produce certain recognizable motor brain patterns (i.e., SMR desynchronization generated by motor attempt or motor imagery). On one hand, BCI illiterates (approximately 20% of healthy subjects) are not able to use motor imagery BCI technology because they do not produce reliable and stable EEG patterns [1]. On the other hand, spinal cord injury (SCI) patients produced weak (or none) detectable SMR activity on the motor cortex during an attempt of moving their paralyzed limbs. In the case of cerebrovascular accident (CVA) patients, the brain neural networks are damaged, which hinders the detection of motor-related brain activity in injured areas and their vicinity. In the three mentioned cases, a possible solution could be to develop an intervention to improve or reconstruct the motor-related EEG activity prior to BCI usage [2].

In this direction, this paper proposes a preliminary study with five healthy subjects to build a possible intervention based on neurofeedback (NF) training. A NF training was designed to increase upper alpha (UA) power in basal state to increase the desynchronization during the execution of the motor tasks. Note that most NF studies related to motor contexts focused on decreasing SMR power during the motor tasks [3]. Recently it was stated that subjects with higher alpha power in basal states could lead to better performances in SMR based BCIs [1].

E. López-Larraz, C. Escolano, and J. Minguez are with the Instituto de Investigación en Ingeniería de Aragón (I3A) and Dpto. de Informática e Ingeniería de Sistemas (DIIS), Universidad de Zaragoza, Spain. J. Minguez is also with Bit&Brain Technologies SL, Spain. E-mail: {edulop, cescolan, jminguez}@unizar.es. This work has been partially supported by projects HYPER-CSD2009-00067 and DPI2009-14732-C02-01 of the Spanish Government, and by DGA-FSE (grupo T04).

II. METHODS

EEG signals were recorded from 16 active electrodes placed at FP1, FP2, F3, Fz, F4, C3, Cz, C4, CP3, CPz, CP4, P3, Pz, P4, O1 and O2 (according to the international 10/10 system). EEG was amplified using a commercial gTec system at a sampling frequency of 256 Hz, power-line notch-filtered at 50 Hz, and bandpass-filtered between 0.5 and 60 Hz.

Five healthy subjects participated in the study. The experiment consisted of five NF training sessions executed in five consecutive days, one session per day. Participants executed, for each session, 5 NF trials of 5 min each. EEG screenings were performed immediately before and after each training session to assess changes in the EEG. In addition, a motor assessment was carried out at the beginning of the first training session, and at the end of the last training session.

a) NF Training: Training focused on the enhancement of UA activity over the motor cortex (locations C3, Cz, C4, CP3, CPz and CP4, referred to as training locations). UA was individually defined as [IAF, IAF+2] Hz range. Feedback was provided visually as the participants faced a square on a screen, either red or blue according to whether the UA power was higher or lower than the baseline, respectively.

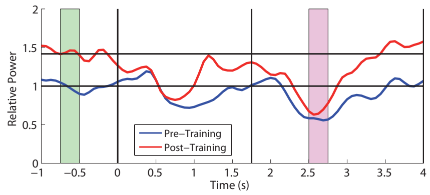
b) Screening: The screening was a 3-min recording in an open-eyes active task to challenge subjects cognitively. Averaged UA power during the screening was considered as the baseline for NF training

c) Motor Assessment: A Go/No-Go task was designed based on [4]. It was divided into 4 runs of 52 trials each: at a random time instant between 1.5 and 2.5 s after the beginning of the trial, a warning 'Go' or 'No-Go' stimulus was displayed; then, an imperative stimulus appeared with an inter-stimulus delay either $D = 0.75s$ or $D = 1.5s$ after the warning stimulus disappeared (this imperative stimulus was always congruent with the warning one); following the imperative stimulus, '+' symbol stayed until the trial had a duration of 5 s. Subjects had to click a mouse button, on 'Go' trials, and to stay relaxed on 'No-Go' trials.

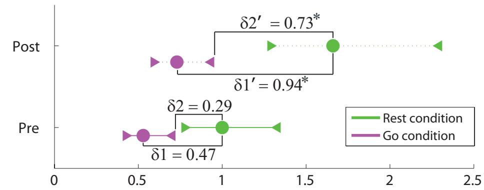
III. RESULTS

A. Neurofeedback Trainability

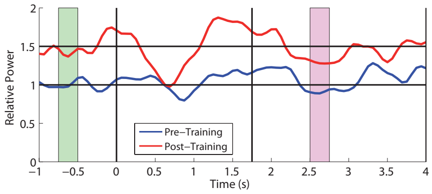
In order to evaluate the progress of the NF training, the average UA power was computed for all screenings and training trials of each session. Training progress was reflected by a significantly positive tendency of the UA power across the sessions ($p = 0.035$). The averaged UA power increased 79% from the pre-screening of session 1 to the post-screening



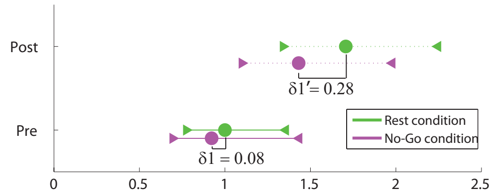
(a) Time-course: Go



(b) Distributions: Go



(c) Time-course: No-Go



(d) Distributions: No-Go

Fig. 1. (a,c) Alpha power time-course for Go and No-Go trials (inter-stimulus condition $D = 1.5s$), averaged for all subjects. Relative power of pre- and post- assessments, normalized to the baseline interval of pre- assessment. Green and magenta selections indicate representative time intervals of Rest and Task intervals, respectively. (b,d) Distributions (mean plus 95% confidence intervals) of the average power of time intervals selected in a,c. Values of metrics $\delta 1$ and $\delta 2$ are presented for each case. The statistically significant values are marked with an asterisk.

of session 5. A positive tendency was also obtained within a session ($p = 0.016$). The average UA power within sessions from pre-screening to post-screening was increased 34%.

B. SMR Desynchronization Analysis

For the analysis of the Go/No-Go task the entire alpha band was considered (i.e., $[IAF - 2, IAF + 2]$). The first analysis assessed the time-course representation of alpha power along trials. A variation of the traditional ERD metric [5] was used: $Rel\_Pow_t = Pow_t/Pow_{BL}$; where Pow_t is the alpha power in time instant t; and Pow_{BL} is the average alpha power of the baseline interval. Baseline was set to the time interval [-1, 0]s (a subset of the rest interval). Desynchronization can be only observed for the Go condition approximately at $t = 2.5$ s, which was approximately 50% (ratio 0.5). When comparing pre- and post- assessment desynchronization values, no statistical differences were found. The aforementioned analysis did not provide information on the effect produced by NF training: the increase of alpha power in rest state. Thus, a second analysis assessed the time-course representation of alpha power, normalizing the post assessment to the baseline interval of the pre-assessment (Fig. 1a-c). A clear alpha power increase of approximately 50% in the rest interval can be observed in both Go and No-Go conditions. Thus, it can be concluded that NF training did not produce observable changes with the variation of the ERD metric, but it produced an increase in desynchronization measured in absolute terms.

C. BCI Features

If a classification problem between Rest and Task was considered, the separability of the Rest and Task classes would be higher after NF. In order to assess the statistical significance, a subset of the rest and task intervals was considered. The two selected time windows of 0.25s are displayed in Fig. 1a-c. The power distributions (mean and 95% confidence intervals) are shown in Fig. 1b-d. Confidence intervals were computed using a t-percentile bootstrap method. $\delta 1$ measures the distance between means of the power distributions in Rest and Task classes. $\delta 2$ measures the distance between the upper confidence interval of the Task distribution (only for Go condition) and the mean Rest distribution. Results show that, for Go trials, the separability between distribution means was significantly increased after NF training ($\delta 1' > \delta 1$; $p = 0.02$). Additionally, separability between classes was also significantly increased ($\delta 2' > \delta 2$; $p = 0.032$). For No-Go trials, there was an increase in the separability between distribution means, but this increase was not significant. Metric $\delta 2$ could not be computed in No-Go trials since upper confidence interval of Task distribution was not lower than the mean of Rest distribution.

IV. Conclusions

With NF training, UA activity was significantly increased for all subjects across training sessions. This increase led to an increase in the SMR desynchronization during the execution of a motor assessment after NF application. Desynchronization was found when measuring absolute power values, which in turn shows an increase in the separability between rest and task intervals in alpha band power. Note that this result may yield better classification performances in BCIs that rely on EEG activity of the motor cortex.

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