Neurofeedback induced restoration on sensorimotor rhythm after 24h of hand immobilization

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Abstract

In this study, we examined the effect of neurofeedback on EEG changes due to immobilization of the dominant hand. Desynchronization of the sensorimotor rhythms during motor imagery was used as a tool to investigate brain activity. The study is based on 8 healthy subjects who underwent immobilization of the dominant hand for 24 hours. The electrical activity of the sensorimotor region of the cerebral cortex was registered during mental imagery of hand movements before the immobilization, soon after its removal and after a single session of neurofeedback. The control of the feedback stimuli was based on changes in sensorimotor rhythms produced by imagination of movement. Preliminary results show that immobilization caused changes in alpha and beta rhythms that were rapidly reversed after a single session of neurofeedback. At the end of the full study, if the here presented observations will still hold, the neurofeedback protocol will be proposed for routine rehabilitation sessions in patients suffering partial or total limb disability.

Key words

Neurofeedback, motor imagery, hand immobilization, brain-computer interfaces

Introduction

For a number of reasons, use of limbs can be strongly impaired or even compromised. Furthermore, this immobilization causes plastic changes in brain cortical circuitry which can further deteriorate the situation reducing the possibility of fully regaining the original limb functionality [1]. In order to understand the cortical changes followed by limb non-usage and to develop the appropriate procedures to restore proper functionality, we started a series of experiments on healthy subjects.

In the present report, preliminary data will be reported on the consequences of limb non-use and the effect of neurofeedback on functional restoration.

One proposed method to reduce the negative effects of limb non-use is motor imagery (MI). MI directly offers brain signals which can be effectively converted into commands for control of external devices [2, 3]. Protocols of this type are known as neurofeedback and the devices, which make use of them, are often referred to as brain computer interfaces (BCI). Systems of this kind ~~type~~ usually estimate the user's motor intention from the changes in brain activity over primary sensorimotor cortex, called sensorimotor rhythm (SMR) and display them through visual feedback [2, 4]. The user can consciously use this information to adapt her/his brainwave activity to reach targeted training thresholds. Previous studies using MI reported plastic changes in the SMR and improvement in motor performance [5]. Here, we studied immobilization-induced plasticity in the SMR after a single-day of hand immobilization. The aim was to quantify the early changes in cerebral oscillations after hand immobilization and the strength of MI based NF on their restoration. The studied variable was the desynchronization of the sensorimotor rhythms during the movement's imagination before and after NF.

Materials and methods

Twelve subjects participated to the experiments(all females, age range 19–26 years, mean age 22 years, standard deviation 1.9). All were naive to BCI use and had full comprehension and use of the Italian language. Eight of them were randomly assigned to the experimental group, while the other four subjects entered the control one. Due to the small sample size of the control group, present results will refer only to the experimental one and have to be considered as preliminary.

Prior to the start of the real experiment, participants received and filled in the following questionnaires: Edinburgh Handedness Inventory, Vividness of Movement Imagery Questionnaire, Movement Imagery Questionnaire – 3, in order to assess the reliability and vividness of movement imagery. All subjects which entered the experimental group were right handed and obtained good performance in the MI questionnaires.

The study consisted of several phases distributed over consecutive sessions. In the first, pre-immobilization session, participants' brain activity was measured in a relaxed state and during engagement in a motor imagery task. The task consisted of the imagination of the right hand closing/opening movement for 35 times. After this recording, the right hand was immobilized and fixed together with the arm in a custom-moulded splint. Immobilization lasted for the following 24h.

The day after (second session), the participants' EEG was measured during performance of the same MI task, in order to compare the effect of immobilization on SMR rhythms in the absence of NF. Then each participant entered the NF training, consisting of 75 trials of motor imagery of right hand movement, lasting about 20 minutes. The feedback consisted in the activation of a video showing the opening and closing of a hand. The video was designed to run when event related desynchronization in alpha or beta frequency bands was detected. This changes in SMR constitute evidence of the real execution of the movement as well as of its imagination [6, 7]. In the last phase, the EEG was again measured with the participants performing MI without NF.

Brain activity was recorded with a standard cap (Electro-Cap International, Inc.) where 12 electrodes were placed following an adapted version of the EEG 10–20 coordinate system [e.g. 8]. Signals were referenced to the Poz electrode and grounded to Afz. Impedance was always maintained below 5 kΩ. Signals were amplified and digitalized with a Micromed amplifier (SAM 32FO fc1; Micromed S.p.A., Italy; high-pass analogical filtering 0.1 Hz; sampling rate frequency 256 Hz). A customized version of OpenVibe software (http://openvibe.inria.fr), controlled stimulus menu presentation, data collection and online processing.

To quantify changes in SMR in recorded data, first a visual inspection and independent component analysis (ICA) were applied to identify and remove any remaining artefacts, i.e., eye blinks and ocular movements, produced by the task [9]. Data from individual electrodes exhibiting loss of contact with the scalp were rejected, as well as those from single-trial epochs exhibiting excessive movement artifacts (± 80 µV). Then, in the selected epochs (started 2s before and ended 4s after cue onset) the Event Related Spectral Perturbation (ERSP) was calculated by means of EEGLab (http://sccn.ucsd.edu/scott/ica.html). ERSP measures average dynamic changes in amplitude of the broad band EEG frequency spectrum as a function of time relative to an experimental event. That is, ERSP measures the average time course of relative changes in the spontaneous EEG amplitude spectrum induced by a set of similar experimental events. These spectral changes typically involve more than one frequency or frequency band, so full-spectrum ERSP analysis yields more information on brain dynamics than the narrow-band ERD [10]. It can be viewed as a generalization of the event related desynchronization analysis (ERD). ERD is expressed as percentage power decrease in relation to baseline. This negative decrease of power spectrum during MI is a marker of cortical activation during motor imagery [11].

Results

Analysis of ERSP during pre and post immobilization yielded two main findings: a decrease of power (MI was less effective in producing the expected, “healthy” desynchronization) in alpha and beta frequencies after 24h of hand immobilization, and its partial recovery after the NF session. This is shown in Figure 1, with respect to three representative electrodes. Note the pronounced desynchronization in the alpha band in C3 and Cp3 before immobilization (blue “clouds” at about 500 msec after cue onset in left column: centre and bottom panels) which reduced after immobilization (central column: centre and bottom panel). In Fc3, instead, immobilization caused an increase in the alpha synchronization for a long time (horizontal red “cloud” at around 15 Hz). MI after neurofeedback caused a reduction in the alpha synchronization (Fc3: compare top panel to the right with top panel in the centre) and less pronounced changes in C3 and Cp3.

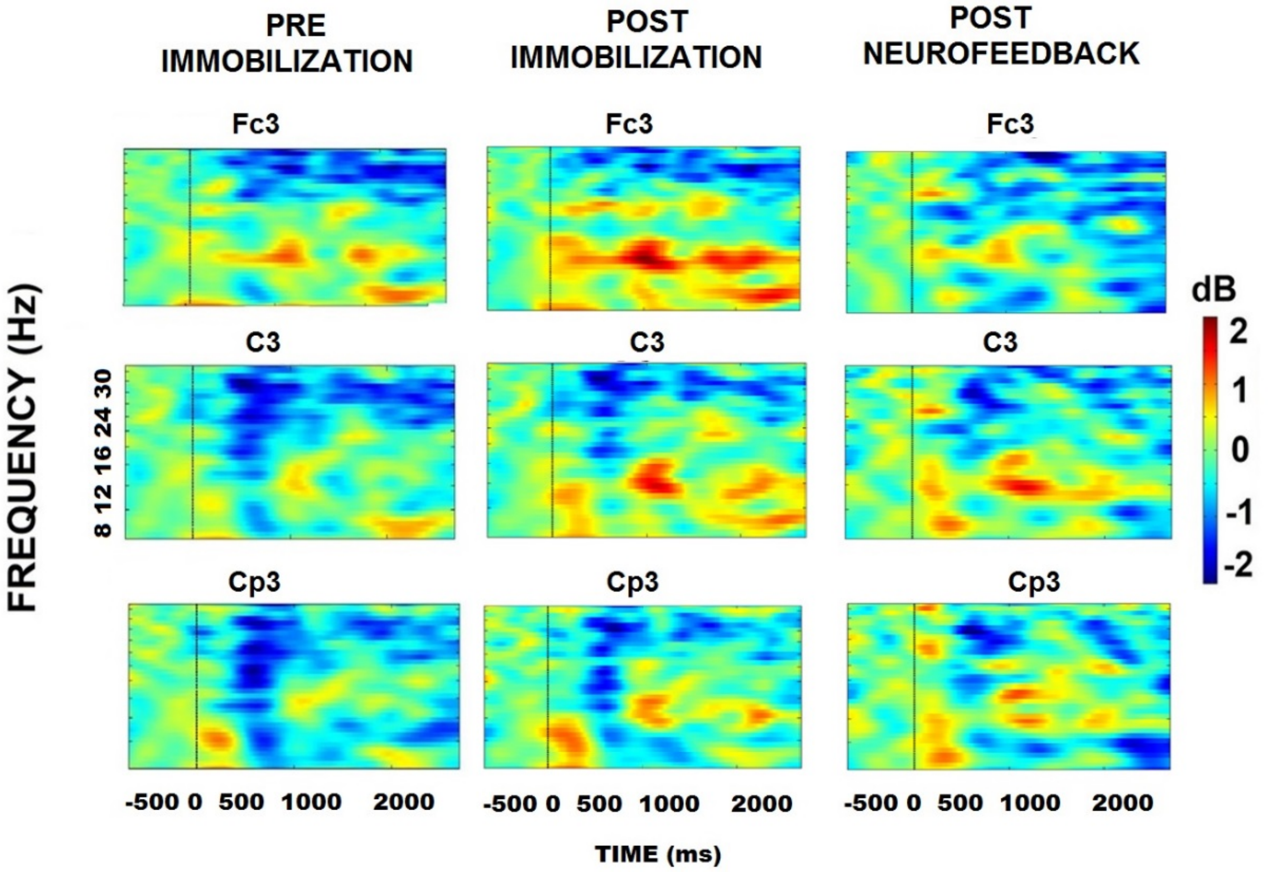

Fig 1. ERSPs induced by motor imagery of right hand movement before hand immobilization (left), after 24h of its immobilization (centre) and following a single session of neurofeedback (right). Grand means of responses (8 subjects) for contralateral hemisphere in the 3 most reactive electrodes (Fc3, C3 and Cp3, located to the left of the midline, at frontal, central and parietal locations) are shown. In each plot, the vertical axis is EEG frequency; the horizontal axis is time relative to cue onset (at time 0); the colour bar is EEG amplitude ratio plotted in ($10\log_{10}$) dB.

Conclusions

In this study, we examined the effect of neurofeedback-based motor imagery on EEG changes due to immobilization of one hand in healthy subjects.

Preliminary results confirm that hand immobilization, even if only for 24 hours, is able to modify the cerebral oscillation of the sensorimotor region, as it has already been shown in a different context [12]. We found lower alpha and beta waves desynchronization after hand immobilization, and its partial recovery after just a single session of neurofeedback treatment, suggesting that neurofeedback is a fast way to assure the consistency and reliability of motor imagery. Moreover, it can rapidly reverse the changes of SMR due to immobilization to the values observed before immobilization.

Control experiments are in progress in order to verify if these encouraging results are really due to NF or are rather the consequence of specific factors related to changes in participants' attention levels, concern over their situation or other factors.

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References

1. Gordon J, Ghilardi MF, Ghez C. Impairments of reaching movements in patients without proprioception. I. Spatial errors. J Neurophysiol. 1995; 73(1):347-60.
2. Hammond D: What is neurofeedback? Journal of Neurotherapy, 2006; 10:25–36.
3. Pfurtscheller G, Muller-Putz GR, Scherer R, Neurper C. Rehabilitation with brain-computer interface systems. Computer 2008; 41:58–65.
4. Nelson LA. The role of biofeedback in stroke rehabilitation: past and future directions. Topics in Stroke Rehabilitation. 2007; 14:59. pmid:17698458
5. Pichiorri F, De Vico Fallani F, Cincotti F, Babiloni F, Molinari M, Kleih SC, et al. Sensorimotor rhythm-based brain-computer interface training: the impact on motor cortical responsiveness. J Neural Engineer. 2011; 8: 25020–25029
6. Pfurtscheller G, Aranibar A. Evaluation of event-related desynchronization (ERD) preceding and following voluntary self-paced movement. Electroencephalogr Clin Neurophysiol. 1979; 46:138-46.
7. Miller K, Schalk G, Fetz E, den Nijs M, Ojemann J, Rao R. Cortical activity during motor execution, motor imagery, and imagery-based online feedback. PNAS. 2010; 107: 4430-4435.
8. Jurcak V, Tsuzuki D, Dan I. 10/20, 10/10, and 10/5 systems revisited: their validity as relative head-surface-based positioning systems. Neuroimage. 2007;34(4):1600-1.
9. Daly I, Nicolaou N, Nasuto SJ, Warwick K. Automated Artifact Removal From the Electroencephalogram: A Comparative Study. Clinical EEG and Neuroscience. 2013; 44(4):291-306.
10. Makeig S. Auditory Event-Related Dynamics of the EEG spectrum and effects of exposure to tones. EEG Journal. 1993; 86: 283-293.
11. Pfurtscheller G and Lopes da Silva FH. Event-related EEG/MEG synchronization and desynchronization: basic principles. Clin Neurophysiol. 1999; 110:1842-57.
12. Kim YH, Park JW, Ko MH, Jang SH, Lee PKW. Plastic Changes of Motor Network after Constraint-Induced Movement Therapy. Yonsei Med J. 2004; 45: 241–246.