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HUMOUR

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Deliverable 5.4

Report on using BCI to support recovery

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Responsible Person: Niels Birbaumer

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Dissemination Level		
PU	Public	**x**
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RE	Restricted to a group specified by the consortium (including the Commission Service)	
CO	Confidential, only for members of the consortium (including the Commission Service)	

Table of Contents

1 Outline 3

2 Afferent feedback in motor learning 3

2.1 Afferent feedback improves learning control of sensorimotor based BCI control in healthy subjects. Neurophysiological and behavioral effects. 3

2.2 Afferent and Efferent Activity Control in the Design of Brain Computer Interfaces for Motor Rehabilitation 5

3 Afferent feedback improves learning control of sensorimotor based BCI control in stroke patients. Neurophysiological and behavioral effects 5

4 Effects of EEG-BCI based stroke rehabilitation training on brain structure. 7

5 Real-time fNIRS based BCI. 7

1 Outline

The aim of Deliverable 5.4 was to report about using BCI to support recovery in particular in case of stroke rehabilitation. All the studies performed according to our *grand challenges* aimed to develop a haptic BCI for motor rehabilitation. In the section 2 we present a study on healthy subjects aiming to test our first hypothesis that afferent feedback improves learning control of sensorimotor based BCI control. Furthermore we present a study investigating neural correlates in healthy volunteers using electroencephalography (EEG) during functional electrical stimulation, passive movements, active movements, motor imagery of the hand and resting to compare afferent and efferent brain signals produced during these motor related activities. A more complete and detailed version of these studies is provided in the linked unpublished manuscripts. In section 3 we first present a controlled study on patients addressing the question whether afferent feedback improves learning control of sensorimotor based BCI control in patients with stroke. Neurophysiological and behavioral effects are presented and described. A more complete and detailed version of the study is provided in the linked unpublished manuscript. In the section 4 the effects of EEG-BCI based stroke rehabilitation training on brain structure are described. A more complete version of the analysis performed is provided in the linked unpublished manuscript.

Finally in the section 5 is described the implementation of a NIRS-BCI system which can be used

2 Afferent feedback in motor learning

2.1 Afferent feedback improves learning control of sensorimotor based BCI control in healthy subjects. Neurophysiological and behavioral effects.

Motor related neural activity based brain computer interface (BCI) technology has been proposed for motor neurorehabilitation, motor replacement and assistive technologies. The use of a BCI as a neuroprosthesis for paralyzed limb assistance or rehabilitation implies afferent information flow caused by the haptic feedback if some sensory pathways are preserved after lesion. It is an open question whether this feedback causes a bias in the regulation of brain oscillations and therefore in BCI control signals. To answer this question we used a motor imagery based BCI coupled on-line with a robotic hand exoskeleton for flexing and extending the fingers of the subjects. The subjects performed five different motor modes related to closing and opening of the hand: motor imagery of the hand without any feedback, motor imagery with online haptic feedback, passive and active movement of the hand and rest. BCI performance was calculated offline for the different motor modes. Three groups were involved in the study. The first group (n=9) received contingent positive feedback, the second (n=7) contingent negative feedback and the third (n=7) sham feedback. The proprioceptive feedback increased the BCI performance significantly comparing motor imagery with and without feedback. Furthermore, in the contingent positive group a significant implicit motor learning effect was observed enhancing BCI performance during motor imagery without feedback. The BCI performance during passive movement observed in the contingent positive group was significantly higher compared to the other feedback groups. We demonstrated that the use of our haptic BCI can be learned and produces an excitation of the sensorimotor rhythm neural network from which passive movement therapies can benefit after BCI training. This effect is very relevant for the motor neurorehabilitation field.

<u>Manuscript in preparation:</u>

Ramos-Murguialday A., Hammer E. M., Caggiano V., Schürholz M., Halder S., and Birbaumer N. On-Line haptic BCI.

2.2 Afferent and Efferent Activity Control in the Design of Brain Computer Interfaces for Motor Rehabilitation

In this work we measured the brain activity of healthy volunteers using electroencephalography (EEG) during functional electrical stimulation FES, passive movements, active movements, motor imagery of the hand and resting to compare afferent and efferent brain signals produced during these motor related activities and to define

possible features for an online FES-BCI. In the conditions in which the hand was moved we limited the movement range in order to control the afferent flow. Although we observed that there is a subject dependent frequency and spatial distribution of efferent and afferent signals, common patterns between conditions and subjects were present mainly in the low beta frequency range. When averaging all the subjects together the most significant frequency bin comparing each condition versus rest was exactly the same for all conditions but motor imagery. These results suggest that to implement an on-line FES-BCI, afferent brain signals resulting from FES have to be filtered and time-frequency-spatial features need to be used.

Manuscript in preparation:

Cho W., Vidaurre C., Hoffmann U, Birbaumer N., and Ramos-Murguialday A. Afferent and Efferent Activity Control in the Design of Brain Computer Interfaces for Motor Rehabilitation

3 Afferent feedback improves learning control of sensorimotor based BCI control in stroke patients. Neurophysiological and behavioral effects

Patients suffering from chronic stroke and no residual finger movements unable e.g. to grasp, do not respond to rehabilitation efforts and treatment attempts of this function. Previous studies have demonstrated successful learning of brain control of a prosthetic device fixed to the paralyzed hand using voluntary up- or down regulation of ipsilesional brain activity. It was proposed that this kind of brain training might facilitate motor recovery. Here we evaluated the efficacy of such an approach that combines daily brain-computer interface (BCI) training with behaviorally oriented physical therapy in a randomized placebo-controlled clinical trial. 32 chronic stroke patients with no residual finger function were pseudo-randomly assigned to one of two age, gender and functional scores matched groups and trained over 17.8 ± 1.4 BCI-training-sessions combined with goal-directed physical therapy. Changes of sensorimotor rolandic brain oscillations of the EEG from ipsilesional brain areas accompanying the attempt to move the paralyzed hand were translated into movement-execution online aided by a robotic arm/hand orthotic device. In Group 1 (n=16) training of voluntary modulation of ipsilesional brain activity resulted in contingent movements of the rehabilitation devices, while in group 2 (n=16) modulation of brain rhythms resulted in random movements of the orthotic devices. Therapists and patients were blind according to group assignment. Placebo-expectancy effects were measured before, during and after training. Clinical motor function scores (goal-attainment scale (GAS), Ashworth Scale , Motor Activity Log (MAL), Fugl-Meyer Scale (FMS)) and electromyography (EMG) from arm and hand muscles and functional magnetic resonance imaging BOLD activity were assessed before, immediately after and 6 month after the intervention.

Patients of the contingent BCI training groups demonstrated significant learning of BCI-control accompanied by significant pre-post improvement in GAS, FMS scores and EMG activation. Clinical improvements were associated with increase of ipsilesional brain activity as measured by BOLD activity and EMG-amplitude of the affected muscles. Placebo-expectancy scores were comparable for all two groups. These results demonstrate a positive and stabile clinically relevant improvement at all levels of observation (neurophysiological, behavioral) following contingent BCI-physiotherapy training in chronic stroke patients without residual finger movements.

Manuscript in preparation:

Ramos Murguialday A., Broetz D., Rea M., Caria A., Laer L., Yilmaz Ö, Brasil F., Curado M., Garcia E., Agostini M., Soares E., Soekadar S., Cho W., Cohen L.G., Birbaumer N. Efficacy of combined brain-computer interface (BCI) and physiotherapy in chronic stroke: a controlled double blind study.

4 Effects of EEG-BCI based stroke rehabilitation training on brain structure.

The effects on brain structure of previously described EEG-BCI training performed on stroke patients are here presented. Here we first describe the general structural brain correlates of behavioral changes which are clinically relevant, and second we document specific treatment-induced structural differences between the treatment groups. The analyses have been performed with both conventional SPM-style parametric tests (multiple regression and two-sample t-test) as well as state of the art machine learning methods (linear SVM with Fisher-Score-searchlight feature selection).

Manuscript in preparation:

Varkuti B., Caria A., Ramos A., Dalboni J., Schurholz M, Laer L, Sitaram R, N Birbaumer. Effects of EEG-BCI based stroke rehabilitation training on brain structure.

5 Real-time fNIRS based BCI.

EKU implemented a BCI system based on functional near-infrared spectroscopy to train participants to volitionally control their brain metabolic activity. The fNIRS-BCI system provides participants with an indirect indicator of brain activity by measuring changes in the deoxyhaemoglobin (HHb) and the oxyhaemoglobin (O2Hb), as well as the total haemoglobin (totHb). Increase in totHb and O2Hb, together with a decrease in deoxyHb can be interpreted as a correlate of active cortical areas. The real-time fNIRS system recently developed by EKU is described in Figure 5.1.

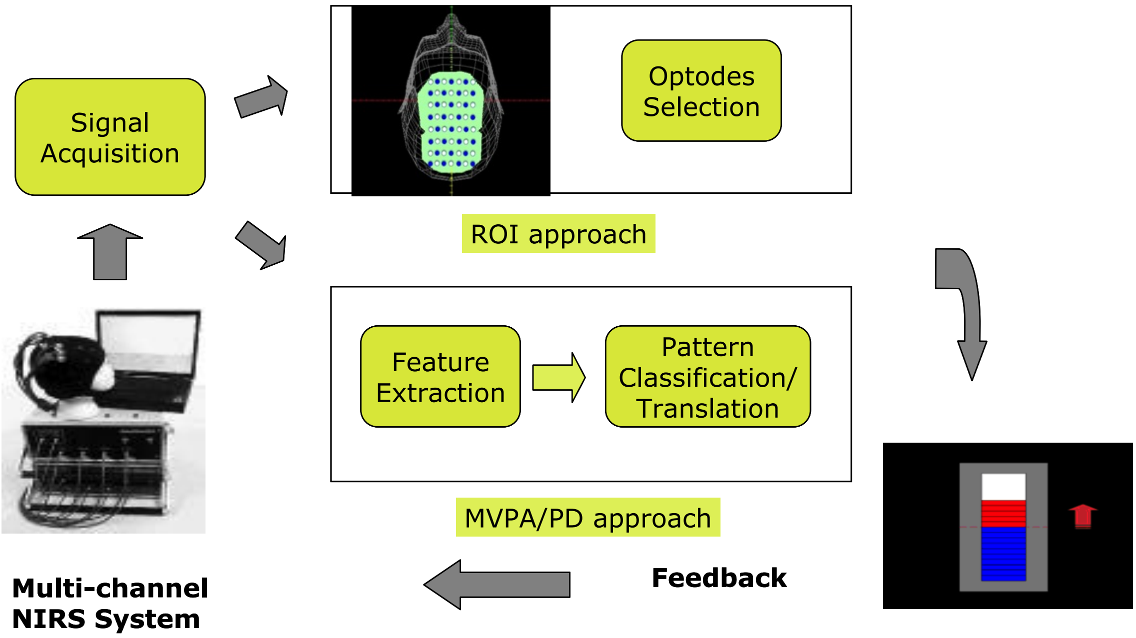

Figure 5.1 Real-time fNIRS-BCI

This system currently based on the Hitachi ETG-4000 device (but also now available for the Shimadzu FOIRE-3000) enables online analysis and feedback of hemodynamic signals from selected optodes, or combination of them, with a maximum delay of about 6s. The system operates at two different wavelengths (856nm and 781nm). The illuminator and detector optodes are placed on the scalp according to the International 10-20 system for EEG electrode placement, Vertex (Cz) is as a reference point for the positioning of the optodes. A pair of illuminator and detector optodes forms one channel. Fifteen illuminators and fifteen detectors in the arrangement resulted in 49 channels on each hemisphere. Near-infrared rays leave each illuminator, pass through the skull and the brain tissue of the cortex and are received by the detector optodes. The photomultiplier cycles through all the illuminator–detector pairings to acquire data at every sampling period. The data are acquired at a sampling rate of 10 Hz and digitized by the 16-

bit analog to digital converter. The fNIRS instrument is capable of storing the raw signal intensity values for each of the 2 wavelengths, the stimuli codes as well as the derived values of oxygenated and deoxygenated hemoglobin concentration changes for all time points in an output file in a pre-specified format. The signal preprocessing, analysis and classification programs are implemented to read the data from the file either in an offline mode or in an online mode.

Furthermore, the same BCI system has been implemented using a portable fNIRS system NIRScout (NIRx).

In a pilot test, using the Hitachi ETG-4000 based BCI, we observed that participants, after a short training of 2-3 runs where online feedback of fNIRS signal was presented, were able to learn to specifically control activity in the brain motor network.