Using a Brain-Computer Interface to Assess Awareness After Brain Injury

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Abstract. This study asks whether brain-computer interface (BCI) technology can provide a clinically viable tool to assess awareness in patients after brain injury. It also seeks to determine whether brain activity, as observed with non-invasive electroencephalography (EEG), can predict possible recovery, and can thereby assist in prognosis and in planning rehabilitation strategies. We present here the study setup and methodology and some initial data. The paradigm consists of acquiring 32 channel scalp EEG while the participant is asked to imagine making specific hand and feet movements. The EEG data is analysed retrospectively to assess the correlations between conditions and the scalp distributions of mu (8-12 Hz) and beta (18-26 Hz) rhythms.

Keywords: Post-brain injury awareness, Motor imagery, Brain Computer Interfacing, spectral content

1. Introduction

The diagnosis of post-brain injury unawareness (PBU) in patients with severe brain injury can be difficult. Approximately 50 percent of patients with apparent vegetative state will demonstrate consistent cognitive responses one month after traumatic, anoxic, or vascular brain injuries [Levin et al., 1991]. PET scan, functional MRI, and EEG data suggest that the clinical diagnosis of PBU is not always accurate [Cruse et al., 2011]. Incorrect classification of a cognitively aware patient as vegetative may result in incorrect treatment and inappropriate long-term care. Even using the best available protocols, there is always a degree of uncertainty in a diagnosis of vegetative state [Cruse et al., 2011; Chatelle et al., 2012]. Although functional PET and MRI studies may identify patients who have been incorrectly classified as vegetative from a brain injury, the expense and logistical difficulties of obtaining these studies make them impractical for routine clinical use, particularly in the acute rehabilitation setting. An EEG-based Brain-Computer Interface (BCI) can non-invasively monitor the brain for responses to somatic, auditory or visual input [Wolpaw and Wolpaw, 2012]. The equipment and protocol are relatively inexpensive, and can be used conveniently in the acute hospital or rehabilitation setting.

This study aims to evaluate awareness in patients who have been clinically diagnosed with PBU using an EEG-based BCI protocol to determine whether a spoken command produces an EEG response temporally related to an auditory stimulus. It seeks to determine whether there are differences in the medical histories of the patients who respond vs. those who do not, and to investigate the prognostic value of the results.

2. Material and Methods

2.1. Subjects

The current participants are 3 patients with traumatic brain injury who were admitted to the Helen Hayes Hospital (HHH, NY, USA) Neurorecovery Program. The inclusion criteria are: ≥ 16 years of age; JFK Coma Recovery Scale (CRS) $\leq$ 10; no serious co-morbidities; no craniotomy defects; no major scalp lacerations; and informed consent from a legally authorized representative. The study has been approved by the HHH Institutional Review Board. The participant is assessed for recovery from PBU by a trained psychiatrist or psychologist. The primary measure is the CRS. Subscales are comprised of hierarchically-arranged items associated with brainstem, sub-cortical, and cortical processes. The CRS was measured within one to two days of the recording. The Glasgow Outcome Scale (GOS) will be measured weekly as a five-point scale. The Functional Independence Measures (FIM) will be used for measuring the severity of disability.

2.2. Experimental paradigm

EEG from a 32 channel referential montage is collected while the participants perform two motor imagery tasks. In each trial of each task, the participant hears one of two commands: 'move hands' and 'relax'; or 'move feet' and 'relax'. The commands are pre-recorded in a female voice and delivered via headphones. Each command is followed by an interval of 5.5 s when the participant is expected to perform the cued motor imagery. Before the start of each run (each set of trials), the participant is instructed to imagine moving both hands or both feet from the time they hear the motor command until they hear the 'relax' command. A set of 20 'imagery' and 'relax' trials form a run, which lasts for about 5 minutes. Four runs are collected in total, two for each motor task: hand motor imagery and feet motor imagery. Hand and foot imagery runs are interleaved.

2.3. Data acquisition

EEG data is acquired at 256 Hz sampling rate, using two synchronized FDA-approved 16-channel g.USBamp amplifier units (g.tec, Graz, Austria). The data are collected with 32 gel electrodes pre-embedded in an elastic cap, in a customized montage. The BCI2000 software [Schalk et al., 2004] platform is used for presenting the commands as well as for maintaining the synchronization of the stimulus presentation with the EEG records.

2.4. Data Analysis

The analysis is performed in three main steps: Pre-processing, spectral estimation, determining statistically significant differences between motor imagery and rest conditions (and between hand imagery and foot imagery conditions). These steps were performed with MATLAB and in-house software.

The EEG data are pre-processed by artifact removal (visual inspection) and notch filtering followed by a spatial filter. The data are then notch-filtered at 60 Hz to remove line noise. Subsequently, the data are subjected to a common average reference (CAR) spatial filter.

The next step is determination of the power spectra for all EEG channels. A 4.5 s period of continuous data, starting 1 s after the end of the auditory command, is used from each trial. The power spectral amplitudes for all channels are then determined for each data segment with a short-time fast Fourier transform (STFT), using a Hanning window of 500 ms for 6-28 Hz with a frequency resolution of 2 Hz.

The spectral estimates for each bandwidth and for each channel are then pooled for the hand and feet motor imagery classes as well as for their respective 'rest' classes. A non-parametric Wilcoxon-Rank Sum test is used to find significant differences in the frequency content of the various EEG channels between the motor imagery and rest conditions. Furthermore, the classification accuracy for hand imagery vs. rest and feet imagery vs. rest is determined.

3. Results

We found significant differences in power in the mu and/or beta frequency bands between the motor (hand or foot) imagery and the rest conditions for normal control participants as well as for the first three participants with brain injury. For one of these, analysis of power in the beta band yielded classification accuracies of 74.7% and 61.2% for hand vs. rest and feet vs. rest, respectively ($p < 0.001$ and $p = 0.02$).

4. Discussion

With further data collection and analyses, this study may validate a useful new diagnostic method for evaluation of patients in an apparent vegetative state. The method might provide useful prognostic information and aid in the formulation of individual treatment and disposition plans. Improving the identification of patients who are more likely to regain some function could yield more appropriate treatment strategies and more effective deployment of available resources.

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