

Classifying Volition for Comatose Patients: a BCI Perspective

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Abstract. Traditional clinical methods for diagnosis of disorders of consciousness are highly subjective and dependant on the patient's ability to move or speak. Objective tools mainly neuroimaging based validation of imagery paradigms akin to those used in brain computer interface applications have partially addressed this problem. But there is now widespread consensus that long term benefits to quality of life for this patient group can be better achieved at the bedside. This work is aimed to develop an objective portable tool at the bedside to establish the ability to respond to command without moving or speaking. A volitional paradigm with a classic motor imagery flavour but specifically designed to utilize the stimuli previously used in fMRI paradigm is developed for this purpose. The neural signatures computed using classifier performance indicate similarity to the areas of brain activation as revealed in the neuroimaging studies. The results show a consistent classifiability of the volitional tasks: 'imagine playing tennis' (IPT) and 'imagine spatial navigation' (ISN) with classification accuracies of more than 90%. The paradigms using these volitional tasks can be further used and implemented on selected patients for objectively detecting awareness.

Keywords: EEG, Minimally Conscious state (MCS), Motor Imagery, Vegetative state(VS) , Volition

1. Introduction

Disorders of consciousness, namely coma, vegetative and minimally conscious states are currently diagnosed on the basis of the patient's clinical history and exhibited behaviour. The clinician's central objective is to determine, beyond reasonable doubt, either that a patient demonstrates no evidence of awareness of self or harbours some inconsistent, but reproducible sign of awareness [Bates, 2005]. This task, as demonstrated in several clinical audits [Andrews et al., 1996], is far from straightforward and there exists a high degree of error in diagnosis (up to 43%). In order to address the principal source of error, namely the highly subjective process of deciding whether an exhibited behaviour is a conscious or unconscious process, research groups have recently started to develop objective tests to reveal signs of awareness [Goldfine et al., 2011]. Furthermore, efforts have been made to develop modes for simple communication [Monti et al., 2010].

Brain computer interfaces can provide non-muscular communication and control of prosthetic devices in persons with severe motor disabilities [Birbaumer et al., 2003]. BCI technology can detect user modulation of neural activity to signal wilful intent. Its success has been mainly with fully conscious, but severely disabled patients unable to move. The training phase of the classic BCI setup presents a potential bedside method to detect awareness in persons without the ability to move or speak after a brain injury.

In this manuscript we evaluate and compare the motor imagery and spatial navigation paradigms with a classic BCI motor imagery paradigm in untrained healthy volunteers. Our objectives were twofold: (a) Do the mental imagery paradigms successfully demonstrated with neuroimaging and validated in healthy volunteers produce similar temporally and spatially resolved patterns of activation detectable using scalp EEG? (b) Can sufficiently robust patterns of activation be detected in untrained BCI volunteers?

2. Material and Methods

Twelve healthy volunteers (11 male, right handed) with no previous experience of BCIs participated in the study, which was approved by the HSSREC, University of Warwick, UK. All subjects gave written informed consent. 32 EEG channels sampled at 200 Hz and bandpass filtered between 0.1 and 70 Hz were acquired using a commercial EEG system (Brain Products GmbH).

Subjects underwent a single EEG acquisition session, during which they were asked to perform two/three tasks in no specific order: (a) task 1: imagine repeatedly moving the dominant upper limb back and forth in the context of

swinging a tennis racket to hit a ball versus rest, (b) task 2: imagine spatially navigating through the rooms of their home; concentrating on recreating the contents of each room rather than the act of movement from one room to another versus rest, (c) task 3: task 1 versus task 2 versus rest. In the rest period subjects were asked to relax.

At the start of each trial subjects were instructed to perform the set task if a marker appeared at the top of the computer screen (i.e., IPT or ISN) and change when the marker changed position, which was associated with the other task (e.g. rest). BCI2000 was used for stimulus presentation.

The analysis was designed using the functions from the Biosig toolbox. A single channel classification-performance (SCCP) based selection is robust and speedy method in which the contribution of each channel to the classification process is weighted using Cohen's kappa coefficient. In order to explore all the best combinations, 435 bipolar channel combinations were created. Classification using linear discriminant analysis is carried out on the autoregressive (AAR) features from the bipolar channel combinations using a k-fold cross validation procedure. The channels which generate the highest values of kappa coefficient are selected for the final classification stage.

3. Results

In case of IPT versus R, the channels placed on the motor areas and the frontal areas provide significantly higher contribution in the classification process between task IPT and R. Similarly, in the case of ISN versus R, 10 subjects show clearly highlighted temporo-parietal, occipital and frontal areas. These areas are supposedly associated with the spatial navigation and rest tasks.

Apparently, for almost all the topographic maps involving the rest state, higher values of kappa are observed for the frontal channels in majority of the subjects (11) implying the contribution of the frontal lobe to the rest state mental activity. The neural signatures of the three task volitional imagery provide clearly demarcated the areas of high activity for the 'rest' (frontal areas), 'imagine playing tennis' (central motor areas) and the 'spatial navigation' (parietal areas). Average accuracy achieved across the group for IPT versus R is 87.06%, while it is 86.94% in the case of ISN versus R. For three tasks IPT versus R versus ISN, the average accuracy is 75%.

4. Discussion

This work provides an electrophysiological framework for using established neuroimaging tasks for objective segregation of levels of disorders of consciousness. The SCCP method bypasses the complicated and cumbersome clinical interpretation of the EEG frequencies from brain injured patients but provides a solution to demarcate areas of high separability between these tasks. As these tasks are classifiable with high degree of accuracy, there exists a sub-group of non-behavioural, but intermittently conscious patients transiting through the continuum of impaired consciousness. BCI may be the most effective technique to detect such patients and provide a communication interface.

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