Dynamics of effective brain connectivity during working memory: potential for a new brain computer interface system

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***Abstract*— Effective connectivity between different brain regions during a working memory (WM) task is assessed using time-varying dynamic Bayesian networks (TV-DBN) and EEG signals. In-Degree connectivity to frontal electrodes in theta band showed higher values during execution and manipulation periods of a low demand WM task compared to those of a more difficult one. In contrast, stronger frontal connectivity manifested during the maintenance period, as a result of increased task difficulty. Utilizing the connectivity values among a few EEG channels and TV-DBN, which is a computationally efficient algorithm, we propose a new brain computer interface (BCI) system.**

I. Introduction

Working memory (WM), which consists of manipulation and maintenance of information for short time periods, is one of the most important cognitive functions. Most of the frontal and parietal regions contribute during a WM task. Despite numerous studies on WM, few of them have evaluated the dynamics of brain networks related to WM. This study aims to investigate the dynamics of effective brain networks of participants engaged in a WM task. We applied the time-varying dynamic Bayesian networks (TV-DBN) algorithm [1] to EEG data to represent how the connectivity values between different brain areas evolve in time. Furthermore, we used the variations in different workload conditions for introducing a new brain computer interface (BCI) method.

II. Materials, methods and results

7 healthy students (all right handed and male; mean age 22.9±3) participated in our study. They performed an N-back task in 3 difficulty conditions (0, 1 and 2). These conditions were presented in a random order in 3 sessions to subjects and each one consisted of 30 letters with 10 targets. Hence there were 60 non-target trials for each condition. In order to remove the effect of motor activity we used these trials for constructing brain networks. EEG data were recorded using Mitsar-EEG-202 system with 31 channels, 250 samples per second and referenced to the average of left and right mastoids. Trials with any types of artifact were discarded. A 4-8 Hz filter was applied to the data, hence only considering the theta oscillations, which are important in a WM procedure. Further data of each trial, from 100ms prior to 2300ms after the stimuli onset, was down sampled by factor 15, to have 40 samples for one trial. We normalize each EEG channel to zero mean and unit standard deviation. The down sampled data were used for multivariate autoregressive (MVAR) modeling, in which each sample was predicted by one previous value of all channels,

$$\mathbf{x}(t) = \mathbf{A}(t)\mathbf{x}(t-1) + \mathbf{e}(t) \quad (1)$$

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x(t) is the down sampled data and **A**(t) shows the weighting coefficients. For calculating **A**(t) we used the TV-DBN algorithm proposed in [1], and then changed all the values to positive ones. This procedure was carried out for all the trials. In order to construct the time-varying effective brain network for three conditions we computed the average of the obtained values for different trials of the same cognitive tasks and then for different subjects. Fig. 1. represents the strength of connectivity values, inflow to the frontal electrodes from all electrodes, for three N-back conditions during stimuli presentation. During the early and late intervals of a trial, which may be named as the maintenance period, the values increased as the task got more difficult and required the maintenance of more letters in memory. However during execution the frontal connectivity in the 0-back task was more dominant compared to the 2-back task, which may be related to the engagement of other brain regions for the purpose of task implementation. Recently ECoG signals were used for controlling a prosthesis using connectivity measures obtained by the TV-DBN algorithm [2]. Based on the aforementioned study and our results we hypothesized that the time-varying connectivity values between N-back conditions can be used as an index to discriminate the 0-back and 2-back single trials for implementing a WM related BCI system based on connectivity measures. For testing this hypothesis the data from one subject was selected. TV-DBN was applied to the 0-back and 2-back data without normalization, since this step cannot be performed in real-time applications. Next we selected five electrodes that elicited maximum inter-task variations. TV-DBN was employed to build the networks for the set of selected electrodes. The 5×5×40 connectivity matrices of each trial for 0-back and 2-back tasks were used to extract features for discriminating the two conditions. Four features were selected from the connectivty matrices and then the data was divided into two parts: train and test. Using an SVM classifier with RBF function we achieved the 79% accuracy, for single trial classification.

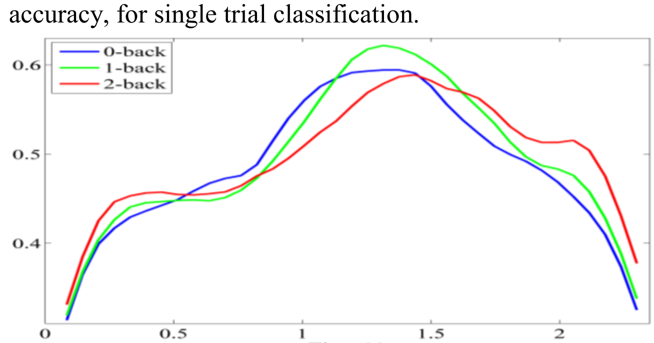

Fig. 1. In-Degree connectivity to the frontal electrodes

References

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[2] Heather L. Benz, et al. "Connectivity analysis as a novel approach to motor decoding for prosthesis control," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 20, no. 2, pp. 143-152, 2012.