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Interdependancy Estimation Between Brain and Cardiovascular Activity

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***Abstract* – This paper states the importance and means of assessing the interdependency estimation between two main systems of the human body: the central nervous and the cardiovascular system. The need for new signal processing approaches for joint quantitative analysis of these systems and their dynamical relations in various physiological conditions is emphasized. Experimental results on synchronization likelihood, phase locking and information transfer between brain and heart during sleep are presented. Directions of further development of signal processing approaches and open problems are stated and the ways of achieving diagnostic benefits from the proposed methods are highlighted.**

***Keywords* – signal analysis, nonlinear coupling, synchronization likelihood, mutual information, central nervous system, cardiovascular system**

I. INTRODUCTION

The characterization of the coupling between brain and heart activity may be beneficial in various fields. One example, where the evaluation of coupling between several body systems is of great importance, is the task of sleep stage scoring. As common approach, sleep is scored by the simultaneous analysis of electroencephalogram, electrooculorgam and electromyogram (denominated as polysomnogram) [1]. The usage of these signals came under criticism because of signals' liability to noise and artifacts and the inconveniences which are linked to their recording: a large number of leads is to be recorded and analyzed at a time. Instead, the use of only one signal derived from the body or even contactlessly would be of great advantage as compared to polysomnographic recordings. Due to simplicity and nowadays existing means of contactless recordings, the electrocardiogram (ECG) and heart rate (HR), respectively, are preferably choices to score sleep stages. However, in order to derive meaningful results from using an ECG instead of the polysomnogram the interdependency between brain and heart activity must be clarified. Although several research groups are involved in such researches, until today there are no automated systems for ECG based sleep scoring available on the market.

The purpose of this work is to give a short overview of current signal processing techniques which might be used for simultaneous analysis of signals describing brain electrical activity and heart activity in various domains. Preliminary results on mutual information, phase locking and synchronization likelihood between heart rate and brain electrical activity are presented.

II. INTERDEPENDANCY ESTIMATION IN VARIOUS DOMAINS

In principle, a large number of parameters describing the functioning of brain and heart during sleep can be calculated and used for analysis. To build reliable automated sleep scoring systems, only those parameters should be selected which give the highest scoring accuracy. Therefore, we consider the selection of suited parameters as essential step to evaluate the coupling between the systems under analysis, namely the cardiovascular and brain electrical activity. To achieve this, characteristics with some quantitative measure of synchronous changes are to be evaluated for the signals, which are recorded simultaneously from the heart and the brain. Afterwards those parameters having the highest coupling should be used for further investigation.

The basic idea to estimate simultaneous changes in signals from heart and brain is the adaptation of linear and nonlinear bivariate signal processing techniques for the use of the signals of different modalities. So far, there have been many bivariate signal analysis techniques developed, and selecting the one which is most appropriate for specific case is not trivial task. Thus the following methods were empirically selected to be used in this work.

A. Time domain

In time domain synchronization likelihood [2] was selected. Synchronization likelihood is a nonlinear measure which is able to detect linear and nonlinear dependencies between two signals. It relies on the detection of simultaneously occurring patterns which can be complex and widely different in two signals.

B. Frequency domain

In frequency domain phase synchronization [3] was used which allows to quantify frequency-specific synchronization (transient phase-locking) between two signals. This measure can be used to estimate the direction of coupling. Although it is mostly used for periodic oscillatory processes, we adapted it to the narrow-band components of the signals from two systems.

C. *Information transfer domain*

From the large variety of information transfer characteristics available now, we restricted ourselves to only one of them - mutual information [4]. Mutual information indicates the amount of information about one random process we obtain by knowing another random process and vise versa. This measure can be asymmetric, defining the driver-response interactions between brain and heart systems and it can be useful for selecting the system which governs sleep during the night.

III. EXPERIMENTAL RESULTS

Preliminary experiments were conducted with the limited amount of data from healthy patients with abovementioned signal analysis techniques implemented in MatLAB. The data from 18 healthy subjects were used; each signal set contains 10 records of brain activity parameters and 45 records of cardiovascular activity parameters. A number of qualitative measures of coupling were calculated for different variations of methods parameters.

On Fig. 1a and 2a the patient's hypnograms are presented, showing the changes of sleep stages during the night. Here WAKE stage is labeled as 0 and REM (Rapid Eye Movement) stage as 5. On Fig. 1b and 1c the time dependence of electroencephalogram power in delta range and normalized high frequency beat-to-beat interval power are presented, and on Fig. 1d the resulting synchronization likelihood for embedded dimension 2 is plotted.

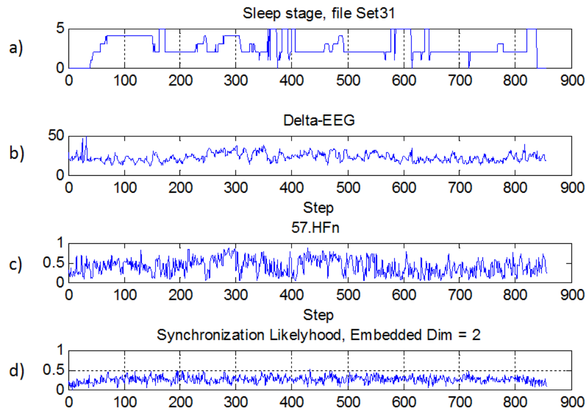

Figure 1. Synchronization likelihood estimation between electroencephalogram power in delta range and normalyzed high frequency spectral range of interbeat interval

On Fig. 2b two pictures show the phase synchronization estimated by phase-locking value (PLV) and mutual information (MI). Color intensity corresponds to the value of synchronization between instantaneous phases of two parameters which have been analyzed: ratio between electroencephalogram power in beta and delta frequency range (Fig. 2c) and mean value of normal-to-normal heart beat interval (Fig. 3d).

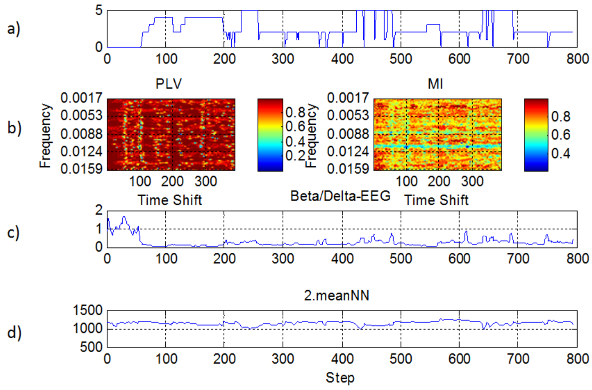

Figure 2. Phase synchronization estimation between mean value of interbeat intervals and power ratio beteen two electroencephalogram frequency bands

As can be concluded from the obtained results, developed quantitative coupling measures varied for different pairs of heart and brain activity characteristics. The strength of coupling also depends on the settings and parameters used for specific method.

IV. CONCLUSIONS

Application of linear and nonlinear measures for analysis of coupling and interconnections between various processes in human body is a fruitful area of research still having more open problems than strictly defined usage routines.

From the preliminary results obtained in this work it can be concluded that all measures employed here are promising for selecting the most coupled parameters of heart and brain activity. However, there is the need for further development of quantitative not qualitative measures of coupling between two systems. On the next stage of our research the goal is to develop the technique for quantitative analysis of different coupling measures, and finding a way to select most optimal parameters for each measure's calculation.

There is also a need for multiclass and multicenter studies and clinical verification of obtained results.

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