Coherence Analysis between ECG Signal and EEG Signal

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Abstract
This paper presents the degree of association or coupling of frequency spectra between the ECG and EEG signals at a particular frequency. Coherence is often interpreted as a measure of 'coupling' and as a measure of a functional association (relationship) between two signals (ECG Signal and EEG Signal). An electrocardiogram or ECG is an electrical recording of the heart and is used in the investigation of heart disease. An electrocardiogram (ECG) is a graphic tracing of the electric current generated by the heart muscle during a heartbeat. It has been used extensively in medicine sine its inventions in the early 1900's and has been proven to be invaluable in various diagnostics applications and clinical applications. An EEG Signal reflects the electrical activity of human brain. EEG signals arises from the fact that these waveforms provide the non-invasive diagnostic tool in a wealth of disorders that include epilepsy and comma assessment in intensive e care unit. In this paper we analysed the association of heart with mind signals (ECG and EEG) by obtaining magnitude squared coherence and phase coherence parameters at a certain range of frequency.

Keywords
ECG, EEG, cross-power spectrum density amplitude squared coherence, coherence phase.

I. Introduction

Biomedical signals carry fundamental information about the nature and the status of the living systems under study. A proper processing of these signals obtains useful physiological and clinical information. The heart is comprised of muscle (myocardium) that is rhythmically driven to contract and hence drive the circulation of blood throughout the body. The pattern of electrical propagation is not random, but spreads over the structure of the heart in a coordinated pattern which leads to an effective, coordinated systole. This results in a measurable change in potential difference on the body surface of the subject and is called as electrocardiogram (ECG). The resultant amplified (and filtered) signal is known as an electrocardiogram (ECG, or sometimes EKG). The ECG is used for various clinical applications such as the detection of irregular heartbeat patterns (i.e. fibrillation & arrhythmia), hearts murmurs (other abnormal sounds), tissue/structural damage (such as valve malfunction) and coronary artery blockage. The human brain is the most resilient and adaptable structure in nature, the source of all of our emotions, perceptions, thoughts, and behaviours. The brain is made up of hundreds of billions of microscopic elements called neurons which use chemical messages to regulate electrical activity throughout the brain. The brain communicates to itself and with the body by means of these electrical changes and our emotions, perceptions, thoughts, and behaviours are the result of the totality of these electrical and chemical changes, although the exact mechanism of how brain becomes mind is not understood. Neurotherapists focus upon rhythms and activity within conventional frequency bands such as delta (0.1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), sensorimotor rhythm or SMR (12-15 Hz), beta (15-40 Hz), and gamma (40 -300+ Hz). Beta activity is usually divided into sub-bands such as beta 1 for lower frequencies (e.g., 12-16 Hz, or 15-18 Hz), beta 2 for middle frequencies (e.g., 18-24 Hz), and beta 3 for higher frequencies (e.g., 24-30 Hz, 30-40 Hz). Frequency bands may vary across clinics (e.g., theta as 4-7 Hz, 5-7 Hz) and the SMR label may be restricted to spindle activity over sensorimotor cortex only. Because wider frequency bands encompass a variety of physiological processes, narrow bands (e.g., 6-8 Hz, 9-10 Hz) or bands tailored for an individual are commonly analysed as well.

Coherence is the degree of relationship or association of frequency spectra between the ECG and EEG signals at a particular frequency. Note the peaks in the power spectral density (PSD) at 1, 4, 7, and 10 Hz, corresponding approximately to the heart rate (60 bpm), T wave, P wave, and the QRS complex, respectively. The spectral content for each lead is highly similar regardless of the lead configuration, although the actual energy at each frequency may differ. The magnitude squared coherence estimate between two signals x (ECG Signal) and y (EEG Signal), is

$$C_{xy}(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f) \times P_{yy}(f)} \quad (1)$$

Here C_{xy} (f) is the magnitude squared coherence between the ECG and EEG signals

coherence phase is given as

$$\theta(f) = \tan^{-1}\left\{\frac{\mathrm{Im}\{P_{xy}\}}{\mathrm{Re}\{P_{xy}\}}\right\} \quad (2)$$

Where $P_{xx}(f)$ is the power spectral estimate of x (ECG Signal), $P_{yy}(f)$ is the power spectral estimate of y (EEG Signal), and Pxy is the cross power spectral estimate of x and y. Coherence is a function of frequency with Cxy (f) ranging between 0 and 1 and indicates how well signal x corresponds to signal y at each frequency. The degree of synchronization in electroencephalography (EEG) signal and ECG signal is commonly characterized by coherence phase and magnitude squared coherence (MSC).

II. Signal Measurement

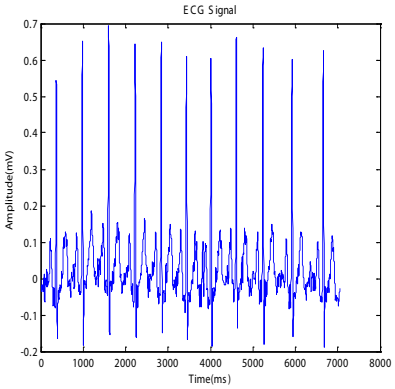
The Multifunctional physiological data acquisition system MP35 (Biopac System Inc.) was utilized for signal measurement for ECG signals and EEG signals (by module SS2LA) in fig.1 & fig.2. The user friendly analysis package Biopac Student Lab 3.7.6 was used for the signal measurement and Biopac Student Lab PRO 3.7.6 for management, including the signal quality pre-screening, data storage and retrieval. The sampling frequency was 1000 Hz for ECG signal and the 250 samples per second for the EEG signal. The signals were verified visually by a well-trained technician. If the signal quality was poor, the signal would be excluded from further analysis and the subject was asked to repeat the experiment once again.

Fig. 1: Multichannel Data Acquisition Unit Connection Lead Setup

Fig. 2: Subjects (EEG & ECG Signals Acquiring)

III. Analysis & Results

The coherence between the measured ECG signal and the measured EEG signal at different sampling rates from both subjects one is for ECG signal and another is for EEG signal in the frequency domain. The sampling rate for the ECG signal is 1000 Hz and for EEG signal is 250 Hz. The maximum coherence is 0.8171 near the frequency 1 Hz and the minimum coherence is 2.4211×10-4 near the frequency 30 Hz. The maximum coherence found between the ECG and EEG near the frequency 1Hz (fig.5(a)). Coherence phase is smaller than the zero which implies that the ECG signal induced changes in EEG signal lags the ECG signal and Coherence phase is greater than the zero which implies that the ECG signal induced changes in EEG signal leads the ECG signal. The minimum phase coherence between ECG and EEG is -2.801rad (approx.) near the frequency 29 Hz. Maximum phase coherence between the signals 3.190 near the frequency 1Hz (fig.5(b)).



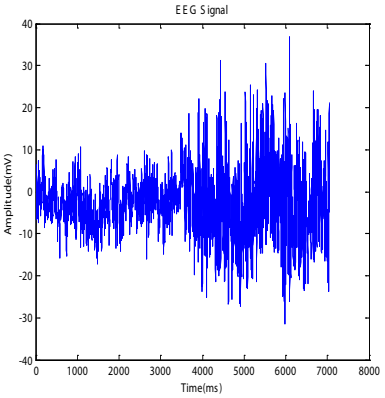


Fig. 3. (a) Measured ECG Signal (b) Measured EEG Signal

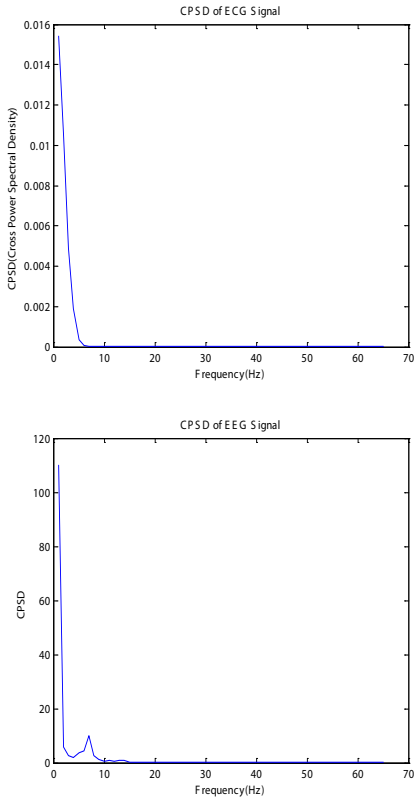
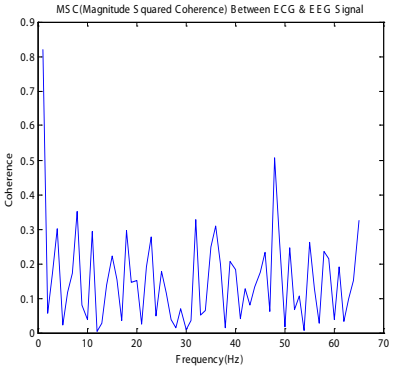


Fig. 4. (a) CPSD of ECG signal (b) CPSD of EEG signal



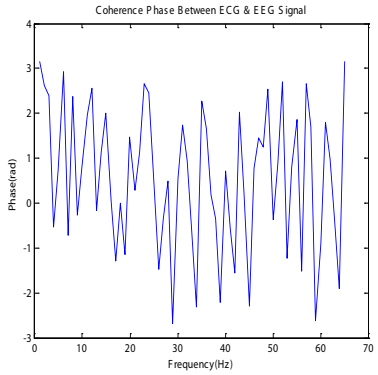


Fig. 5. (a) Coherence between ECG and EEG signals (b) Coherence phase between ECG and EEG signals
These results matlab code developed in Matlab(R2010a)7.10.0.

IV. Conclusion

This study utilized welch method for spectral estimation to investigate the coherence between the ECG signal and the EEG signal at particular frequency and under the different frequency bands. Both signals are completely coherent if the magnitude squared coherence is equal to 1, if MSC is equal to zero then the both signals are independent to each other. The results shows the both signals are coherent at the frequencies at which the magnitude squared coherence (MSC) is greater than 0.5 and both signals are incoherent (less coherent) if MSC is lesser than 0.5. The existence of the coherent peak can be determined by checking whether the corresponding peak related to the corresponding frequency of the ECG signal. It may possible to acquire the EEG signal information from the ECG signal by PSD estimation by welch method.

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