Brain Mapping of a Wavelet Analyses of Subjects with Obstructive Sleep Apnea

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Abstract

Obstructive Sleep Apnea Syndrome (OSAS) is a very common sleep disorder with potential severe implications in essential aspects and the patient’s health.

This study addresses the evaluation of the EEG energy-based brain mapping in before, during and after the OSAS episode using continuous wavelet spectral analyses.

The results show that there is a significant reduction in the energy of a frequency band but an increase in β band, in overall brain. θ and α have an increased energy in the parietal and occipital cortex, but decreased in the other areas, mainly after the OSAS episode.

1. Introduction

Obstructive Sleep Apnea Syndrome (OSAS) is a very common sleep disorder affecting 4% of men and 2% of women [7] and it’s characterized by recurrent arousals and respiratory events, disrupting normal sleep patterns [4]. OSAS may be caused by a partial or complete collapse of the upper airway resulting in repetitive hypoxic and hypercapnic episodes, with a concomitant loss of airflow in the presence of continued diaphragmatic efforts [6]. Somers et al. (2008) described that OSAS may contribute to the development of respiratory and cardiovascular disorders, such as hypertension, ischemic heart disease, stroke or cerebrovascular accident and neurocognitive impairments [8].

Neurophysiological assessment through the electroencephalographic (EEG) signal provides an objective method for detecting changes in cortical activity. The EEG spectral analysis was found to be a very useful tool to assess the EEG power in four stated EEG frequency ranges:(a) The lowest amplitude wave band and with highest frequency, 18-30 Hz, are named beta rhythm and is associated with active state;(b) Alpha rhythm lies between 8-12 Hz and an amplitude of 50 µV and is associated with a relaxation state;(c) Larger regular waves of frequency range 4-7 Hz called theta rhythm have been recognized for sleep state, and;(d) Less than 4 Hz is called the delta rhythm and has a high energy value in states of profound sleep or coma.

Some studies concerning the brain activity patterns mapping of patients with OSAS have been reported by several technics, such as, functional magnetic resonance [6] and EEG energy [5]. These studies only compared individuals only with apnea and with apnea and restless legs syndrome (RLS).

This study addresses the EEG energy-based brain mapping before, during and after the occurrence of an apnea episode during NREM-2 sleep in order to access the dynamics of the brain activity in different frequency bands. Using the wavelet spectral analyses in each EEG channel is possible to estimate the mean energy of each part of the brain with the purpose of exploring the features that could result in memory loss, cognitive dysfunctions and deprivation of sleep.

2. Methods

Polysomnographic signals were recorded on a computerized polysomnography system (Sommologica 5.0.1, Embla) during the patient sleep time (±8 h). EEG electrodes were positioned according to the International 10-20 System and 21 recordings were obtained from the following leads: Fp1, Fp2, Fpz, F3, F4, F7, F8, Fz, C3, C4, Cz, P3, P4, Pz, O1, O2, Oz, T3, T4, T5 and T6, in reference to linked ears (A1 and A2). The EEG signals were acquired at a sampling frequency (Fs) of 100 Hz. The nasal airflow was recorded as well.

The cessation of the air flow during more than 10 s in NREM-2 sleep stage and more than 60 s isolation were the criteria of selecting an apnea episode. Each episode was divided into three segments according to the episode’s phase: before (pre), during (dur), and after (post) an apnea event. Each EEG epoch detected was visually scanned for artifacts and for exclusion of bursts of k-complex and delta activity occurring at the end of the apnic episodes in close association with microarousals [2]. The resulting dataset includes 171 episodes and 10773 (171 episodes × 3 phases × 21
channels) epochs.

2.1. Wavelet transform

The signal was processed for the several EEG channels individually. For each epoch the mean value were removed and were submitted to a spectral analysis using a continuous wavelet transform (CWT) for the four different frequency bands described earlier.

The wavelet transform decomposes a signal in to a set of basic function scaled wavelets. These basic functions are obtained by dilations, contractions and shifts of a unique function called wavelet prototype.

The used prototype wavelet is the Morlet function [3]:

\[
W(t, f_0) = A \exp\left(-\frac{t^2}{2\sigma_f^2}\right) \exp(2i\pi f_0 t)
\]

with \( f_0 \) as the frequency band \( \sigma_f = 12\pi\sigma_t \), and \( A = (\sigma_t\sqrt{\pi}^{-1/2}) \).

2.2. Energy Calculation and Brain Mapping

After processing the EEG signal \( x \), the mean energy for each channel \( c \) and frequency band \( f_0 \) was calculated by the following equation:

\[
E_p(c, i, f_0) = \frac{1}{N} \sum_{n=1}^{N} |x(c, n) \ast W(n, f_0)|^2
\]

where \( E_p \) represents the energy for each apnea segment \( p = \text{pre}, \text{dur}, \text{post} \), \( i \) represents the episode \( i = 1, ..., M \) and \( n \) the sample \( n = 1, ..., N \). Finally, the next equation gives the relative energy of each channel:

\[
e_p(c, f_0) = \frac{1}{M} \sum_{i=1}^{M} \left[ \frac{E_p(c, i, f_0)}{E_{\text{pre}}(c, i, f_0)} \right] - 1
\]

The brain mapping was based on the aproximation of the head to a semi-sphere and interpolating the channel energy values using the Matlab toolbox EEGLAB with the function topoplot(). EEGLAB is a software toolbox for Matlab (more information is freely available from http://www.sccn.ucsd.edu/eeglab/) [1].

3. Experimental results

The mapping of the relative energy mean values for each frequency band and apnea episode phase is presented in Fig. 1 and the respective standard deviation in Fig. 2. In this preliminary study, although the standard deviation is high in the frontal and central cortex (C3, C4, F3 and F4 electrodes), it is quite visible that the delta waves decrease energy during the episode and don’t replenish in the next phase for all the brain spectra.

As for the theta waves, during the episode there is an increase in the most central area (Cz), in the parietal (P3, Pz and P4), occipital (O3 and O4) parts of the brain but decreasing in the other areas and after the episode, the occipital areas decrease anergy, but the parietal and frontal areas have more energy. The alpha waves are slightly different than the theta variation but less pronounced.

The increase of the beta energy in all the brain after the episode indicates that the subjects had an arousal, concurrent to the fact that these patients don’t have a normal sleep patterns.

4. Conclusions

Considering that each patient has significant amount of episodes, and many of them aren’t isolated, it is possible to conclude that these patients don’t have a full replenishment of the brain energy during the night and not all areas are affected in the same way during an apnea episode. It is plausible to say that this patients don’t rest while sleeping how they should.

It is also curious to establish the relationship that the zones with a higher standard deviation for all frequency bands are in areas which represent the pre-motor, motor and visual areas of the brain.

References

Figure 1: Mean of relative energy mapping: (a) Delta waves during apnea episode; (b) Theta waves during apnea episode; (c) Alpha waves during apnea episode; (d) Beta waves during apnea episode; (e) Delta waves post apnea episode; (f) Theta waves post apnea episode; (g) Alpha waves post apnea episode; (h) Beta waves post apnea episode. Since the delta waves have a higher energy content, the colorbars have a wider range of values for an easier perception.

Figure 2: Standard deviation of relative energy mapping: (a) Delta waves during apnea episode; (b) Theta waves during apnea episode; (c) Alpha waves during apnea episode; (d) Beta waves during apnea episode; (e) Delta waves post apnea episode; (f) Theta waves post apnea episode; (g) Alpha waves post apnea episode; (h) Beta waves post apnea episode. All the figures have a color range from 0 (dark blue) to 1 (dark red).