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QUANTIFICATION OF CHIRP-LIKE STRUCTURES OF EEG TIME-SERIES

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Abstract: In this paper we introduce a procedure based on Matching Pursuit with Gabor-chirping dictionary and apply it to the spectral decomposition of a whole-night EEG signal from a group of nine young normal subjects. It was thus possible to identify sleep spindles (SS) and quantify them not only in frequency but also in modulation of this frequency. We identified a slowing pattern for these elements that should be explained in terms of their thalamocortical generating mechanism.

keywords: EEG, Matching Pursuit, Signal analysis.

1. INTRODUCTION

One of the most fascinating problems of real signal analysis is precisely its lack of stationarity [1]. In the case of biological signals, as is the case of EEGs, this is more the rule than the exception. Furthermore, most tools, both linear and non-linear, are designed to work with stationary signals. So it is natural that the next step in biosignal analysis is precisely addressing the non-stationary components [1, 2]. But here we have an additional problem: the size of the piece of signal that we have to deal with.

Small blocks of signal, lasting only half a second, are an important part of the study of sleep EEG. Finding patterns with pathophysiological significance in this "microstructure" of the EEG is probably one of the greatest challenge for electrophysiology in the next years. The EEG of sleep is particularly rich in variations, and various short duration elements have been extensively studied and classified, showing correlation with the quality of sleep, memory consolidation and epilepsy, among others. This is precisely the case for Sleep Spindles [1, 2] (SS). The SS is a wave of short duration (0.5s-2s) with envelope type behavior and frequency ranging from 11Hz to 16Hz central frequency, depending on scalp position.

The aim of this paper is to introduce a methodology that can extract the most important feature of SS (its central frequency of oscillation) and introduce a measure of local dispersion for that frequency, which is the frequency modulation (or "chirping-rate"). The tool follows a Matching Pursuit approach with Gabor-Chirping atoms as the basis [5]. In the next section we describe the basics of tool used and the EEG sample.

2. METHODS

2.1. Matching Pursuit with Gabor Chirping Dictionary

Matching Pursuit is not a transform, it is an adaptive approximation of the signal with a set of fundamental functions chosen from a dictionary. In the MP approach a signal $S(t)$ is taken and subsequent adaptation steps are made writing $S(t)$ in terms of a basic and redundant dictionary of functions $D = \{g_{\gamma_i}\}$

$$S(t) \simeq \sum_{i=1}^{M} a_i g_{\gamma_i}, \tag{1}$$

where γ_i represents a set of parameters that characterize the dictionary functions, M is the number of steps and a_i is an amplitude term which may be incorporated to g without loss of generality. For a signal of size N, $D = \{g_{\gamma_i}\}$ is a redundant dictionary of $i > N$ elements which will include at least N linearly independent vectors.

As an adaptive filter, the MP procedure matches the signal with a function g_{γ_i} at each step i, leaving a residue $R_{i+1}S(t)$ to be matched by the same procedure in step $i + 1$.

The dictionary used for time-frequency analysis is built from Gabor chirping functions as

$$g_\gamma(t) = \alpha e^{-\pi((t-b/s))^2} \sin(2\pi\omega(t(1+\beta t)-b)/N+\phi), \tag{2}$$

where N is the size of the signal, the set $\gamma = \{\alpha, b, w, s, \beta, \phi\}$ represents parameters of dictionary functions and α is chosen such that $|g_\gamma| = 1$ [5]. To this dictionary a set of Dirac's delta and Fourier functions is added in order to deal with time and frequency well-localized structures. A dictionary size of 10^6 Gabor atoms was used here. This kind of approach is being used in EEG for example in [4] and references therein.

2.2. EEG Sample

Subjects (aged 20-34, average 24.6) were nine male volunteers with no history of drug use, neurologic diseases or problems related to sleep, who reported regular sleep schedules from 6 to 8h/day. They completed an informed consent and agreed not to use alcohol, caffein or any drugs in the 24hs prior to the investigation. Subjects underwent two studies, the second night being used in this experiment. This sample is better described in a previous work [4].

Briefly, continuous recordings were performed throughout the sleep period (23:00-07:00 h) on an 18-channel analog NIHON-KOHDEN polygraph with 12 bit digital conversion (STELLATE RHYTHM V10.0). The basic montage included fifteen scalp silver disk electrodes combined into 11 bipolar EEG leads, including C3-A2, C4-A1, Fp1-T3, T3-O1, Fp2-T4, T4-O2. All studies were recorded on hard disk (128Hz sampling rate) for posterior analysis. Conventional scoring [3] was performed on 20-second epochs prior to quantitative analysis. Overall information on sleep architecture was obtained hereby.

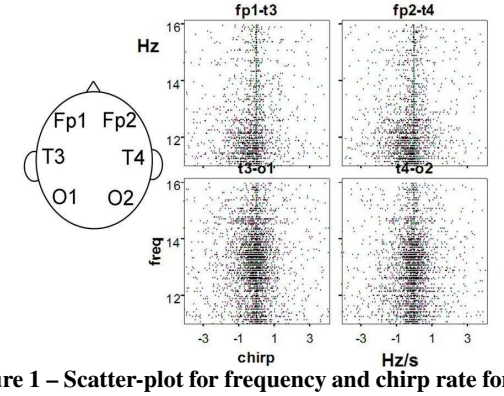

Figure 1 – Scatter-plot for frequency and chirp rate for the four channel combinations. Head with electrode positions is depicted at the left-side of the figure.

2.3. MP Procedure

The procedure to find SS using MP meets the following criteria: each signal is decomposed into windows of 16s (or 2048 points) and these windows are submitted to MP using a stop criterion of 96 iterations. On average, this means over 95% of signal energy reconstruction. Once the signal is all decomposed, each atom over $100\mu V$ amplitude, lying between 11Hz and 16Hz and with duration between $0.5s$ and $2s$ will be treated as a potential SS, being collected for analysis of their characteristics. This procedure was performed in channels Fp(1,2)-T(3,4)-O(1,2) in order to obtain antero-posterior information from both hemispheres. The amplitude criterion was set in order to retain the top 10% elements with highest amplitude in analysis.

3. CONCLUSION

With this procedure it was possible to extract, for the first time, a "scatter plot" of central SS frequency against the "chirping rate", depicted in Figure 1. We can see a presence of faster spindles in posterior channels (T(3,4)-O(1,2)), as expected. This figure shows absence of significant correlation between central frequency and chirping rate. But SS tend to have more negative than positive chirping rate, and that goes for rapid posterior as well as slow anterior SS.

The concept of "instantaneous frequency" is somewhat dubious. What we are measuring here is not a definite frequency, but a temporal distribution of frequencies that can be used to define time zones where they begin and end on the EEG phasic events. If the frequency distribution in this temporal zone varies not only in intensity, but also in frequency, we will say that it is "chirping". The non-stationarity of the EEG is a classical concept, therefore the presence of "chirps" in the frequency distribution is somewhat expected.

However, the results show that, in this sample, there are three types of structures: spindles with positive, negative and non-modulating frequency. The asymmetry of these distributions indicates that these features are not randomly distributed. This behavior may be related to mechanisms of neuronal recruitment. The presence of larger number of negative chirping SS may imply that neuronal recruitment is acomplished all at once and the system would then gradually lose inertial phase (at least on a larger scale than positive chirping, which also occur).

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