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Time-Frequency Spectral Differences in Event-Related Potentials between Neurotic and Stable Persons in Human EEG

Georgiev S.[1], Minchev Z.[1, 2], Philipova D.[1], Christova C.[1]

[1]Institute of Neurobiology, Bulgarian Academy of Sciences
23 Acad. G. Bonchev Str., Sofia 1113
[2]Institute for Parallel Processing, Bulgarian Academy of Sciences
25A Acad. G. Bonchev Str., Sofia 1113
E-mails: stilliyan@mail.bg, zlatogor@bas.bg, dolja@bio.bas.bg, ch.christova@gmail.com

Summary: The aim of this work is to show how Wavelet and S-transform Power Spectrum Analysis could be used for detection of the time-frequency spectral differences in series of Event-Related Potentials recorded from neurotic and stable persons. We compared the EEG records in simple counting task condition of 30 healthy subjects divided in stable and neurotic groups according to there scores in neuroticism scale on Eysenck's Personality Questionnaire. Significant differences were found in the theta and alpha EEG bands. The stable persons are characterized with more prominent theta and less prominent alpha spectral power compared to the neurotic group. The application of complex decomposed functions for both Wavelet and S-transform Power Spectrum Analysis showed to be more useful for the discrimination between both groups of subjects.

Key words: EEG, Event Related Potentials, Wavelet Power Spectrum Analysis, S-transform Power Spectrum Analysis

1. INTRODUCTION

One of the fundamental personality trait in the study of psychology is neuroticism. It can be defined as an enduring tendency to experience negative emotional states. Individuals who score high on neuroticism are more likely than the average to experience such feelings as anxiety, anger, guilt, and clinical depression.

Neuroticism appears to be related to physiological differences in the brain. Hans Eysenck theorized that neuroticism is a function of activity in the limbic system, and research suggests that people who score highly on measures of neuroticism have a more reactive sympathetic nervous system, and are more sensitive to environmental stimulation.

Behavioral genetics researchers have found that a substantial portion of the variability on measures of neuroticism can be attributed to genetic factors [1]. A study on the topic has found that healthy subjects neuroticism scores are related to serotoninergic pathways in thalamus [2]. More detailed neuroimaging analysis that use magnetic resonance imaging to measure brain volume found that the brain volume was negatively correlated to neuroticism when correcting for possible effects of intracranial volume, sex, and age [3]. Functional magnetic resonance imaging (fMRI) experiments have demonstrated that regions of the amygdala exhibit differential responses to emotional stimuli in individuals who describe themselves as highly extraverted or neurotic [4].

Recording an EEG in a resting state [5] calculated absolute and relative Fourier Transform spectral powers for individually adjusted delta, theta, and alpha bands. Neuroticism was positively related to alpha and negatively related to delta power spectra determined by the Fourier Transform.

Recording an EEG at rest in two different conditions (eyes open and eyes closed) [6] found negative correlation between theta band power and neuroticism in eyes open condition. [7] found that alpha and beta correlated negatively with neuroticism in males, although not in posterior sites. During a performance of mental tasks [8] demonstrated that persons with low scores on the neuroticism scale showed larger amounts of frontal midline theta rhythm.

However most part of the literature data concerning the EEG Fourier spectral differences between persons with low and high neuroticism scores in healthy population are done by the analysis of spontaneous EEG activity. There are less data for EEG Fourier spectral differences between stable and neurotic persons in healthy population in the time window of presentation, evaluation and cognitive processing of some stimulus or event. In other words there are less data concerning the spectral differences of event-related brain potential between stable and neurotic persons.

In the literature there are many classifications of EEG signal as noise, quasi-periodic and even fractal or chaotic signal. Nowadays, the most commonly used methods for signal processing of quasi-periodic signals include techniques like Fourier and Wavelet Analysis. Whereas a Fourier transform provides information on the dominant frequencies, wavelet analysis has the added advantage of providing time localisation of the various frequency components. The Continuous Wavelet Transform (CWT) is used to decompose a signal into wavelets, small oscillations that are highly localized in time. Whereas the Fourier transform decomposes a signal into infinite length sines and cosines, effectively losing all time-localization information, the CWT's basis functions are scaled and shifted versions of the time-localized mother wavelet. The CWT is used to construct a time-frequency representation of a signal that offers very good time and frequency localization.

The aim of this work is to test the usefulness of Wavelet analysis (with real and complex Morlet functions) and S-transform for analysis of spectral characteristics of the Event Related Potentials (ERP) of human EEG in which the personality differences for neurotic and stable persons classification is presumed.

2. MATERIALS AND METHODS

77 healthy volunteers participated in the study. All subjects were right-handed [9]. The subject was comfortably seated in an ergonomically designed chair within a soundproof, electrically screened chamber monitored by a Canon Video System. The right hand and forearm were positioned along the armrests. The right index finger was immobilized within a rigid rail attached to a pull-push force transducer. An electroencephalogram (bandpass filtered between 0.3 - 70 Hz) was recorded from Fz, Cz, Pz, C3' and C4', using Ag/AgCl electrodes with reference to both processi mastoidei, according to the system 10 - 20. An electrode placed on the forehead served as ground. We recorded EEG under two equal audio series in pseudorandomized order of 50 low (800 Hz) and 50 high (1000 Hz) tones with an intensity of 60 dB, duration 50 ms and randomized interstimulus interval between 2.5 - 3.5 s. In the experimental series persons were instructed to count the low tones and to ignore the high tones in the series. The EEG data was written onto a hard drive in trials with length of 2000 ms (500 ms before the stimulus onset and 1500 ms after the stimulus onset) and sampling rate of 1000 Hz per channel.

Each person filled the self report Eysenck's Personality Questionnaire (EPQ) adapted for Bulgarian [10]. According to the scores in the neuroticism scale the persons were divided in neurotics (more that 15 points of neuroticism scale) and stable (7 and less then

7 points in neuroticism scale). After the personality type classification for further analysis we used only 30 persons (17 males and 13 females).

3. WAVELET SPECTRAL ANALYSIS

For mathematical analysis we used only the artifact free trials and MATLAB® 6.5. All trials there reached amplitude more then ± 50 μV in the time interval of the record were automatically rejected. The signal was filtered first with linear detrend procedure and second with low-pass Chebyshev filter of order 3 with cutoff frequency 70 Hz.

We computed the S-transform for each trial of our experimental series. S-transform [11] is a type of time-frequency analysis that uses different window length depending on the analyzed frequency:

$$ST(\tau, f) = \int_{-\infty}^{\infty} x(t)w(t-\tau, f)\, e^{-2\pi i f t} dt \qquad (1)$$

To obtain the time-frequency [2000x100] matrixes for each person, record and tone we performed averaging procedure for each person, record and tone separately.

Further we analyzed the data with Continuous Wavelet Transform (CWT), using the real and complex Morlet wavelet representation. On Fig. 1 is depicted the real and imaginary part of the Morlet wavelet function:

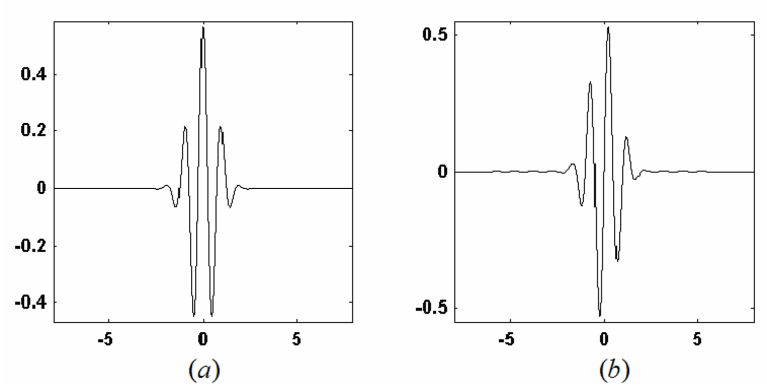

Fig. 1. Real (*a*) and Imaginary (*b*) parts of the Morlet wavelet function

The utilized by us real Morlet wavelet function is denoted by (2) and the complex one by (3):

$$\psi(x) = e^{-\frac{x^2}{2}}.\cos\ 5x \tag{2}$$

$$\psi(x) = \sqrt{\pi.f_b}\ .e^{2\pi i f_c x}\ .e^{-\frac{x^2}{f_b}} \tag{3}$$

Both (2) and (3) are depending on two parameters – bandwidth f_b = 1 and wavelet center frequency f_c = 1.

Taking into consideration that the wavelet transform $W(t, s)$ with complex wavelet is also a complex one, we calculated the Wavelet Power Spectrum (WPS):

$$\mathrm{WPS} = [\mathrm{Re}(W(t,s))]^2 + [\mathrm{Im}(W(t,s))]^2 \tag{4}$$

We determined the CWT scales analytically following the method of [12] by generating a set of cosine waves with known frequencies (from 1 to 50 Hz) and computing the scales at which the wavelet power spectrum reaches its maximum for each known frequency.

The wavelet power spectrum for real and complex Morlet wavelet was calculated for each trial and the scale-period matrixes were averaged for each tone and record separately. To obtain the time-frequency [2000x50] matrixes for each person, record and tone we performed an averaging procedure for each person, record and tone separately.

4. STATISTICAL ANALYSIS

We divided the volunteers into two groups according to EPQ neuroticism scores. The persons with less than 8 points in neuroticism scale were classified as stable and those with more than 15 points were classified as neurotics. We compared the two groups using nonparametric Kruscal-Wallis statistical analysis. Each coefficient of the wavelet power matrix was compared with the corresponding coefficients of power matrixes for the same tone and record.

5. RESULTS

We have conducted power spectrum analysis within complex, real Morlet wavelet function and S-transform power spectrum calculation for both neurotics and stable persons, considering five leads: Fz, Cz, Pz, C3’ and C4’. The averaged results for Pz record for both neurotics and stable persons for low and high tone stimuli of the Wavelet Power Spectra with real Morlet wavelet function are depicted in Fig. 2; those for complex Morlet wavelet function in Fig. 3 and the averaged S-transform Power Spectra in Fig. 4:

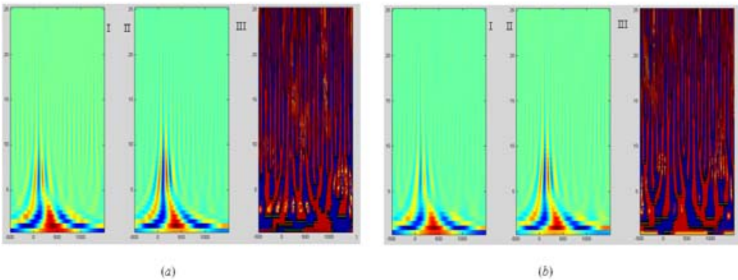

Fig. 2. Averaged Wavelet Power Spectra with real Morlet wavelet function for Pz record for high (*a*) and low (*b*) tones for neurotics (I) and stable (II) persons and Kruscal-Wallis statistical analysis (III)

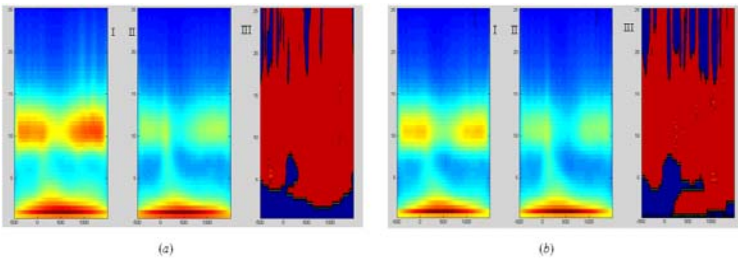

Fig. 3. Averaged Wavelet Power Spectra with complex Morlet wavelet function for Pz record for high (*a*) and low (*b*) tones for neurotics (I) and stable (II) persons and Kruscal-Wallis statistical analysis (III)

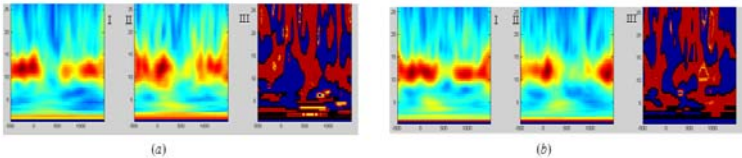

Fig. 4. Averaged S-transform Power Spectra for Pz record for high (*a*) and low (*b*) tones for neurotics (I) and stable (II) persons and Kruscal-Wallis statistical analysis (III)

6. DISCUSSION

Our initial analysis based on Fourier Power Spectra showed that in the time window between 0 and 800 [ms] after the stimulus onset the stable group is generating more theta power in the spectrum compared to neurotics. In the same time period the Fourier Power Spectra of neurotics is more prominent in the alpha II (10 - 12 Hz) frequency band. It stayed unclear if these differences are available for the entire time window or they are significant only in the certain moment. For that reason, by using Wavelet Power Spectra Analysis, which allows more accurate detection both in time and frequency domains, we have tried to locate the moment after the stimulation in which the EEG differences in ERP series between stable and neurotics are significantly different.

The wavelet analysis with real Morlet function didn't show reliable significant differences between both groups. In our case more profitable were both complex methods – the S-transform and the Continuous Wavelet Transform with complex Morlet function.

The analysis with complex Morlet showed that in the time interval between 200 - 300 ms after the low frequency stimulus the neurotics are generating significantly more prominent alpha spectral power compared to the stable persons. In the time period of 0 - 800 ms after the stimuli the stable persons are generating more theta spectral power compared to the neurotics notwithstanding that the differences are not significant.

Similar are the results of S-transform application. Here, again, the stable persons generated more prominent theta spectral power compared to the neurotics and the differences are significant in the time window between 300 - 400 ms. The neurotics generated more

prominent alpha power spectrum and the differences are significant in the time window 700 - 800 ms after the stimuli presentation.
So we can draw back a speculative conclusion that in cases of power spectra comparison of ERPs the use of complex functions for signal decomposition is more profitable. In the same time we must be careful because the places of significant differences can differ according to the type of the decomposing function.

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