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EEG Spectral Analysis in Serious Gaming: An Ad Hoc Experimental Application

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Summary: The application of serious gaming technology in different areas of human knowledge for learning is raising the question of quantitative measurement of the training process quality. In the present paper a pilot study of 10 healthy volunteers' EEG spectra is performed for ad hoc selected game events ('win' and 'lose') via continuous wavelet transform (real and complex) on the basis of the Morlet mother wavelet function and S-transformation. The results have shown a general decrease of the alpha rhythms power spectra frequencies for the 'lose' events and increase for the 'win' events. This fact corresponds to an opposite behaviour of the theta rhythm of the players for the same 'win' and 'lose' events. Additionally, the frequency changes in the alpha1 (8-10.5 Hz), alpha2 (10.5-13 Hz) and theta2 rhythms (6-8 Hz) were supposed to be a phenomena related to positive and negative emotions appearance in the EEG activity of the players regarding the selected 'win' and 'lose' states.

Keywords: EEG, Spectral analysis, Wavelet analysis, S-transformation, Serious gaming

1. INTRODUCTION

The huge variety of computer games and the development of the 'serious gaming' technology is growing their role in the educational process [11]. Nowadays, personal computers, game consoles (e.g. Xbox, PlayStation or GameCube) and the Internet have emerged different kind of solutions for single and multi-players games, starting from complete virtual worlds (e.g. Second Life), continuing with role games (e.g. World Warcraft) and ending with military tactical first-person shooters (e.g. Project I.G.I. - I'm Going In, Counter-Strike, Call of Duty or HALO 3, Virtual Battle Space 1&2).

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Generally, 'serious games' are games, associated with the development of computer games for educational purposes, in different areas of human knowledge, not just for fun and entertainment but for learning [7, 14]. What is also interesting about 'serious games' is their role in virtual simulations via Computer Assisted eXercises with different useful applications for training [14].

In general, the major disadvantage of nowadays human-in-the-loop simulations is the lack of measurement and analysis of the players' psycho-physiological indicators, i.e. a quantitative measurement of the training process quality. However, it is true that psycho-physiological studies on computer games have been carried out for the last decade [1].

Here it should be noted that the nature of emotions and behaviour of computer game players may be modelled and studied from a psycho-physiological perspective, with the help of special tests and measurements of physiological parameters such as: galvanic skin conductivity, heart rate, brain and muscle activities dynamics, respiration dynamics, biochemical body status, reaction times and other indicators of the human central and peripheral neural system [2-5, 8, 9, 12, 16, 17].

The aim of the present paper is to demonstrate an ad hoc experimental methodological approach for studying the spectral electrical brain activity (EEG) during selected representative events considering 'win' and 'lose' states and related to these emotions measured via EEG activity changes from a first-person-shooter type 'serious' computer game.

2. MATERIALS AND METHODS

Computer Game Setting

The computer game on focus is the Project I.G.I.: I'm Going In - a well-known tactical first-person shooter 3D virtual environment developed by Innerloop Studios® and released by Eidos Interactive®. It offers a realistic weaponry and tactical combat situations simulation [6].

The game was installed on a HP 6730s laptop machine with Intel Pentium Dual-Core Processor T4200, 3072 MB RAM, 320 GB SATA HDD, ATI Radeon HD 3430 video card with 256 MB dedicated video memory and with WXGA BrightView 15.4” screen.

Additional USB keyboard and mouse were added for players’ convenience during EEG recording. The activities of the gaming were additionally recorded with a BB FlashBack® screen capture program for event synchronization in the spectral analysis stage (see paragraph 3). An ad-hoc keyboard and mouse logger program for detecting the players’ activities (moving and shooting) and external 12 bit ADC EEG 1000 Hz sampling device synchronization was developed in Borland Delphi Enterprise® 2007 environment.

EEG Recording

We recorded 10 healthy young volunteers (age: 25-33 years, 8 men and 2 women, all right-handed) EEG (bandpass filtered between 0.3 - 70 Hz) from Fz, Cz, Pz, C3 and C4 records using Ag/AgCl ‘Nihon-Kohden’ electrodes (mounted on the player’s head with Ten20 conductive EEG paste) with reference to both processi mastoidei, according to the system 10-20 and sampling frequency f_s = 1000 Hz. The volunteers sat within a soundproof, electrically shielded chamber (Faradey cage).

During the EEG recording, the volunteers were only stimulated via the visual part of the I.G.I. game and the sounds were muted. The EEG data was written onto a hard drive in 5 trials with length of 2 minutes, repeating one and the same 10 sec episode selected from the game.

3. SPECTRAL ANALYSIS

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 the Fourier transform provides information on the dominant frequencies, wavelet analysis has the added value of providing time localization of the various frequency components.

The Continuous Wavelet Transform (CWT) is used to decompose a signal into wavelets, small oscillations that are well localized in time. As far as the Fourier transform decomposes a signal into infinite length sines and cosines, effectively losing all time-localization information, the CWT basic 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.

As the aim of the current pilot study is to explore ‘win’ and ‘lose’ states and related emotions measured via EEG activity changes, we have found suitable to use CWT and its modification in the form of S-transformation that corrects the phase skews.

For the present mathematical analysis we have used the raw recorded trials and Matlab® 6.5 environment. All trials that reached amplitude of more than ± 50 μV in the time interval of the recording were automatically rejected. The signal was further filtered firstly with a linear detrend procedure and then with a low-pass Chebyshev filter of third order with cutoff frequency of 70 Hz.

We computed the S-transform for each trial of our experimental series. The S-transform [13] is a type of time-frequency analysis that uses different window length depending on the analyzed frequency:

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

Further we analyzed the data with CWT, using the real and complex Morlet wavelet representation. Fig. 1 depicts the real and imaginary part of the Morlet wavelet function:

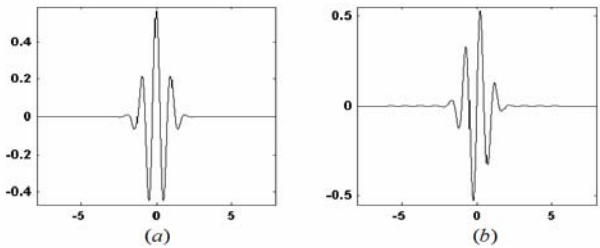


Fig. 1 Real (a) and Imaginary (b) parts of the Morlet wavelet function

The real Morlet wavelet function which we used is denoted by (2) and the complex one is denoted 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) depend 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 [10] 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 spectral analysis was performed for each two-minute trial and averaged for all 5 series of each volunteer separately and at the end averaged for all 10 volunteers who took participation in the pilot study.

Two basic states, 'win' and 'lose', were observed by means of spectral analysis related to the results of successful hit to a hostile enemy soldier, i.e. a 'win' state (see Fig. 2*a*) and a successful hit of a hostile enemy soldier to the player, i.e. a 'lose' state (see Fig. 2*b*).

(a) (b)

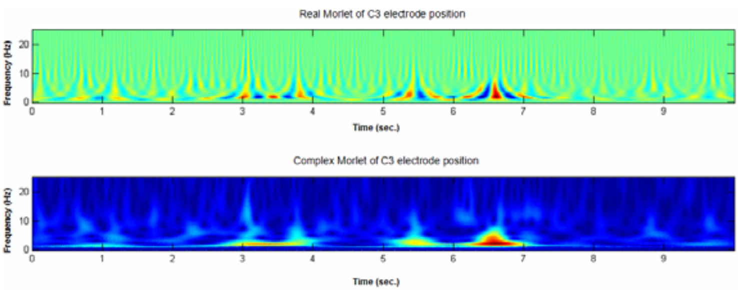
Fig. 2 The two basic states 'win' (a) and 'lose' (b) that were observed by means of spectral analysis related to the present study

4. RESULTS ANS DISCUSSION

We have conducted power spectrum analysis within real, complex Morlet wavelet function and S-transform power spectrum calculation for all 10 participants considering five leads: Fz, Cz, Pz, C3 and C4. The averaged results for C3, C4 records of the Wavelet Power Spectra with real and complex Morlet wavelet function are depicted in Fig. 3; the lateralized C3-C4 records in Fig. 4 and the S-transformation - in Fig. 5.

During computer games playing the human's EEG is reflecting a very complex sensory, cognitive and motor information processing. The main idea of this pilot study was to find those EEG frequency bands which are distinguished for selected moments of 'win' and 'lose' events and correspond to correct decisions and actions compared to mistakes and lethal situations.

Our significant findings from the spectral analysis depicted in Fig. 3, Fig. 4 and Fig. 5 are in the EEG alpha and theta frequency bands. The moments related to enemies' searching, successful shooting to enemies, without enemy hit to the player are related to enhanced alpha2 (10.5-13 Hz) oscillations. While, in the opposite, the moments of enemy successful shoots - to an enhanced alpha1 (8-10.5 Hz) oscillations.



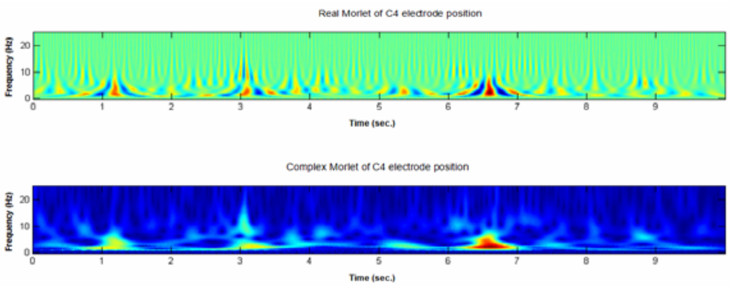


Fig. 3 Averaged Wavelet Power Spectra with real and complex Morlet wavelet function for C3 and C4 records

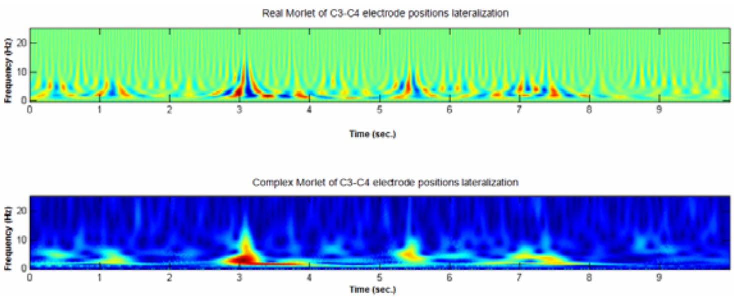


Fig. 4 Averaged Wavelet Power Spectra with real and complex Morlet wavelet function for lateralized C3-C4

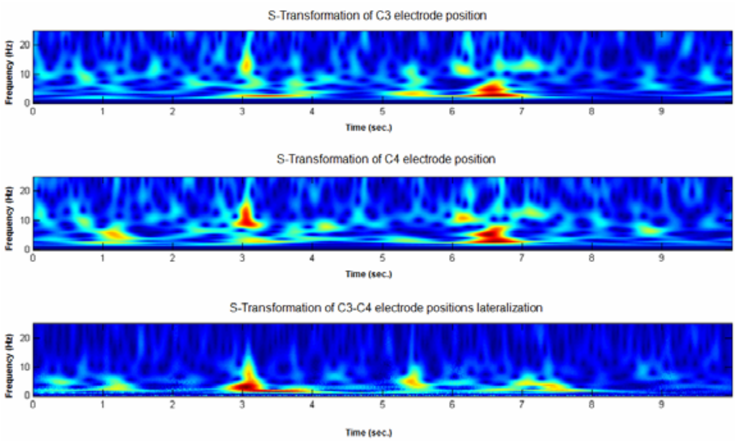


Fig. 5 Averaged S-transformation for C3, C4 and for lateralized C3-C4 records

Additionally, we have to note that the higher frequency oscillators of the theta2 frequency range (6-8 Hz), which is generally related to negative emotions could also be a reason for the spectrum enhancement close to the alpha2 frequency range due to its relation within negative emotions [15].

As far as the obtained results look interesting and reliable from an investigational point of view, the authors plan to implement them in a neurofeedback training for players' performance improvement measurement.

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