Brain activity: beta wave analysis of 2D and 3D serious games using EEG

M. HOSŤOVECKÝ AND B. BABUŠIAK

Abstract

Neuroscience and gaming are among the most rapidly increasing research areas. Today, researchers look for a way to develop a serious game, which would improve some chosen knowledge of participants at schools or work. Therefore, it is very necessary to have some feedback whether a serious game is going to improve chosen knowledge. One of the possibilities is to use a neurofeedback using electroencephalography (EEG). Brainwaves, especially beta waves (12Hz - 30Hz), are very important if we want to evaluate the effectiveness of game methodology. Beta waves are activated just when the participant is concentrated. The main goal of our research was to measure and confirm brain activity of beta waves when playing 3D and 2D serious games and compare them. In the last part of paper, we introduce some benefits and profits of using serious games and neurofeedback.

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General Terms: serious games, beta waves, EEG, neurofeedback
Additional Key Words and Phrases: human-computer interaction, education, learning, cognition

1. INTRODUCTION

The term game is known from our childhood as a source of knowledge and entertainment. Every person in his or her early childhood met with some form of the game (computer or non-computer games), whether parlour game or single player game. The game can be defined as an activity of an individual or a group and its course is determined by the rules of the game that are followed by the players to complete the game successfully. Rules of the game determine the game point, that is the way in which the player has to follow to become a winner, and, vice versa, they define the conditions under which the player loses the game. The game helps us to while away the time, have fun, and meet new people. Winning or losing the game also influences whether we are having fun by playing games or not. In most cases, victory means to defeat the opponent, that means to be better, which gives us more pleasure than a loss. On the other hand, when we play the game in order to develop our skills, it does not imply, because the player is able to learn from his or her mistakes regardless of the victory or loss. Ultimately, this means that it does not

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matter whether we won or not, we can say that we are winners because we learned something new.

During the last 15 years, we have witnessed an increasing number of computers games, which are focused on education. These games are called serious games (SG). Today, we have wide range of these games from those designed for healthcare to education and training, industry or army as well.

Serious Games are presented in a large area of knowledge. Michael proposes the following thematic classification: Military Games, Government Games, Educational Games, Corporate Games, Healthcare Games, Political and Religious Games. The very rich typology of Serious Games identified News Games, Advergames, Military Games, Exergames, Edugames, Datagames, etc. However, there are some studies classifying serious games according to specific criteria [1; 2].

In connection with serious games, there are many definitions today. The first formal definition of the concept would appear to have been introduced by Abt [3]. In his book, Abt presents simulations and games to improve education, both in and outside of the classroom. Nowadays, most recent definitions, such as those of Chen & Michael [1] and Zyda [4], appear to stem from Sawyer's influence. Although the general definition of "Serious Game" appears to be shared by many people, the domain boundaries of the Serious Games field are still subject to debate [5]. Chen & Michel defined SGs as: "games that do not have entertainment, enjoyment or fun as their primary purpose" [1]. This definition is in line with other authors who are interested in SG [6; 7; 8; 9; 10; 11; 12]. Another definitions says: "A serious game is a computer application whose initial intention is to combine with consistency, both serious aspects (serious) such as teaching, learning, communication or information, with playful springs from the video game" [13].

Last but not least, by playing serious games we develop our skills and abilities. There are games, which are focused on development of our skills or knowledge in a specific area or subject. After the rise in technological computer performance, serious games are becoming more attractive for pupils, students and employees as well. Most of these games and their designers also try to convey a particular message for players. Today, serious games can be multiplayer, favouring teambuilding and collaboration / cooperation in facing challenges and issues [14; 15; 16; 6]. An interesting future research direction might measure EEG during a cognitive activity oriented game, like longest traveling salesman game, and compare the convergence towards results with an approach based on artificial neural networks [17] or measure EEG during a cognitive activity web-based simulation [18].

2. SERIOUS GAMES & EEG

In last decades, we could see an increasing interest in Electroencephalography (EEG) in serious games. This measurement of brain waves becomes increasingly popular with game makers, psychologists as well as neurologists.

EEG is a non-invasive diagnostic method to measure electrical activity of the brain. It is a non-invasive method with electrodes placed along the scalp. The international 10-20 system of the electrode placement is shown in Fig. 1. Area of the cerebral cortex. This system was developed to ensure standardized reproducibility so that subject's studies could be compared over time and subjects could be compared to each other [19].

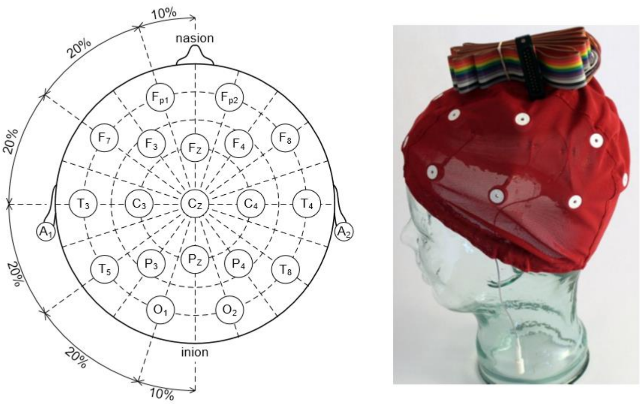

Fig. 1. The international 10-20 EEG system (left) and the EEG cap used in experiments

The EEG activity can be divided into bands by the frequency. The frequency bands are extracted from EEG signal using spectral method such as PSD, FFT or STFT. The main energy of EEG signal measured on the scalp falls in the range of 0.5 – 30 Hz. Four basic bands are recognized in this range:

- *delta* (0.5 - 4 Hz).

The delta brainwaves are slow, loud brainwaves (low frequency and deeply penetrating, like a drum beat). They are generated in deepest meditation and dreamless sleep. Delta waves suspend external awareness and are the source of empathy. Healing and regeneration are stimulated in this state, and that is why deep restorative sleep is so essential to the healing process [20; 21];

- *theta (4 – 8 Hz).*

The theta brainwaves occur most often in sleep but are also dominant in deep meditation. Theta is our gateway to learning, memory, and intuition. In theta, our senses are withdrawn from the external world and focused on signals originating from within. It is that twilight state which we normally only experience fleetingly as we wake or drift off to sleep. In theta we are in a dream; vivid imagery, intuition and information beyond our normal conscious awareness. It is where we hold our 'stuff', our fears, troubled history, and nightmares [20; 21];

- *alpha (8 – 12 Hz).*

The alpha activity is best seen in the posterior regions and is typical for relaxed and reflecting states of mind. It emerges with closing of the eyes;

- *beta (12 – 30 Hz).*

The beta activity can be divided into sub-bands: low beta waves (12 – 15 Hz), mid-range beta waves (15 - 20 Hz) and high beta waves (18 – 40 Hz). Mid-range beta activity is associated with increases in energy, anxiety, performance and concentration. The beta activity is most evident in frontal regions [22].

3. METHODOLOGY OF RESEARCH

When the cap channels were selected and the games were made, we needed to check out whether the neurofeedback system at the beta wave level works and whether beta waves will be activated in real time.

3.1. Purpose of the study

The aim of our research was to determine brain activity of respondents focused on beta waves of university students from two regions of Slovakia (Trnava, Žilina). After that, we construct three hypotheses, shown below.

These hypotheses were evaluated:

(1) *The beta waves will be confirmed in at least three quarters of all respondents during playing a serious game in 2D.*
(2) *The beta waves will be confirmed in at least three quarters of all respondents during playing a serious game in 3D.*
(3) *Higher frequency cycles of beta waves per second will be confirmed during playing a 3D serious game than during playing a 2D.*

3.2. Research instrument

We used the standard 10-20 EEG system consists of 19 electrodes (Fig. 1). We wanted to investigate brain activity over all possible scalp areas; therefore, all 19 electrodes were involved in the measurement. The EEG signal was measured by BIOPAC MP36 data acquisition system. The system features precise built-in universal amplifiers. It can record a wide range of physiological signals such as ECG, EMG, EEG and many more. There is a complication in number of measured channels; one Biopac MP36 is able to measure maximum of four channels. The combination of five Biopac systems is needed to measure 19 channels (Fig. 2). The start of EEG recording is synchronized between units by Sync input.

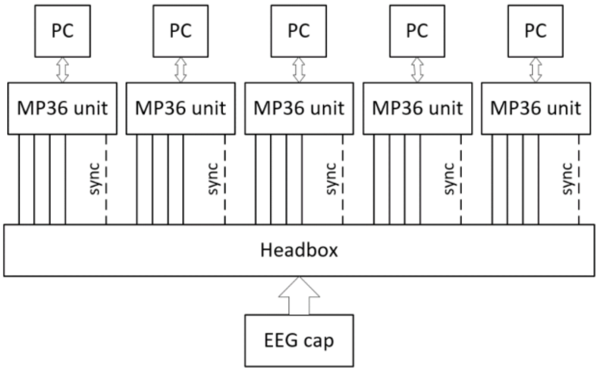

Fig. 2. Arrangement of 19-channeled EEG system

The EEG electrode cap is connected to the headbox. The headbox provides interconnection between the EEG cap and Biopac MP36 units. The synchronization button is placed on the headbox and ensures starting of acquisition at the same time for all connected units. An electrolytic gel is applied between electrode and scalp skin to achieve low impedance. The scalp was cleaned by isopropyl alcohol 70% in the area of electrodes placement. The impedance of each electrode was checked by BIOPAC acquisition system before measurement. The impedance between electrode and scalp was around 10 kΩ for all electrodes and measured subjects.

The video is recorded simultaneously with EEG on the first PC. The video recording is started before EEG acquisition, so the start of EEG measurement is seen in the video and the synchronization can be reliably performed. The synchronization between EEG and the video helps identify the reason of EEG activity change during the gameplay. Moreover, the Biopac software allows adding time stamps into EEG record to mark some important events during experiment.

Measured EEG data is processed and analyzed in MATLAB programming language. The data from each PC is connected together, so we get 19 channelled EEG. The EEG signal is often analyzed in frequency domain. We used two spectral methods for data analysis: Power Spectral Density and Short-Time Fourier Transform.

Power Spectral Density (PSD) using Welch estimation is defined as:

$$PSD = \frac{1}{K}\sum_{i=0}^{K-1} P_i\left(k\right), \quad (1)$$

where K – number of segments,

Pi – partial periodogram.

The partial periodogram Pi is defined as:

$$P_i\left(k\right) = \frac{1}{L}\left|\sum_{n=0}^{L-1} x\left(n\right) e^{-j\frac{2\pi}{L}kn}\right|^2, \quad (2)$$

where L - length of the segment,

x(n) – discrete signal in time domain with length of L.

Input sequence of signal x(n) is usually weighted with some type of a window. Each segment is windowed with a Hamming window in our study.

Short-Time Fourier Transform (STFT) is used to determine the frequency spectrum of signal segments as it changes over time. The STFT divides a longer time signal into shorter segments of equal length and then compute the Fourier transform separately on each segment. Spectrogram is a graphical interpretation of STFT. The spectrogram plots the changing spectra as a function of time.

3.3. Participants

Participants were 24 university students of informatics (14 males and 10 females) with the mean age of 22.9 years (SE = 0.06, range: 21– 24 years). The research sample consisted of two university students from two regions of Slovakia, i.e. Zilina (University of Zilina), Trnava (University of Ss. Cyril and Methodius). Students participated in the research on a voluntary basis, i.e. they could decide for themselves whether they will take part or not. Respondents were addressed by the school's management, which received an accompanying letter clarifying the research and its purpose as well as the internet link to an electronic application form. The alternative way of addressing them was a social network Facebook.

3.4. Results of research

The main goals of our interest were:

- to create a serious game focused on English prepositions of place for pupils of second level of primary schools.

- to measure- beta wave activity of respondents during playing a serious games (same games focused on English prepositions, the only difference: one game is 2D and second one in 3D. All other attributes of games were identical: colour, characters, walls, objects, questions etc.).

Before carrying out the research, it was necessary to prepare the classroom for measurement. It means we turned off all devices inside labs (computers, servers, printers etc.) which could disturb the measurement of beta waves.

At the beginning of the experiment, respondents are instructed to close his/her eyes for at least 30 seconds. After that, the respondent stay in the "rest state" for approx. 2 minutes and then they start to play a game. The rest state is a state before gaming when the participant does not concentrate on anything special. Then the game starts and the participant is in the state of concentration to gameplay. The power spectral densities (PSD) of the respondent 1 for mentioned situations are shown in Fig. 3. The beta activity is best seen in the frontal regions, that is why the signal from F3 electrode was chosen (see Fig. 1).

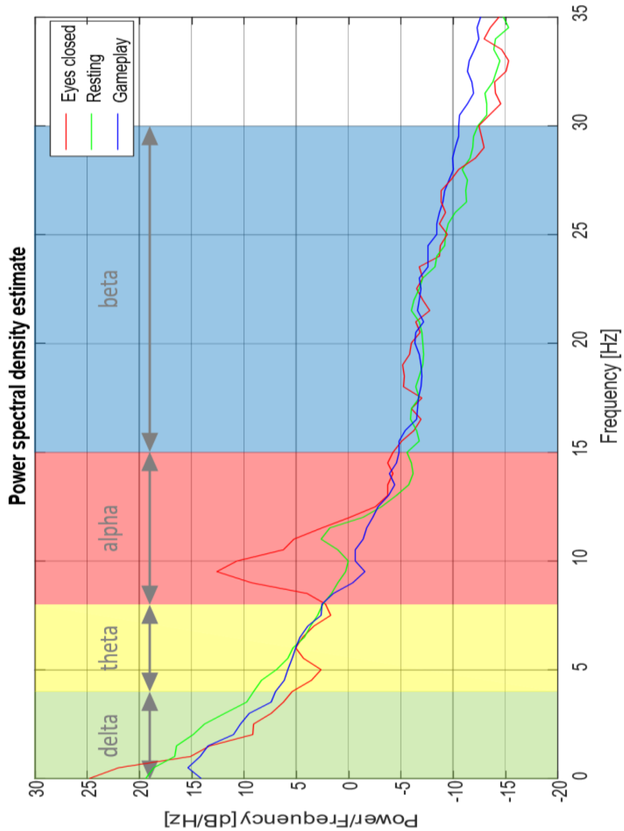

Fig. 3. Arrangement of 19-channeled EEG system

The alpha activity raised up during eyes closed. This fact corresponds with the description of alpha activity. Furthermore, we assumed that the beta activity would rise up after the game starts, but this assumption was not right, as can be seen in Fig. 3. The power of beta activity is approximately the same as in the previous situations – eyes closed and a rest state. The highest difference in situations is expressed in delta and, in part, theta range.

The STFT provides information about brain activity change over time. The spectrogram of the same signal as shown in Fig. 3 is displayed in Fig. 4. The time interval between time stamps marked as “1” and “2” belongs to the eyes closed situation. The power of alpha activity, best seen at 10 Hz, is significantly higher in comparison with the other intervals. The following interval, the resting state, is between stamps “2” and “first 3”. In this interval there is still occurrence of alpha activity and higher power of delta and theta activity. The game starts at stamp “3” and ends at stamp “4”. During the gameplay, the alpha activity is getting low as well as the delta activity. The time stamp “4” marks the end of the game and transition of mind to the resting state. The spectrogram of the “resting state 2” after the gameplay is different when compared to the “resting state 1” after relaxing with the eyes closed. There is a rest of alpha activity in the “resting state 1” from the previous relaxed state.

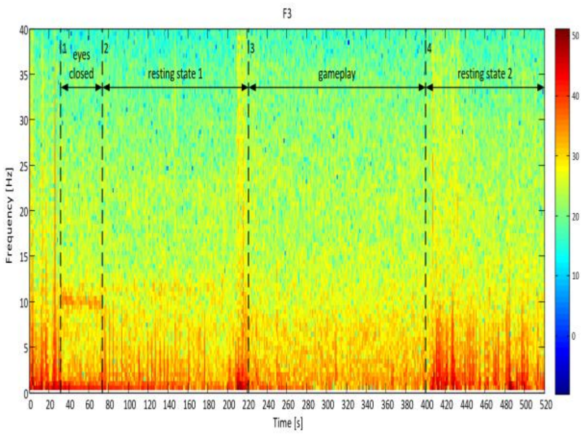

Fig. 4. Spectrogram of channel F4 (Respondent 1).

Based on the spectrogram in Fig. 4, we can constitute that each state has a characteristic pattern of spectrogram. To support this statement, we computed an average brain activity for each state. The brain activity is divided into four frequency bands - delta, theta, alpha, and mid-range beta (Fig. 5).

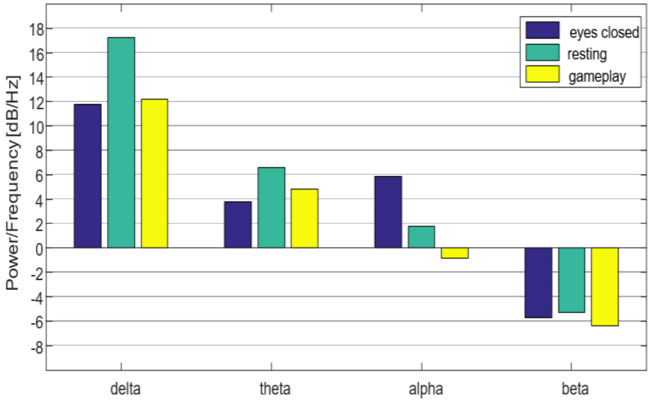

Fig. 5. Brain activities during different states of respondent 1

From Fig. 5, we can see that the delta and theta activities during the gameplay are considerably lower than during resting, but slightly higher than during relaxed state with the eyes closed. This trend is common for all investigated respondents as seen from the next figure. The power of the brain activities is not directly comparable within respondents because of different skin-electrode impedance and the brain physiology among individuals. Therefore, the power of the brain activity is normalized to interval <-1;1>. The example of the normalized brain activities for six chosen respondents is shown in Fig. 6. The trend of the brain activities can be studied across the respondents. The alpha activity should be the highest during the eyes closed interval, but it is not because, as some of the respondents said, they were not able to relax. The Mid-range beta activity is associated with busy or anxious thinking and active concentration. Therefore, we supposed that mid-beta activity will be the highest during the gameplay but this assumption was not right as it is seen from Fig. 6. The beta activity has the highest frequency (12 – 30 Hz), but the lowest amplitude; therefore, the beta is most attenuated by the crane and surrounding tissues. On the other hand, the change of delta and theta activity provides reliable information about the various states.

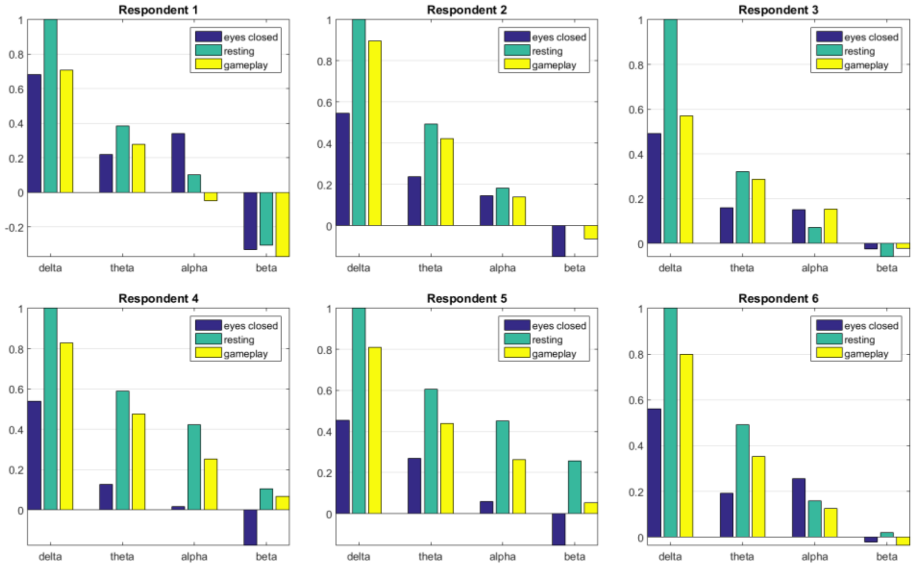

Fig. 6. Brain activities during different states across six representative respondents

We included 24 respondents into our experiment. The box plot of collected data set represents median, range, variability or spread of measured data. Another future statistical analysis could use clustering of features to agglomerate narrow-band spectral powers of the EEG based on their similarities. [23] We aimed to statistics about power of the delta and theta activity during different states (Fig. 7).

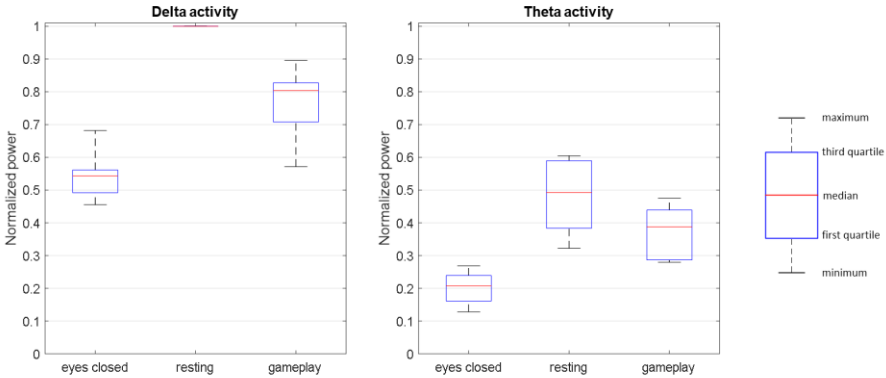

Fig. 7. Box plots of delta and theta activity during different states

Based on Fig. 7, we can declare that power of delta and theta activity during gaming is lower than during the resting and higher than during the relaxed state with the eyes closed.

DISCUSSION

By placing the game into the real environment for testing by real users (pupils of the second level of primary schools), the logical errors were detected that we were not able to see as developers because of the lack of outer perspective. Users filled in a questionnaire in which they answered questions about their views on the various elements of the game. Using their responses, we investigated the shortcomings; their removal should improve the overall quality of the game. The problems encountered were mainly of logical nature, but there were some shortcomings related to the graphic and visual aesthetics of scenes and the way of character commanding.

In the base of the results hypotheses no. 1 a no. 2 were received and confirmed. Hypothesis no. 3 was not received and not confirmed.

We assumed that the beta waves will rise up after the game starts in comparison with the resting state. The beta activity is associated with anxiety and concentration, which are needed for a game. This assumption was not right as it is seen in figures Fig. 3 - Fig. 6. The change of beta activity is dependent on the place of EEG measurement across individuals and beta waves are highest at the start of concentration and then they fluctuate over time [24]. In other paper [25], the concentration is determined from alpha rhythm due to its significant responses to mental stress. The alpha activity is lower under stress task in all channels [25]. This statement is true for most of the respondents but not for all of them in our case (respondent 3 in Fig. 6). In our experiments (24 subjects), we observed that delta and theta waves during the gameplay were lower than during resting state across all investigated subjects (Fig. 7). Moreover, delta and theta waves during gameplay were higher in comparison with resting state with the eyes closed (Fig. 7).

According to our experiments, the magnitude of beta waves is not a reliable indicator of concentration when playing 3D and 2D serious games. On the other hand, the change of delta and theta activity seems to be a good indicator of concentration on a serious game.

4. CONCLUSION

This paper proposed a methodology for brain activity – neurofeedback of serious games. In the theoretical part, we dealt with the characteristics of computer games, especially serious games. We developed a computer game (a serious game) for fixed English prepositions in 2D and same serious game in 3D. We defined the process of measurement of brain activity at the level of beta waves, described methodology and participants as well as standardized EEG system. In statistical analysis, we described the selected results of respondents when we see the beta activity has the highest frequency but the lowest amplitude. The results analysis has shown no statistical differences between 2D and 3D serious games focused on English prepositions.

Future research will focus on a methodology of neurofeedback that enables experts to describe differences in brain activity in 3D serious games between men and women.

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