Towards a Quantification of EEG Brain Activity in the Self-Pacing Regime

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Abstract

The processing of motor, sensory and cognitive information by the brain can result in changes in the dynamics of the EEG in the form of Event Related Desynchronization (ERD) or Event Related Synchronization (ERS). The first one concern a decrease in the amplitude of a rhythmic activity, when there is an increase in excitability against cortical activation, while the second corresponds to an increase in amplitude of a rhythmic activity, resulting from a deactivation of this same cortical area. The analysis of these two phenomena in specific frequency bands - alpha (8 - 13 Hz) and beta (14 - 30 Hz) - allows the understanding of the cerebral activity. This study focuses on the quantification of cerebral activity by determining the ERD and ERS on the referred band, induced by self-paced movements, by using EEGLAB and MATLAB tools. The results indicate that the amplitudes of the resting brain signals are greater than the amplitudes during the performance of an activity, which indicates that a greater desynchronization of the signal is accompanied by a decrease in the amplitude of the same. As a conclusion, the cerebral activity varies in terms of synchronization and desynchronization among certain frequency bands in several zones, according to the tasks performed.

Keywords: Electroencephalogram (EEG); Event Related Desynchronization (ERD); Event Related Synchronization (ERS); alfa band (8-13 Hz); beta band (14-30 Hz); Self-pacing.

1. Introduction

The electroencephalogram (EEG) records the amplified electrical activity coming from the brain's nerve cells - the neurons. Through the placement of electrodes on the scalp, it is possible to obtain a sinusoidal signal, which is generated by the electrical fields that are the basis of the generation of the EEG [1].

It is known that the characteristics of the waves recorded in the EEG change according to the physiological condition of the individual and is different on waking, sleeping, dreaming, etc., with changes on amplitude and frequency. The EEG common frequencies bands are alpha (8-13 Hz), beta (14-30 Hz), theta (4-7.5 Hz) or delta (0.1-3.5 Hz) [2, 3]. These frequency bands are more evident in specific brain zones, at rest or depending on the stimuli to which the brain is subjected. These stimuli / events produce responses of different neuronal structures that alter EEG dynamics. Such changes can be classified as Event Related Desynchronization (ERD) and Event Related Synchronization (ERS) [3,4]. The first relates to a decrease in the amplitude of a rhythmic activity, when there is an increase in excitability against cortical activation, while the second corresponds to an increase in the amplitude of a rhythmic activity, resulting from a deactivation of the same cortical area [3,4].

According to the previous explanation, there are then three different states of cortical processing [3]:

1. Neutral or resting state, with no specific processing of sensory, motor or cognitive information;

2. Active state with high information processing in a specific system and increased excitability of cortical neurons. This state is characterized by ERD;

3. Deactivated state, with reduced information processing in a specific system and decreased cortical excitability. This state is characterized by ERS in the lower alpha and beta bands.

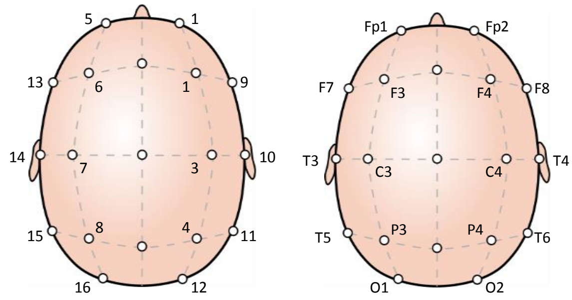
Since ERD/ERS is a response of different neuronal structures, the objective of this study is to quantify this response within specific frequency bands - alpha and beta - in individuals, when placed in self-pacing activity. This term refers to a self-managed activity whose stimuli are triggered by the individual, in a rhythm of his own that do not originate from the outside (for example, counting 5 seconds and, at the end of each time interval, lifting a finger) [5]. One of the aims of this type of study is, for example, to decode voluntary movement before the action towards implementing practical brain-machine interface (BMI) technology for intuitive neuroprosthesis [6].

After ERD/ERS quantification in 3 different participants, the purpose was to perform a study of the diverse values obtained and to define if they can be used as an individual measure of the normality of the cerebral activity, analysing the variations in terms of locations of the scalp.

2. Materials and Methods

Three healthy individuals, two females, one male, with similar age (young adults – 20-22 years old), highly educated, and not using pharmacological treatments, were studied on a voluntary base. For the acquisition of the EEG signals we studied all individuals, placing electrodes on the scalp surface according to the10-20 International System [3]. In this study, only 16 electrodes were placed in the right and left hemispheres, as shown in figure 1 a) and b). This number of electrodes was sufficient to capture information from the various zones of the scalp and to reduce the interference between the signals of neighbouring channels. Since the electric potential is a relative magnitude, it was necessary to use a reference, given by the sum of the electrodes electrical signals acquired in each channel and divided by the total number of channels (average). In addition to the electrodes placed on the scalp, another three were placed: one in the extensor/flexor of the right hand, one in the left hand extensor/flexor and another on the chest to record the ECG.

The experimental procedure comprises two parts: one at rest and another of self-pacing. First, the signal was recorded with the eyes open for two minutes, followed by acquisition with eyes closed for two minutes. After, we ask the individual to open the eyes and close three times to see the artefacts. In the second part, the participant, in waking state, counts for five seconds and then rise his right hand. This protocol was repeated for up to five minutes and, when finished, the individual is asked to repeat the same procedure for the left hand.



a) *b)*

Figure 1. *Positioning of the electrodes extracted from EEGLAB loaded data: a) by index; b) by name.*

The acquisition of the signals was done through the Brain Wave II EEG equipment, that works with BWAnalysis software [7]. This software, running in a computer with Windows operating system and using a 300 Hz sampling frequency, exports the data to the edf. file format [8] that, posteriorly, are loaded and worked in EEGLAB [9] and MATLAB [10]. With the signals loaded, the software EEGLAB allows to perform a graphical analysis while MATLAB can run signal processing algorithms with the multi-channel numerical data.

The ERD calculation was performed with MATLAB according to the classical method, which consists in the following sequence of steps [2]:

1. Filter the signal with a bandpass filter referring to the frequency range to be studied;

2. Raise the signal squared to get its energy;

3. Average the amplitudes for each sample in all the tests;

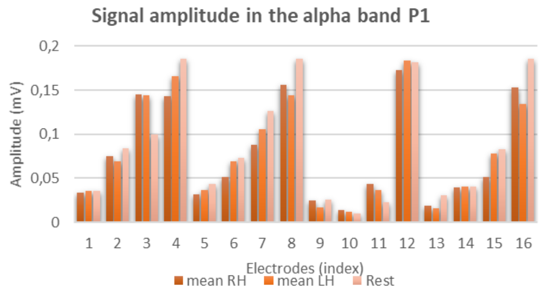
4. Subtract for each sample the mean of the sum of all amplitudes of the signal;

5. Add the amplitudes of all samples, within each test, and divide by the total number of samples;

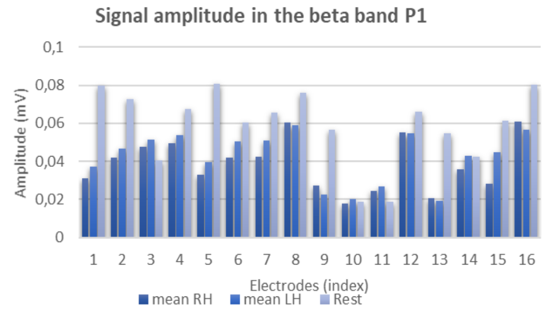
6. Calculate the ERD, which is given by: ERD% = ((A-R) / R) x100, where A is the calculated power in the analysis interval and R is the bandwidth in all assays.

3. Results

In MATLAB, the signal from each electrode was filtered according to the frequency band of interest and the mean amplitudes of each were calculated through the procedure previously explained. These amplitudes were then compared with the basal activity (at rest) of the participant, in order to observe their evolution before a situation of brain activity. The graphs 1 and 2 illustrate the comparison between the amplitude of each channel at rest and the amplitude of each active channel, in alpha band and in beta band, respectively, for the participant 1.



Graphic 1. Comparison between the signal amplitudes at rest condition and during activity in the right hand (RH) and left (LH) movement situations, in the alpha frequency band, for the participant 1 (P1).



Graphic 2. Comparison between the signal amplitudes at rest condition and during activity in the right hand (RH) and left (LH) movement situation, in the beta frequency band, for the participant 1 (P1).

According to the previous graphs, it is observed that it is an amplitude of rest and greater in almost all others, to the amplitudes recorded in situations of activity. These data indicate that a desynchronization activity is accompanied by a decrease in signal amplitude, as explained in the introduction [2,6]. Although the trend observed in the charts is in accordance with the literature, there are some channels that register an amplitude increase. This relates to the fact, in different locations, in real time, a synchronization is accompanied by an increase in amplitude and indicates a reduction without information processing.

Index	ERD P1 (%)	ERD P2 (%)	ERD P3 (%)
1	-99,5859	-99,5820	-99,0842
2	-98,0215	-98,0087	-99,8129
3	-92,7123	-92,9783	-98,8494
4	-93,4838	-93,2125	-95,5767
5	**-99,5988**	-99,6145	**-99,9881**
6	-99,1365	-99,0864	-99,7644
7	-97,5036	-97,4459	-99,1970
8	-92,3399	-91,7575	-93,8982
9	**-99,7930**	**-99,7947**	**-99,9812**
10	**-99,9282**	**-99,9290**	**-99,9427**
11	-99,3325	-99,3155	-97,6271
12	-90,3750	-90,5365	-96,9397
13	**-99,8638**	**-99,8680**	**-99,9895**
14	-99,4664	-99,4120	-99,8795
15	-99,0910	-99,0734	-99,0050
16	-92,3850	-91,7960	-96,4430

Table 1. Desynchronization values (in percentage) associated with each electrode, in the right hand movement situation, analysed in the alpha frequency band, for the three participants (P1, P2 and P3).

Index	ERD P1 (%)	ERD P2 (%)	ERD P3 (%)
1	**-99,6777**	**-99,6191**	**-99,9830**
2	-99,4183	-99,4043	-99,8365
3	-99,2072	-99,2196	-99,5729
4	-99,1752	-99,1779	-99,2399
5	-99,6312	-99,5997	**-99,9739**
6	-99,3410	-99,3700	-99,6935
7	-99,3552	-99,3516	-99,7165
8	-98,8607	-98,8217	-99,3456
9	-99,5988	-99,6058	**-99,9670**
10	-99,5045	-99,5827	-99,8871
11	**-99,7294**	**-99,7237**	-99,2458
12	-98,9947	-98,9879	-99,3319
13	**-99,7480**	**-99,7301**	**-99,9791**
14	-99,4771	-99,4753	-99,5283
15	**-99,7212**	**-99,699**	-99,2646
16	-98,8066	-98,8039	-99,6833

Table 2. Desynchronization values (in percentage %) associated with each electrode, in the right hand movement situation, analysed in the beta frequency band, for the three participants (P1, P2 and P3).

The amplitudes observed previously suggest that, in fact, during the activities a signal synchronization of the electrodes occurred. In order to quantify this activity (DRE), calculations were performed in MATLAB not only with the purpose of recording the desynchronization values, but also with the objective of comparing them in the different frequency bands.

Regarding the frequency bands, as we have seen, it is known that the alpha band desynchronization is more evident in the posterior zones and in the beta band, in the lateral and anterior zones of the scalp. However, according to the results of table 1, it is possible to observe that the higher values of desynchronization (highlighted in black), correspond to anterior zones of the scalp, so it was expected that these appeared in the posterior part. It can be explained by the role of such zones on the processing of the mental activity. In table 2, the highlighted values correspond to the desynchronization of the signals of the electrodes positioned on the lateral and anterior parts of the scalp, which is in conformity with the expected one. However, the participant 3 (P3) was the one that showed a better result, and the higher percentages appear in electrodes in the posterior zone, which is characterized by the appearance of frequencies of the beta band.

a)

b)

c)

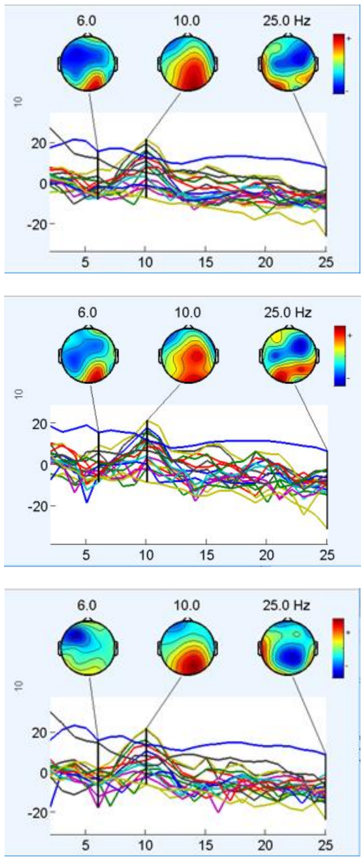
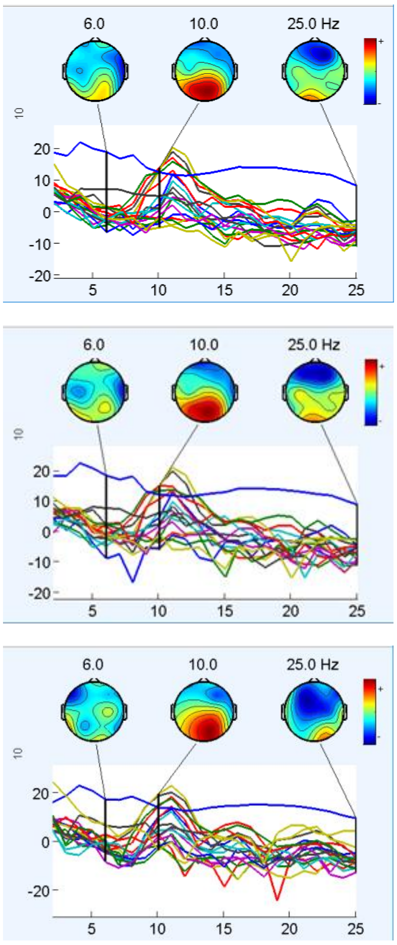


Figure 2. *Spectral maps related to the activity resulting from a stimulus with the right hand, for the participant 1: a) in the total time of the stimulus; b) before the stimulus; b) after the stimulus.*



a)

b)

c)

Figure 3. *Spectral maps related to the activity of a left-hand stimulus, for the participant 1: a) in the total time of the stimulus; b) before the stimulus; c) after the stimulus.*

After the analysis of the desynchronization values, it is also important to know what happens before and after the stimulus, in terms of signal power and amplitude. For this study, the signs were cut in the EEGLAB and spectral maps were elaborated for each participant, however, only the results of the participant 1 will be exposed here, due to the extension of data.

In figures 2 and 3 it is possible to observe that the alpha band frequencies are more prominent in the posterior region of the scalp along the right and left hand movements action.

In figure 2 c), it is clearly noticed that a greater spectral power of the scalp is observed tending more towards the left hemisphere, mainly related to an activity of the right-hand. On the other hand, in figure 3 c), it is observed that the higher power was more evident in the right side, which is related to an activity of the left-hand.

4. Conclusion

In this study, all the methods of processing EEG signals were performed with the purpose of quantifying the brain responses to stimuli. According to the literature used, it is known that the response of brain activity changes depending on the type of stimulus to which the brain is submitted and depending on the brain areas, that is, the calculation of the signal varies according to a task. The obtained results are in conformity with this assertion because, for the movement situation of the right hand and the left hand, the brain activations, in terms of power, frequency and amplitude, have changed.

The results showed that the amplitude of the resting signal was greater than that one reported during the execution of a task, when the amplitude decrease. This was related to an increase in the desynchronization. For future work and for obtaining more reliable results, it would be important to analyze the signs of more information, with a larger sample, as conclusions are more accurate and are more likely to approach the expected fundamentals

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