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Analysis of Event Related Potentials of Motor Imagery Signals

Leonardo Gongora, Dario Amaya and Olga Ramos
Virtual Applications Group (GAV), Nueva Granada Military University (UMNG), Bogota, Colombia

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Corresponding Author:
Leonardo Gongora
Virtual Applications Group (GAV), Nueva Granada Military University (UMNG), Bogota, Colombia

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Abstract: The analysis of EEG signals is considered as the starter point of the development of human-computer interfaces. In this work are described the acquisition and processing phases of a set of EEG signals that were acquired when a Motor Imagery (MI) test was performed by a subject. The signals were acquired using a paradigm that was designed according to the characteristics of the analyzed process. As analysis method, the Event Related Potential (ERP) approach was used. As result of this methodology, strong relationships between some motor cortex areas and the MI process were found.

INTRODUCTION

Motor Imagery (MI) can be defined as the mental representation of a motor action without physical movement. According to the above, MI processes are mental simulations of motor actions; that is why they are called as imaginative processes (Cengiz and Boran, 2016).

The applications of motor imagery vary between medical and engineering approaches. Medical analysis has demonstrated that under specific conditions that could be set and controlled within tests design, is possible to improve the execution of repetitive movements when MI is applied as mental exercise. Such improvement could be applied to sport activities and rehabilitation for patients with physical impairments (Kranczioch *et al*., 2014).

MI applied as mental practice exercise for rehabilitation procedures, has gained a lot of interest during the last years. As an example by Malouin and Richards (2013) are shown some applications of MI for the rehabilitation of motor functions as well as possible methods for the implementations of such method to obtain satisfactory results. In this work there are shown the approaches for the treatment of neurological conditions like Parkinson disease and injuries on the spinal cord. This work demonstrate the applicability of MI in the treatment of severe motor diseases.

Other works focused on the analysis of the actual neurologic processes involved in MI, show the great variety of applications within the Human-Computer Interaction (HCI) field using Brain-Computer Interfaces (BCI) (Tan and Nijholt, 2010). Classification tasks between two different kind of mental states are usually implemented.

Pfurtscheller *et al*. (1997, 1999) the stages of acquirement, data rejection, processing and classification of motor imagery for the left and right movements for the left and right arms respectively of a defined population of subject are shown. The experimental design of the paradigm for acquisition and classification tasks is implemented jointly with Common Spatial Patterns (CSP) show recognition indices above 98%.

Recent works as the one shown by Marzoli *et al*. (2013) show the relations between the brain processes that involve the movement of the dominant hand of a subject while the imagery action of other subject is performed. This work shows the related characteristics between to apparently different cognitive processes. On one side, the imagination of a self-movement and on the other the imagination of other person performing the same action. The works explained above, show the great potential of MI in motor rehabilitation and the development of user interfaces.

Motor Imagery is a mental process that can be characterized by analyzing the EEG signals acquired when it is performed. EEG signals represent the electric potential variation that is generated though the scalp as result of neurological processes. There exist many methods for analysis of such signals, like temporal based methodologies, statistical and spectral representation, time-frequency decomposition, among others (Motamedi-Fakhr *et al*., 2014).

As analysis method, in this work is used the representation of the signal variations over time using Event Related Potentials (ERP) which can represent and register the neural activity in spatial terms using an electrode location system that is dependent of the EEG acquisition system.

Applications of ERP-analysis in mental processes which are related to activities like listening of music, show the advantages of this technique which gives a description of the involved areas of the brain of the listening state (Poikonen *et al*., 2016). In this research, the relationship between the peak magnitudes of the potentials and the time when those occur are integrated to generate the characteristics ERP diagrams which provide the location in the brain where is generated a mayor accumulation of potentials, when the Motor Imagery process is held.

According to the above characteristics of the ERP diagrams, the inclusion of Brain-Computer Interfaces was proposed for the experimental design of the methodology in this approach. According to this, the EMOTIV Epoc+ BCI system, was chosen for the high-quality signals this device can acquire with enough temporal-spatial resolution relation. In the present document are described the acquirement, processing and analysis of the EEG signals when MI is performed.

MATERIALS AND METHODS

Motor imagery data acquisition: EEG data analysis trough ERP when Motor Imagery processes are performed, allows to find the brain areas with more neural activity. Such analysis help to characterize the neurological processes and serve as a basis for developing further recognition and classification phases which could be applied in BCI approaches. In this research is presented the ERP analysis of EEG signals for Motor Imagery when the movement of the right arm is performed.

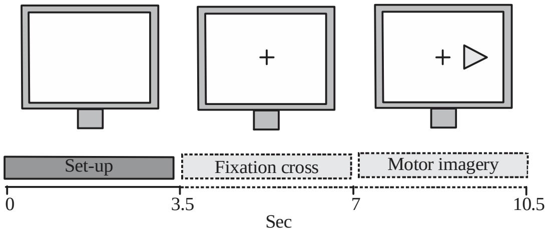

Fig. 1: Paradigm description for right motor imagery

Experiment description: This approach was defined as a user-independent analysis. According to this, a male 22 years old voluntary participated as the subject of analysis. The subject was right-handed and healthy without any physical or psychological abnormality. The subject participated voluntarily and the experimental phase was initiated after the participant signed an informed consent.

For the EEG acquisition, the participant was trained to use the acquisition system and was instructed about the test protocol. After the instruction, the subject was asked to remain in a “relaxation-state” in front of a monitor that was located 80 cm approximately. The monitor was used to display some reference marks that indicated the user the start and end times of the imagery task, for each of the samples. Figure 1 depicts the paradigm acquisition procedure.

Figure 1 shows the experimental paradigm for acquisition of the MI signals. Each session started with a “dead-time” for system set up; in this period, the monitor was in blank state and lasted 4.5 sec, also it was expected that in this time the subject got prepared for the beginning of the test. Each signal sample period (labeled as trial) was started with the presentation of a cross symbol at the center of the screen which indicated to the subject that the MI process was going to initiate. After 3.5 sec of the cross legend fixation, an arrow appeared pointing to the relative east of the monitor, this indicated the beginning of the imagination task by the subject and lasted 3.5 sec.

The fixation cross and MI periods were continuously repeated to reach the number of signals per session; which for the experiment was of ten signals. The full acquisition consisted of ten sessions which gave as result the acquisition of 100 Motor Imagery signals.

EEG data acquisition: The use of wearable devices for the measurement and cquisition of EEG signals, has been usual during the last years ecause of the high quality characteristics and features these ind of devices offer, integrating high technology resources at ow cost and high operation reliability which is comparable to he performance of specialized systems for EEG acquirement (Martinez-Leon *et al*., 2016). The system used in this application is wearable device and s known commercially as the EMOTIV Epoc+ BCI equipment. he Epoc+BCI system developed by EMOTIV Inc. is a evice for electroencephalographic signals acquisition, it has 14 hannels which are integrated in a headset. The sensors of he Epoc+system are located using the international location ystem 10-20.

Figure 2 shows the spatial distribution of the EMOTIV Epoc+electrodes over the scalp. The names associated to each electrode correspond to the 10-20 location system definition which establishes the relative positions of each channel according to the morphological characteristics of the skull. Similarly each electrode is related to specific brain areas and functions (known as Broadmann areas) and are involved in the neurological processes for cognitive, sensorial and/or motor responses.

The sampling method of the Epoc+system is defined as sequential and works with a default resolution of 14 bits (configurable at 16 bits) and has a sample frequency of 128 Hz which can be configured at 256 Hz. With those characteristics are guaranteed the high temporal resolution (for common cortical processes) with enough spatial resolution achieved through the channel distributions (Tan and Nijholt, 2010). The registered data are sent wirelessly to a computer system by Bluetooth 4.0 technology. With this it is possible to visualize and store in real time the EEG signals.

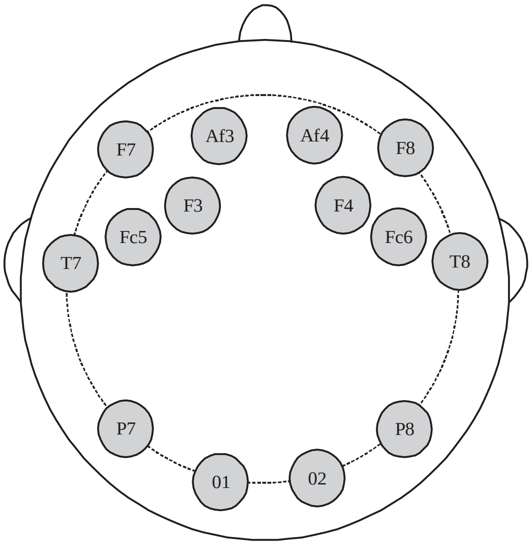

Fig. 2: Electrode placement for the EMOTIV Epoc+

Data processing: The motor imagery process was measured through the EEG signals acquired using the extraction paradigm shown and explained from Fig. 1. The 14 EEG signals were stored for further processing using the Software Development Kit of the Epoc+system. The set of 100 trials were acquired at a sample frequency (f_s) of 128 Hz during a sample time (t) of 3.5 sec which derived in the acquisition of vectors of 448 data length per signal. Each vector represented the discrete sequence of the waveforms acquired by each channel.

Each trial was conformed of 14 signals of length of 448 data and was stored as a data arrangement that contains information of the motor imagery process performed by the subject during the 3.5 sec according to the paradigm. From such process, a container matrix of dimensions 14×44800 was obtained for the 100 trials. That matrix was processed using the open source environment for electrophysiological signal processing: EEGLAB (Delorme and Makeig 2004) with was used for obtaining the characteristic ERP for the 100 trials arrangement.

ERP calculation: Event Related Potentials (ERPs) are patterns that are associated to voltage variations within the EEG signals. These could represent changes derived from the appearance of sensorial, motor and/or cognitive stimulus on the brain (Landa *et al*., 2014). High peaks in the ERP representation could appear due to the accumulation of action-potentials in specific time intervals. Such over action-potentials could be a previous response to voluntary movements or events produced by neural activity of a person. That is why ERPs serve as analysis tools in relation to repetitive neurological processes like MI in this case.

The Event Related Potentials can be described in three dimensions. In the neural activity dimension known as Amplitude; the stimulus response or Latency and the temporal-spatial response in terms of voltage over the brain cortex, also called temporal distribution (Sanei and Chambers, 2007). According to this, the EEG analysis from the ERP methodology gives a point of view that relates brain areas from the spatial resolution reached by the acquisition system and the times when the signal changes occur. In this way, the brain activity can be analyzed as a series of graphs that involve time, potential and spatial distribution variables; as shown in Fig. 3.

Figure 3 shows the amplitude representation of the EEG signals in relation to the neural activity and location in brain areas. As can be observed, the variation gradient coefficient is color coded and it is used to determine the according to the spatial distribution on the brain, obtained by the BCI system channels. EEG signal classification from the ERP, can be divided in two types; first, the

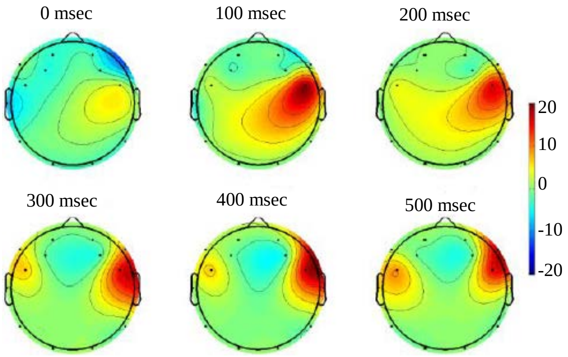

Fig. 3: Event Related Potentials representation

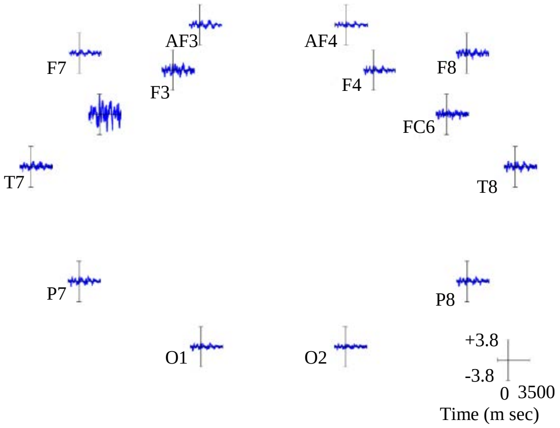

Fig. 4: ERP in rectangular array for MI signals

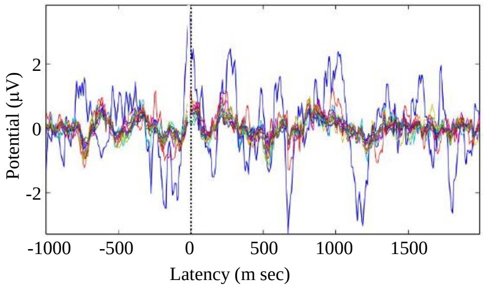

Fig. 5: Overlapped ERP signals

signals with have high magnitudes within the first 100 msec after the stimulus are called Exogenous. On the other hand the Endogenous signals are the ones that do not depend of a stimulus or physical attribute (Sur and Sinha, 2009). In this case, according to such classification, the signals present Endogenous and Exogenous responses simultaneously.

RESULTS AND DISCUSSION

Figure 4 shows the resulted signals from the application of the ERP approach. In this figure are condensed the characteristic ERP from the 100 trials that contain relevant information of Motor Imagery of the motor response of the right arm of the subject.

The signals of Fig. 4, correspond to the variation of the potential over time that was measured with the Epoc+ system. The resulted set of signals, define the MI process for the experiment. Such waveforms, are limited by a time interval within which occur sensorial, cognitive or motor events and is called the event epoch. All the epochs of the signals are averaged and as result are obtained the patterns of each channel that are shown in Fig. 4. Between the limits of the time interval of each epoch is defined a time period that is known as the latency of the signal and for this case is framed between -1000 to 1992 msec.

In Fig. 4, the averaged epochs of the 14 channels are shown and can be noticed that some of the epochs have greater magnitudes that others. Such behavior corresponds to the signals of the channels FC5 and F3 and could denote a high neural activity of the brain areas measured by those sensors. Figure 5 shows the overlapped epochs of the 14 channels by this representation is possible to observe in detail the relation between the magnitudes of those signals.

Figure 5 shows the averaged characteristic signals that were measured with the acquisition system. Those representations share similarities that could be used as features for further signal classification. As can be observed, there exist relations between some of the channels which correspond to the AF3, F7, T7, P7, O1, O2, P8, T8, FC6, F4, F8 and AF4 channels.

Figure 6 summarize some of the statistical data calculated from the resulted ERPs, as a mean of verification of the data analysis. Figure 6 show the peak values and standard deviation of each of the resulted averaged epochs of the channels group of the EMOTIV Epoc+. In this representation is observed that the peak values for the channel FC5 are the higher of the signals set (With a maximum amplitude -A_{max}-de 3.735 μV and minimum-A_{min}-of -3.349 μV), followed by the F3 channel (A_{max} = 1.196 μV and A_{min} = -1.305 μV). According to these observations the maximum range of the voltage of such signals goes from 2.5 μV and 7 μV respectively, much greater than the average peak to peak value of the rest of the signals: 1.6689 μV.

Such behavior is clearly associated through the standard deviation values for each channel; for the channel FC5 the standard deviation is the higher with a value of 1.176. This value shows a highly variable signal, explained by the non-stationary nature of EEG signals.

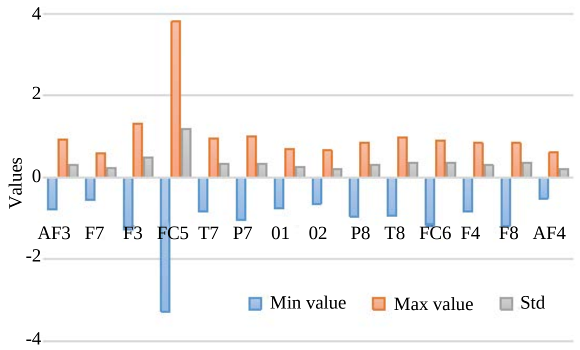

Fig. 6: Peak values and standard deviation of the MI signals

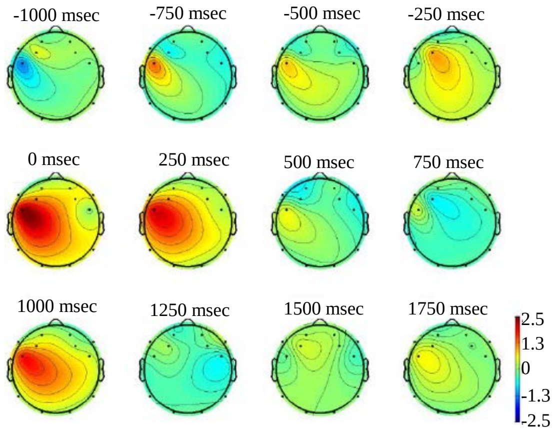

Fig. 7: ERP diagrams for Motor Imagery

Taking into account that all the channels measure the same event at the same time but with a spatial difference, the resulted magnitudes can be represented by scalp distribution maps that show the relations between the signal magnitude, the spatial distribution and the occurrence time (Picton *et al*., 1995). Figure 7 shows the scalp distribution maps for MI of the 14 channels.

Figure 7 shows the ERP scalp maps of the motor imagery process of the experiment. As can be observed there exist a strong relation between the spatial distribution measured by the variation coefficient and the magnitudes shown in Fig. 6.

Such observations give an analysis point from which it is posible to find characteristics between the analyzed events and the brain áreas involved; for this case the cannel FC5 has the higher magnitude of all the channels and its A_{max} occurs at time 0 according to the normalized time scale. For the F3 channel a similar event occurs at the -250 msec time which can be taken as a feature for the imagery task. The ERP scalp diagrams show the dynamic neural activity in the brain when different cognitive, motor and sensorial events occur.

For the experimental test performed and described through this document, the participation of the motor cortex is higher in comparison with the other areas measured by other channels. More specifically channels FC5 and F3 have high activation potentials on the Broadmann areas 6, 8, 9, 44 which are located on the agranular frontal, intermediate frontal, granular frontal and opercular areas BrainMaster which are part of the motor cortex in charge of the movement preparation. This observation is similar to the results found by Schnitzler *et al*. (1997) and the analysis summarized by Romero *et al*. (2000) and Seegelke and Hughes (2015) which show a direct relationship between the overt motor execution and the imagery and by this such processes can be considered as equivalents.

CONCLUSION

The use of Event Related Potentials (ERP) as analysis method for signals that contain information related to cognitive, sensorial or motor processes, as shown in the results the ERP is a suitable tool that describes in a detailed form, how the signals change over time, their nature and the brain areas involved on the generation of such kind of potentials.

The Broadmann áreas related to each cannel of the Epoc+ system, correspond to the neurological process for motor response. This is similar to the results presented in similar works found on the state of the art and in this case correspond to the Broadmann areas 6, 8, 9, 44.

The signals acquired by the F3 and FC5 channels, had the higher magnitudes from all the channels of the EMOTIV system. The MI process of the right arm according to the ERP diagrams have mayor influence in the temporal-frontal areas of the brain. This can lead to further HCI applications using the information of high activation.

The non-stationary characteristics of thye EEG signals, require to apply methodologies to analize time and frequency. In this case, the ERPs show features of the neurological processes beyond the classical approaches which complemented with other mathematical tools like the Wavelet Transform, could serve as a basis for feature extraction and possible implementation of recognition algorithms in further stages of development of such kind of systems.

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