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Peeking Inside the Mind

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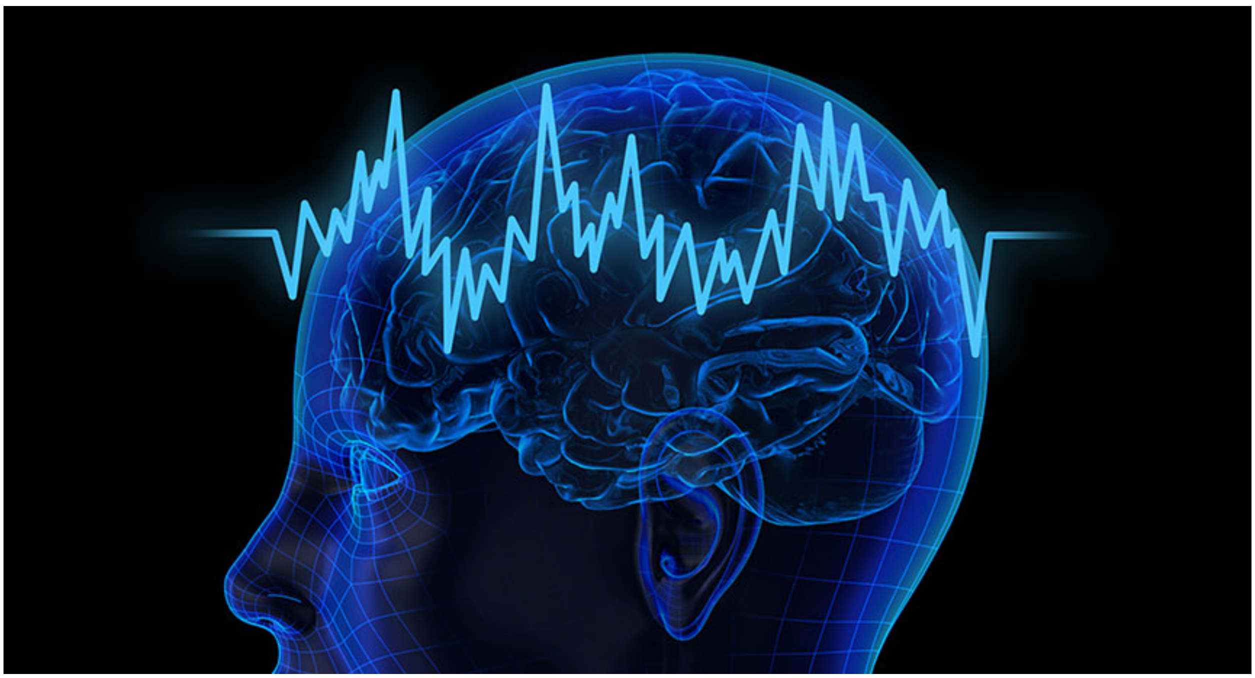

EMOTIV

Abstract

The brain is the central organ of the nervous center in humans, with around ninety billion neurons that carry out all of our everyday functions. In this project, our objective was to better understand how the brain works and learn to manipulate it. We focused more specifically on brain waves. These brain waves are recordings of the voltage of the electrical field that the firing neurons create, while communicating with each other. They do this by emitting electrical impulses such as action potentials and EPSPs. These impulses happen due to the transmission of ions through the membrane of neurons. As a consequence, these ions change the concentration of charges within and around the neuron which creates a dipole. To complete this project we used an Electroencephalography (EEG) headset, a device used to record electrical brain activity. While recording, the headset measures the *sum of multiple electrical impulses*, meaning that the dipoles and neurons have to fulfil specific conditions (alignment, synchronization). Also, we required some help from computer science and applied Python programming language to implement the signals from the headset into our game and set up the control. Finally, we were successful in understanding and manipulating the brain waves and used our recorded data to control a video game.

Introduction

Our brain can send and spread many electrical impulses and signals in a matter of milliseconds. Knowing this, can we extract valuable signals from the brain? More specifically, can we use EEG signals to control a video game? The electroencephalography (EEG) is a device used for recording brain activity. It is most often used for diagnosing epilepsy, although it is not only a device used for medical purposes it is also used for scientific research. Its discovery is credited to Richard Caton, an english scientist, who in 1875, recorded the electrical activity of the brains of rabbits and monkeys. The first recording of electrical activity in the human brain was done by Hans Berger[1] in 1924. Today this method is developed and widely known as one of the ways to experiment and do research on humans in the field of neuroscience. Using this device we would like to be able to control a game with mental activity and understand how the EEG works. We must start from the beginning, a neuron cell, in order to be able to later understand and use EEG recordings. Understanding how a neuron works is the basis which will enable us to work with the EEG.

[1] Millett, D. (2001). Hans Berger: From Psychic Energy to the EEG. *Perspectives in Biology and Medicine* 44(4), 522-542. Johns Hopkins University Press. Retrieved September 2, 2019, from Project MUSE database.

Neuron

Neurons are the functional cells of the nervous system. The main body of the cell, which we refer to as the soma (*Figure 1*) carries the nucleus and all the other general organelles. Dendrites, branch out from the top of the soma and they are receivers of signals. On the opposite end, we have the axon. Axons usually conduct the electrical signals that are spreading around the brain. Axons are inclined to be much longer than illustrated in Figure 1. Neurons in the brain are connected together by synapse. Altogether understanding these components and basic concepts help us depict how neurons communicate.

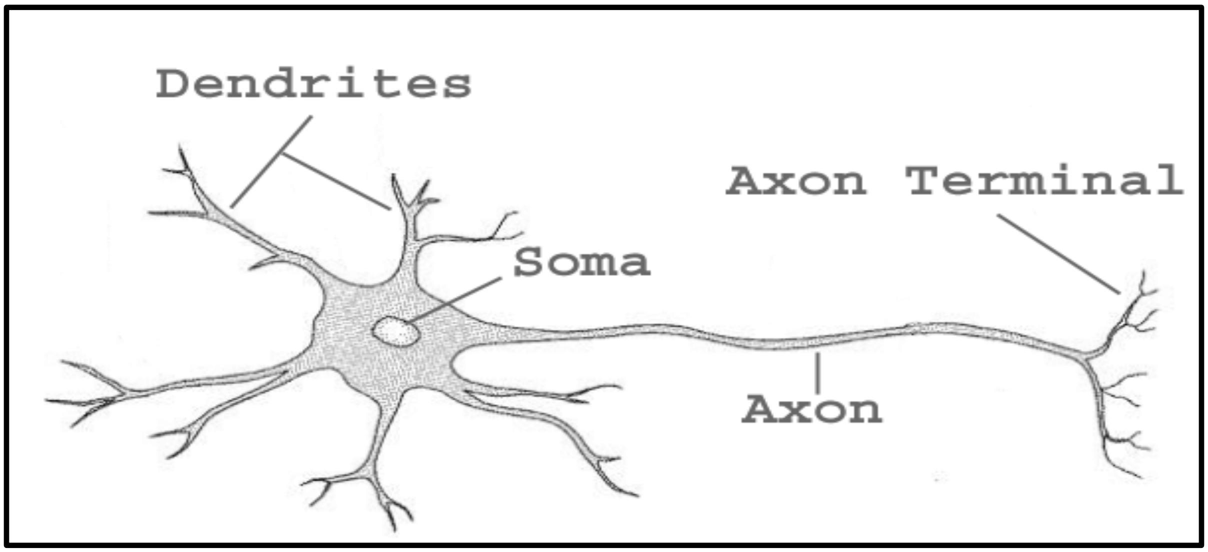

Figure 1: Artistic representation of the anatomical parts of a neuron.

Neuron Communication

All the functions of the human brain derives from the communication of neurons in the nervous system. The way they interact is by sending electrical impulses around the brain, the action potential. An action potential is an electric signal which is caused by the trade of ions inside and outside the cell. An action potential originates in the axon hillock (located at the very front of the axon), then goes through the rest of the neuron's axon without a decrease in amplitude, and ends up in the axon terminals, where it starts the synaptic transmission. In these terminals, the action potential opens some ion channels, letting calcium ions enter the cell; these ions let neurotransmitters out of the cell, so that these chemicals can connect to the neighbouring neuron's channels, letting sodium ions enter the second cell.

Once the chemicals have reached the neighbouring neurons, an electrical impulse will be created as a consequence of letting ions into the cell. This new impulse is called an EPSP which stands for Excitatory Postsynaptic Potential. It is a weaker signal compared with the action potential. However, if a neuron receives more EPSPs, they can sum up creating a stronger signal. The sum of EPSP is responsible of the action potential creation. If there are multiple EPSP reaching the axon hillock at the same time, the membrane potential will reach a threshold and an action potential will be created. The EPSP signal's strength decreases because of energy dissipation, therefore if the signal is not strong enough, the action potential's creating process will not be triggered.

When an EPSP reaches the dendrites, some positive ions enter the neuron. Consequently, the area outside of the dendrites will be negatively charged and the region around the axon will be relatively more positively charged. The oppositely charged regions result in a dipole. A dipole is an area of positive charge separated from an area of negative charge by some distance. Neurons create their own dipoles because of the ion flow through the membrane. Neurons thus have their own electrical field. The EEG cannot receive only one neuron's electrical signal, but it can receive the sum of multiple neurons' electrical signals from a certain area. This summation can happen only when the dipoles are parallel oriented (in a manner that identical charges face in the same direction, so that the charges do not cancel out each other) and when neurons are acting at the same time; this is called synchronous activity.

Electroencephalography (EEG)

There are numerous methods with which neuroscientists can measure mental activity[2]. However, only a few of them can be used on alive humans, fMRI and EEG being the more prominent ones. fMRI is a cutting-edge technology, just like EEG, however it extends the frame of our given project, since it is complicated to operate and it requires a very strong financial background. In addition, if fMRI is very precise spatially (which area of the brain is activated), the EEG is extremely precise temporally. For these reasons, this project is based on EEG measurements. The electroencephalography (EEG), measures electric signals coming from the brain. These signals are the result of electrical fields created by dipoles around the neurons in the human brain as discussed earlier. There are a number of sensors responsible for receiving signals from a given part of the brain, frontal lobe, temporal lobe, parietal lobe, etc. Each signal goes through various layers in the brain until it reaches the skull and the electrode. Unfortunately, since EEG records extraordinarily small signals, it is not only sensitive to the

[2] Calcium Imaging, Patch clamp, Intracellular and Extracellular recording, fMRI (functional Magnetic Resonance Imaging), EEG.

signals of interest (brain activity), but to the noise around it as well, such as electric impulses arising from computers and muscles. For that reason the headset has a pair of reference sensors (P3,P4), sensors that receive signals from both the environment and the brain. They are particularly important, as they are responsible for subtracting the unnecessary, noisy data from the signals of interest.

There are certain oscillations in the signals (between lower and higher frequency, See Figure 4; black and purple curve) that are being recorded by the EEG headset due to the varying amount of incoming information. These could be either the result of different mental activities, or the changing amplitude of noise. Luckily, we are able to control both of the above. Increased focus or stress means high frequency signals. On the other hand, closing eyes, and relaxing results in lower frequencies.

Methods

Throughout our project, we used an EEG Epoc+ headset produced and distributed by Emotiv[3]. The headset was kindly provide by Epoc+ to help students to get familiar with cutting edge neuroscience techniques. It has sixteen sensors out of which fourteen are ordinary sensors, measuring only the electrical activity of the brain, and two are reference sensors. See Figure 2 for the locations of the sensors on the subject's head. Each sensor has a textile contact surface and an electrode built in. Concerning the setup, the device is completely wireless, we synchronized it with our computer via bluetooth. After that, we had to place each sensor into the given locations on the headset, and put on a saline solution[4] (0.7-4 percent sodium chloride and less than 4 percent by volume isopropyl alcohol) right on the top of the contact surface of all sensors to eliminate the air between the skull and the sensor, so that the electrical conductivity is increased. Then, we had to launch the corresponding software (Emotiv Pro) and achieve a sufficiently good contact quality rate see Figure 3, to get meaningful signals out of the headset. Contact quality is measured in percentage. The higher percentage the better, if it is lower than 75% you should keep readjusting and moving hair. A contact quality higher than 75% should be fine to work with. You need to make sure that the electrodes which are recording the part of the brain you need the signals from have the best contact quality. Before adjusting any of the recording sensors, it is strongly advised to calibrate the reference sensors first.

[3] https://www.emotiv.com/product/emotiv-epoc-14-channel-mobile-eeg/

[4] We used the Bausch+Lomb Bio true multi-purpose solution

On the software we could see the signal that each electrode received. But if we wanted to take signals from the EEG and work with them in our project, we had to complete the Fourier transformation. This process decomposes the signal into all of its constituent waves. As a result we could see the dominant frequency of the signal recorded by the given sensor which we could use to control the game. In order to do so, we used Python programming language to implement the signals of the EEG headset into our video game. We put the data we received from the EEG headset in a function. A function that performed the Fourier transformation of the data and returns the score.

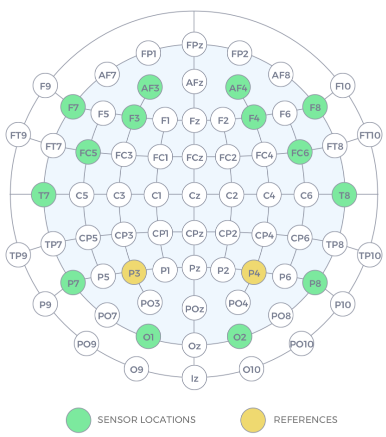

Figure 2: The locations of all the sensors on the top of the subject’s head, facing in North direction (Iz-FPz)

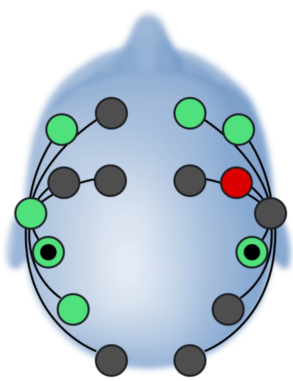

Figure 3: Contact quality is measured for each position. Each sensor is represented by a circle in its corresponding location. The black means no contact detected, red: poor, orange: average, green: good contact quality.

Each piece of data could be put into a different category based on the frequency. Different frequencies are categorized as different brain waves specific to a certain state or activity. Alpha waves are the waves typical for a relaxed state (around 8 to 12 Hz). Beta waves are more correlated to being focused (around 12 to 40Hz). With this knowledge we could set up a game based on relaxing or focus/being stressed. Of course this categorization is a bit arbitrary as it depends on the each person, but on average, these ranges tend to be accurate.

Results

At first hand, we had to get involved in the usage of the EEG device itself and the corresponding software, consequently we completed some sessions and made recordings of our brains (Figure 4). Later on, we realised we have to reduce the noise and refine the signals recorded, thus we applied a process called average smoothing (Figure 5). For accurate control with the signals an algorithm performing the Fourier transformation had to be created too. Last but not least, We developed our own game in which the player would be put in a stressful situation and the way to win was to relax. For that, the player had to close the eyes, direct thoughts in a calm manner and achieve a highly relaxed state. Of course, the player had to wear the EEG headset while playing, in order to record their brain waves.

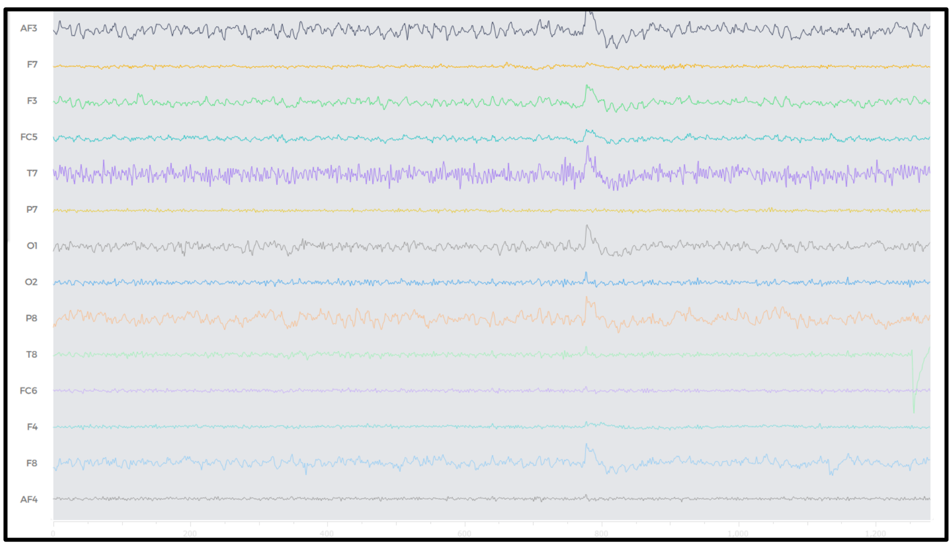

Figure 4: Graph of the signals that each sensor received during recording, in the Emotiv Pro software.

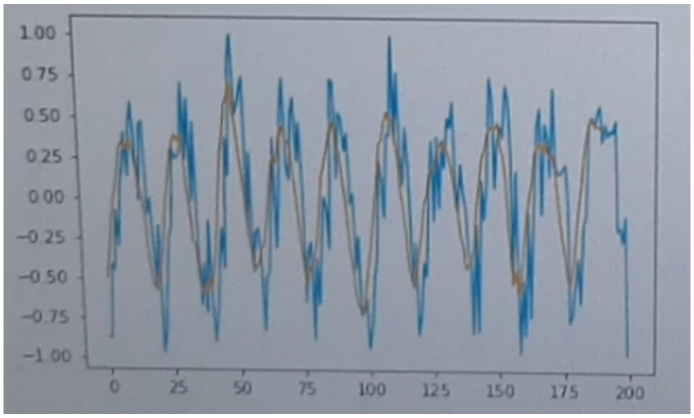

Figure 5: Average smoothing of (fake) data by taking the average of local maximas and minimas. The smoothed data is plotted in orange.

<u>Pictures during work</u>

Discussion

The EEG headset not only records data from the brain, but also from the surrounding area which is noise. This noise was useless information which we had to separate from the actual data we used. In order to get a signal with the least amount of noise and the most strength, we had to accomplish the Fourier transformation. The Fourier transformation is not easy to understand.

To get data, good contact quality must be obtained. Contact quality depends on the person's hair, skin thickness, skull shape. So we sometimes spend up to 15 minutes adjusting the headset and moving hair around. Before letting a new player try the game, it's advised to try the EEG on them, to check the normal brain signals of the player. We had to adjust the limit and also the ease at which the player can relax, so we had to change the marker which the player had to reach in order to win based on them. In addition, it does not record all the signals because of the number of electrodes, there isn't enough, so some signals are too far away. The recordings depend too much on specific conditions, it will only record a signal if the neurons are oriented parallel and synchronized. The technology we used is certainly efficient but still it requires further improvement, mostly the refinement of sensitivity.

Conclusion

To conclude, we were able to successfully control our game by mental activity, capturing the electric signals of our brain with the EEG headset. We can control our brain waves, and use them to navigate in a video game. This project has enabled us to use professional methods of brain recording and to understand the brain better. In order to use this method we had to learn theory about the basics of neuroscience, but also programming in Python. We also had a fair amount of practical learning and use of the EEG headset. Though the programming part required a bit more knowledge than what we had and what we could entirely understand, the project is feasible, complete and enjoyable. On the whole, the project demanded a lot of time, concentration and effort but still we can all agree on that dedicating ourselves to work on this topic was a good choice and that our expectations were perfectly complied, if not exceeded. In 10 days we have learned a lot about how scientific projects work, how the working progress looks like and perhaps most importantly, how it feels to be a scientist and work in such a community.