

Université de Montréal

Using Electroencephalograms to Interpret and Monitor the Emotions

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Résumé

Le long voyage de la technologie a totalement changé la vie des gens : les humains ont marché sur la lune, les rovers¹ découvrent Mars, les ordinateurs sont une partie inséparable de nos vies et dans le domaine de la santé, il y a des traitements pour beaucoup de maladies et l'espérance de vie a été significativement accrue. En plus, les scientifiques ont étudié les émotions humaines et ont essayé de les détecter en se basant sur différents paramètres tels que l'expression faciale, la parole et l'intonation, la réponse électrique et la communication verbale. Ces méthodes fonctionnent sur la base de l'effet des émotions humaines sur le corps et le comportement, mais l'émotion n'est pas le seul paramètre qui affecte le corps et les attitudes des gens. De plus, les personnes pourraient faire semblant, cacher leurs émotions et contrôler leurs réactions. En plus, les personnes ayant une limitation physique réduiront la précision de la reconnaissance correcte des émotions. Les chercheurs ont trouvé une relation directe entre les émotions et les activités cérébrales, les gens ou les limitations physiques ne pourront pas réduire la certitude de l'émotion détectée.

Nous avons utilisé les EEG (électroencéphalogramme) pour créer un outil appelé Emotimap, qui détecte les émotions actuelles, surveille l'évolution émotionnelle en temps réel, et détecte également l'émotion générale. L'émotion actuelle est ressentie de façon brève et forte par rapport à des facteurs émotionnels et l'émotion générale est celle qui engage les gens pendant une longue période. Emotimap utilise des formules pour calculer l'Arousal et la Valence des personnes, puis ignore les sensations non stabilisées et cartographie le résultat sur les deux dimensions du diagramme de Circumplex de Russel pour détecter les émotions.

Nous avons demandé à 20 personnes de participer à une expérimentation dans laquelle ils sont confrontés à différents facteurs émotionnels dans une réalité virtuelle (RV) isolée pour observer et sauvegarder l'information du facteur émotionnel et de leurs réactions. Les résultats montrent que les participants ont ressenti exactement ce qui était attendu avec le taux de 37,73% lorsque la distance métrique est seulement 1,55%, la distance métrique étant la proximité du

¹ Les Rovers sont les robots envoyés sur Mars.

ressenti et de l'émotion attendue (un plus petit nombre montre la plus grande similitude). La comparaison des différentes formules montre que les équations les plus similaires sont des formules avec le même nombre de capteurs utilisant β et β_{low} avec le taux de 40% de similarité, avec une distance métrique entre 20% à 60%. La raison est que certaines équations détectent les émotions plus tôt et d'autres forment des pics d'amplitude plus grands. En détail, les relations mathématiques avec β_{high} détectent une émotion un peu plus tôt que les équations avec β_{low} . De plus, les formules avec douze capteurs suivent les changements très faibles d'amplitude des EEG, les formules avec quatre capteurs sont plus sensibles dans les pics, et les formules avec deux capteurs sont les plus sensibles. La comparaison de la similarité des réactions des participants avec la similarité des caractéristiques basées sur le test Big 5 montre que l'effet de la mémoire est plus fort que l'effet de leur caractéristiques. En analysant les résultats, Emotionap a pu détecter avec succès l'émotion générale du participant avec un taux de 95%.

Mots-clés : IA, Émotion, EEG, RV

Abstract

The long journey of technology has totally changed human's life: human stepped on the moon, Mars rovers² are discovering the Mars, computers are one inseparable part of our lives and in the health section, people live longer, there are treatments for lots of sicknesses. Also, scientists have studied human's emotion and tried to detect their emotions based on different parameters such as facial expression, speech and intonation, electrical response, verbal communication. These methods work based on the effect of human emotions on body and behavior, but the emotion is not the only parameter that effect on body and attitudes of people. Additionally, people could pretend, hide their emotions and control their body and reactions, also, people with a limit on their body movement will reduce the accuracy of correct recognition of emotion. Researchers found a direct relation between emotions and brain activities, people or limit in body movement could not reduce the certainty of detected emotion.

We used EEG (Electroencephalogram) to create a tool called Emotimap that detects current emotion, monitor emotional evolution in real-time, also detects the general emotion. Current emotion is brief and strong, emotions that people feel again any emotional factor and general emotion is the emotion that engages people for a long time. Emotimap uses formulas to calculate the Arousal and Valence of people then ignore unstabled feels and maps the result on the two dimensions Russel's Circumplex diagram to detect the emotions.

We asked 20 people to participate in an experimentation in which they faced up with different emotional factors in an isolated Virtual Reality (VR) to observe and save the information of emotional factor and their reactions. The results show participants have felt exactly what was expected with the rate of 37.73% when the metric distance is just 1.55%, metric distance is the proximity of felt and expected emotions (smaller number shows the more similarity). Comparing different formulas shows the most similar equations goes to formulas with the same number of sensors using β and β_{low} with the rate of 40% of similarity, with metric distance in range of 20% to 60%. This is because some equations detect emotions sooner and some others are more strong in picks amplitude. In detaile, equation with β_{high} detects an

² Rovers are the robots sent to Mars.

emotion a little bit sooner than a equation with β_{low} , also, formulas with twelve sensors chase the EEG amplitude changes very weak when equation with four sensors are more sensible in picks, and the formulas with two sensors are the most sensible. Comparing the similarity of the participant reactions with their similarity of characteristics based on Big 5 test shows that the effect of memories is more stronger than the effect of their characteristic. Analysing the result shows Emotionap could successfully detect general emotion of participant with the rate of 95%.

Keywords: AI, Emotion, EEG, VR

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Table of abbreviations

RV : Réalité Virtuelle

VR: Virtual Reality

IA: Intelligence Artificielle

AI: Artificial Intelligence

EEG: Electroencephalograms

BCI: Brain-Computer Interface

DNA: Deoxyribonucleic acid

IADS: International Affective Digitized Sound system

IAPS: International Affective Picture System

SD: Standard Deviation

To my mother

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I would like to thank professor Claude Frasson, my research director for his trust when he accepted me as a member of HERON and all his support and advice that helped me so much in the research.

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1 Introduction

1.1 General context

The development of science and its effect on human life is immense. Technology advancement has a variety of benefits to humans life, such as safety and ease in travel by creating secure vehicles and airplanes, health by developing new methods of surgical procedures and new medications. These days people live longer, babies die less than any time registered in history, but it does not mean that they are living better[1]. But these are one side of the coin, technology development has brought some complexity to human's life, airplanes crash, vehicles make sound noise and pollution, and drugs have side effects. Technology could also affect human emotions, technology development changes life style of people, that make them to adapt themselves to a new and unfamiliar situation. For example, in modern life, the count of people who live far from their family is much more than before, the number of people who keep their privacy again their family and share their private life on social media for the strangers is growing. All these new habits could lead people to be alone, with no real emotional attach that could end with emotional problems[2].

All these problems are a big objective for a scientist to find a way to keep human health emotionally. At first, we need to find a way to recognize the emotional state of people and to reduce their negative emotion. Obviously, the first method to recognize emotions is their assertion which is not reliable, because

- they could pretend to feel a fake emotion,
- their emotional state could be very complex and not easy to recognize,
- sometimes they could not be capable to explain their feels (babies, retarded).

Scientists have tried different methods to retrieve the emotion of state of a human such as facial expression [2-4], behavior [3], speech and intonation[2,4], electrodermal response [2], verbal communication [3] and head movement [4]. Although these methods could retrieve the emotion, the result is not very reliable because people can pretend know their emotion, or sometimes one emotional factor could affect people differently. For example, in a situation when

people should get moderately angry³, one person who is aggressive will get angry when a calm person will stay calm. On the other hand, if the action of people is not standard, we could not expect a clear result. For example, a facial expression system could not recognize the emotion of a person who has knitted eyebrows, or a person with disorder on his/her face [5,6].

For another example, speech and intonation system would not return good results [5], for the person who has tongue tie problem or a person with blood pressure problems, he/she could be recognized as a nervous person when we use electrodermal response system to find her/his emotion. there are some cultures in which people try to hide and do not show their emotions⁴, their face is normal when they feel bad or good, if they were trying to hide their emotion for a long time, this could affect even their heart rate, their face or body reaction. There is another group of people in society who have an handicap, some of them could not talk, some of them could not control his/her face or body movement, etc.

The research shows a relation between the emotional state and brain signal [2,5,7-18] but it is not very easy because brain structure is very complex and we do not access to all the brain parts [12]. We used Emotiv headset as a low-cost headset to retrieve raw EEG data from the brain [7], then We developed an EEG interpreter and monitor called Emotimap which receives raw data, filters them and recognizes the current and general emotion of a human. In this method, we easily avoid the participants pretending, side effect of sickness on participants' face, heart rate, etc.

Emotimap could be used in a wide variety of purposes and systems. Everywhere we need to be aware of emotional state such as medical application [3], Video game [3,4,19,20], Marketing [3,13], Learning environment [4], Health care system [4,13], Brain-computer interface (BCI) [19,21-23,20], Transport [13] and Commerce [7].

³ later we will explain that the reaction of people is based on lots of thing like memory and personal life of person and of course emotional situation around person that is why we could be witness of totally different reaction to one single emotional factor. The memory of everybody has more powerful effect on his/her current emotion.

⁴ In our experiment, we found that some people show their emotion in their face or body action and the others did not show any emotion when they felt good or bad, interesting part is similar behavior follows the similar cultures, we will explain it in detail in the experiment chapter.

1.2 Research objective

Emotion has a positive or negative impact on human life in personal and societal aspect. One person with positive emotion has a healthy mental life and when a person lives with negative emotion such as being nervous, stress full, etc. he/she has problem in his/her personal life, in family life and in professional life. The person carries a heavy problem with his/her self, usually in private, which makes his/her partner and kids under emotional pressure, that make them potentially future mentally sick person. It could be worse if he/she holds an important job position, for example, a pilot or a surgeon who has people's life in their hand.

There is a mutual relationship between healthy people and healthy society. As much as the number of healthy people in a society goes up, the society is healthier and in a healthy society, the risk of people's mental illness is less and less. That is why we wanted to create a method and a tool to help people live healthier by detecting and controlling emotion. The goal of owning a tool that could recognize how we are emotionally is the base of this research. We can use this tool to make sure if the pilot is mentally ready for the fly, the surgeon is prepared for a hard surgery today. The tool which can help a psychologist to monitor the patients' emotional state to cure them faster.

The goal of this study is to find a fast and reliable method to recognize the emotion of people and monitor the evolution of their emotion in a way that the user could follow easily his emotional reactions. This tool will be able to connect to any kind of EEG headset⁵, and to interpret and monitor the emotions in real time, or offline, also it could be used in other software.

1.3 Thesis organization

In the present work, we explain the importance and technique of recognizing the emotion of a human, and we detail our method and system called Emotimap. The structure of the report is the following

- In Section 2 we discuss the importance of recognition and regulation of emotion.

⁵ The number of sensors and their position, will effect on precision of results.

- In Section 3 we describe how we measure the emotion and what methodology is used. We detail the Emotimap system that we developed and the experiments done for assessing the system.
- In Section 4 we present the results obtained and discuss the advantages of our approach.
- Section 5 concludes our work.

We attach in annex the paper accepted at the international conference on Brain Function Assessment in Learning (BFAL) 2017, Patras Sept 23-25, 2017 Springer–Verlag–LNAI. Using Electroencephalograms to Interpret and Monitor the Emotions, Amin Shahab and Claude Frasson, September 2017.

2 Importance of recognition and regulation of emotions

Developing science gives the humanity the abilities that no one could imagine before. For example, in health domain, in the past, lots of people could die prematurely because of illness, but technology brings us now a cure for them and no more person die because of such diseases. Today doctors could use x-ray images, different chemical test, biopsy and lately intelligent systems which can assist the doctors to find cancer tumor in x-ray images and in real time endoscopy. Doctors can find an enormous amount of information from deoxyribonucleic acid (DNA) of people, that help them to know lot more about our body individually. Now, they can prevent, recognize and cure lots of physical sickness that we could not imagine before. Majority of these improvement is related to body and technology development in mental side is not as advanced as in physical side.

Handicaps: sometimes the soldier who has defended his country remains with a handicap, sometimes some babies born with a problem, some people lost parts of the body or their abilities in an accident. They need help to do a primary activity, and they have right to live just like the other people, and if they do not society should take care of them. If we could bring them back their abilities, it is a great help to them, to their family and society. Reading their mind and send a command to a robot that talks or a robot that works like hand or foot or a robot who could call the emergency when it is necessary could help them live independently, so emotion recognition is very important and keeps their hope and confidence.

Gold age: people lose they abilities when their age goes up. They will need help in some cases and it is hard for an independent person to see he/she could not live without his/her children help. It happens when elder people have an enormous amount of experience and society will lose him/her because of age. On the other hand, when they need help, they will believe that they are bothering people around them, then they hide their need and their emotions, and in a loop, they hide more what they need and their need more and so on, and in this case it would be beneficial to recognize their emotion.

If we could recognize people emotion we could also use this ability in other cases such as:

- When a baby does not stop crying, and we do not know what is wrong, an emotion recognition could help us.
- When an unconscious person arrives at the hospital, we could get lots of information from his/her mind.
- Help the handicap play music by their mind.
- Read the mind or recognize the emotion of person in court with permission of the judge, or maybe when a baby is kidnaped, and police have one suspect.
- Identify the emotion state of people with important jobs, to find if their mind is ready and stable, for example, pilots, surgeon, etc.

The ability of being aware of what is going on in someone's mind could be a threat again personal privacy. In fact, almost everything human invented could be used in a good way or bad one, but the reason of creation is need. Then continue living without technology is not going to be easy and we need to use new technologies, inventions and methods. To limit the loss of privacy we must find a way or make the rules to respect the privacy and be aware that there is always a group of people who can abuse the technology for their benefits.

2.1 Emotional recognition systems

2.1.1 Introduction

Many researchers have tried different methods to detect people's emotions. Some of these methods return better results and some of them need special situations to work. For example, some methods need to have a visible sight of eyes or face of a participant, some others need to receive the voice of a participant. Any of these prerequisites is a limit in our work when universal and functional method should work for anybody and with minimum of the prerequisites. In this section we will explain some emotion detection methods.

2.1.2 Methodology and problematic

In this part, we will present some emotion detection methods and explain how these methods work and what is their weaknesses.

The first method we explain uses heart rate [13] to recognize the emotion. This method is based on the effect of emotions on heart rate using trained labeled heartbeats to find received heartbeat belong to which emotional category. The weakness of this method is that other things could affect heartbeat, for example sickness like high or low blood pressure, heart arrhythmia and overweight problem. Therefore, we could not expect this method to detect the emotions of sick people correctly.

Another method is facial expression [2,3] which is trying to detect emotion from the situation of face element. Humans could understand or at least predict people emotions from their face. The sense of eyebrows, the situation of eyes and lips, the front and some time the color of the face (is it red or pale) could give us clue about emotions of people. This method uses the same parameters to detect the emotion. Face expression has some limitations, participant's face should be visible means participant should be in a bright room, always in front of a camera and should not use instrument like Virtual Reality (VR) on the head. Another problem is that the participant could mimic and hide his/her real emotion, then facial expression method would detect a totally wrong emotion. The other limits of the method is that it could not work properly if the face has a problem such as a paralysis.

Verbal communication [3], speech and intonation[2] is used to recognize the emotions too. The problem is that some people who cannot talk, or talk with tongue tie. Also, some people hide their emotions in talking, and the number of emotions that this method could recognize is limited.

Another method that could recognize emotion more or less with the same problems are based on behavior [3], electrodermal response [2], skin conduction [13]. Another modern method is using the brain signal [2,12,13] to recognize the emotions. The problem of this method is that we need an instrument which must be connected to the head of people. However, this method has good benefits. At first, this method retrieves the emotion directly from the head so people could not hide their emotion, we do not need to see them or hear them, they could be even sleeping or in a comma and the emotions we could recognize are not limited. In our research, we have used this method which will be explained in the following chapter.

2.1.3 Conclusion

Recognizing human emotions gives us great ability to cure their emotional and mental disease researchers have examined different methods to recognize the emotions of a human, they tried to retrieve the emotion from heart, skin, face and brain signal. Every method has some advantages and disadvantages, but the method that could directly extract the emotion from brain signals⁶ is the most precise.

2.2 Emotion Reduction Systems

2.2.1 Introduction

Scientists and researchers have worked on the evaluation of human health in different ways. But a human has two aspects, the body and the mind. The body is accessible and even the most interior part is more accessible than mind. On the other hand, physical health problem, usually has visible effect or pain, but the effect of mental problem is hidden inside the behavior of people, and the sick person will carry the problem till it gets worse. These two reasons explain why we do not have tools and methods for observing, imaging and testing the mind as much as the method and technologies that we use to diagnosed physical health problems.

One of the most common mental problems in city life is being nervous. The complexity of life, thinking about bills, sickness, kids, failure in marriage and lots of other things to be worry about is on the mind of people who live in middle of traffic, noise, and pollution and etc. put stress on a lot of poeple. Then we need to do different things to get back our calm. Then the researcher should observe the people lives, and find the element and parameters which are common in more healthy people. Then we could use these parameters and measure the power of every element based on the different emotional states of people to help them to be calm and live more happy.

⁶ Some people believe that source of emotions is the heart and some other believe emotions are created inside and by the brain. Researchers have found direct relation between brain activities and the emotions of human, then if even brain is not source of emotions but is nearest known part of body to the source of emotions.

2.2.2 Methodology

The brain does not understand if a person is doing something or just thinking about it. In fact, we could use the memory in the brain to create emotions inside the brain [3]. The brain will simulate the real situation through the senses such as visual, odor, taste, audio and tactile sensors. The idea is to extract the visual, odor, taste, audio and tactile elements from the situation that people find themselves calm, and use the parameters in a calming sequence such as video game, music, etc.

From now on, we call these parameters that could change the emotional state of people, *emotional factor* and they are two types; positive emotional factors are supposed to make people feel good and negative emotional factor are supposed to make people feels bad⁷. In this research, we have introduced one negative emotional factor composed by images and four positive emotional factors which are images, texts, films 360 degrees and music. In the experiment, we put the participant in a virtual reality ambiance where he sees a sequence of images that make him feel bad, then after every negative image, he can see one image, film 360 degrees, text or hear the music. All the time his emotion is registered, and then we can study his emotion and the effect of different types of emotional factors. In following sections, we detail the emotional factor.

2.2.2.1 Music

One of the most effective and strong elements that make people feel positive or negative is music. Music is one unrepeatable part of human life. From very long time ago and in every point of earth, we could find a very simple instrument or a complex one that people used to make a harmonic sound. The effect of music on a human is so strong that sometimes people show their emotions by smiling, crying and even dancing. Dance is following the harmony and rhythms with the body. Then, of course, the music is one of our chosen emotional factors.

⁷ These emotional factors are supposed to make people feels positive or negative, but in experiment I saw people do not feel what is expected. The reason is the emotion created is based on the memory of people and people have totally different memories. This topic will be more explain in section three.

Music has lots of different aspect such as genre, rhythm, tempo, melody, and orchestration. There are the researchers who study the effect of music on human emotion, and it is not the goal of this research, then we simplified it, by choosing just instrumental music with simple orchestration but a variety of rhythms, tempos, and genres. Three music tracks are natural sound taken from IADS (International Affective Digitized Sound system). IADS⁸ is a collection of images to simulate and study the emotions [3,24].

2.2.2.2 Text

In a hard time of life, one phrase of a great or successful person could bring us the motivation, helps us to feel better or may be make the person sad or angry, because they think they are under presser of the problem and just talking is easy. That is why we wanted to test it and find out for how the rate of people who get calm or upset according to the type of text. We created a robot that extracted some phrases in English from great politics, artists, and scientists from the internet, then we translated them in French and Farsi. The purpose of this translation was that the participants do not waste any second to translate the phrase and eventually reduce that emotional reaction.

2.2.2.3 Movie 360 degree

The most similar situation to the reality is virtual reality. New technology brings us the ability of using films 360 degrees or virtual reality to put the participant in the middle of a scene where he can turn around and look up and down to watch and hear. This technology engages the audible sense and eyesight of human; we used the film 360 degrees in the experiment. The films are chosen on the color, place and calmness and excitement of films. We used some films that contain scenes such as under the sea, sea side, sky diving, etc.

⁸ IADS is a collection of sound that is developed and distributed by NIMH center of emotion and attention (CSEA) at the University of Florida.

2.2.2.4 Image

Image with colors, scene and elements in it is one strong emotion creator. Then we used the image as one of the emotional factors, and we chose the labeled images of IAPS⁹ (International Affective Picture System) used as one of the most used and popular labeled image dataset to study the emotions[3,24,25].

As we explained, we show the participant the images that make them feel bad, sad, nervous, etc. To do that, we used the images of IAPS as a negative emotional factor and then one positive image, text, music or film 360 degrees as a positive emotional factor to measure and observe their emotional reaction. To classify the emotions, we used the arousal and valence of the images, arousal and valence exist in IAPS. Then we mapped the images to Russel diagram [26] and used K-nearest neighbor method to assign the emotion and distance from symbol of emotion on the diagram to every image. Then we chose the nearest image to emotion as symbol of that emotion and used them as negative emotional factor or positive emotional factor.

⁹ IAPS is a collection of pictures that is developed and distributed by NIMH center of emotion and attention (CSEA) at the University of Florida.

3 Measuring the emotions

3.1 Introduction

The ability to extract the exact emotion of a human would be a very useful tool that is demanded for a variety of different purposes [17,26], from entertainment to health [3,13,19]. There are people who hold a very important job, people who have human life in their hands, like a pilot or a surgeon, their job is so important that they do not work alone. The problem is that the team members trust them so much, that they would not stop them or warn them until it is too late. If we had a headset that could measure the mental preparation of them before surgery operation or flight, lots of human error could not happen, and lots of lives could be saved. For another example, this tool could be a very helpful assistant for a physiologist who needs to spend a long time to get into the patient's mind (and the mind is very complex), a big deal for juniors. This problem increases when there is patient with a real problem that needs more help than the others, but this tool could easily show the real emotion of the people. Sometimes small kids cannot explain themselves, and their parents do not take them serious attention. Also, for elder people, it is very hard to accept that they are losing some of their abilities, or fear that they could need help from their children, with the possibility of not explaining exactly how they feel or what they need. A tool that can read their emotion from deep side of their mind could help the humanity to save lots of lives, and also help the people help to be more happy.

The researchers have worked on different methods such as heart rate, skin conductance [13], facial expression, speech and intonation and electrodermal response [2] to retrieve the emotion of a human. All these methods are trying to recognize the emotion from the effect of the emotion on the body, for example, facial expression tries to extract the emotion from the expression of the face, or heart rate wants to retrieve the emotion from changes of heart beats. Of course, the emotion could effect on our body, a human could understand the emotional state of people by looking to their face, observing their body language or their talking speed and their intonation but the problem is that the emotion is not the only thing that effect on our body. Sometimes sickness like, blood presser or high heart beat could effect on the heart rate. A system based on speech and intonation system could not recognize the emotion of people who have asthma or person who has tongue tie problem. Another problem of these systems is there are not

very precise; they could not separate the similar emotions such as Bored and Hesitant or Astonished and Aroused. But maybe the bigger problem is that people could hide or pretend their emotion by practice, and there are some cultures that teach to their people not to show their happiness or sadness very clear.

The recent research shows that the emotion could be retrieved from brain signal [2,13]. But the problem of extracting the emotion from the brain is that the brain has a very complex biological system [12]. We do not have access to all the parts of the brain; we can just retrieve the signal of the cortex of the brain, that means we do not have access to major parts of the brain. Figure 1 shows the cortex with a cut on the brain.

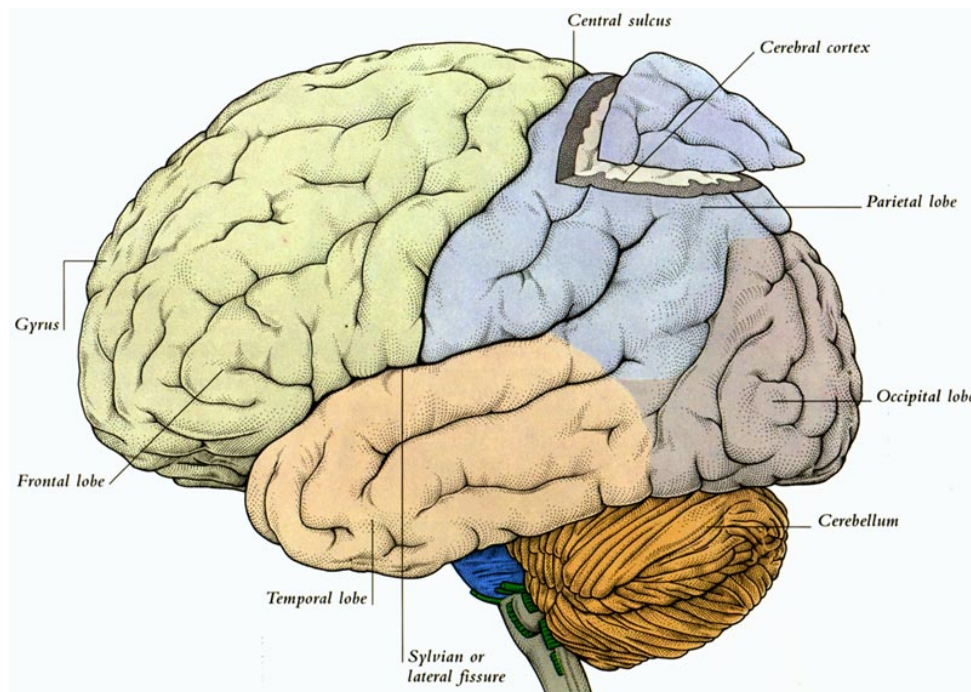


Figure 1. The brain parts - Cortex of the brain [27]

Another difficulty of retrieving data from brain signals is that the brain is controlling all the parts of body non-stop. What human can see, hear, sense, dream, the hormones and anything that we could imagine is governed by the brain. If we assume that there is no noise or failure in signals, there is still a huge amount of data that we do not need to extract.

3.2 Methodology

In this research, we chose the signal brain to extract the emotion, because of its accuracy. The purpose is to recognize the emotion and monitor it, then we use the two dimensions circumplex space model (fig. 2), to extract and monitor the emotions [3]. In this diagram, we could map the emotions to one 2D diagram with the axis of Arousal and Valence. By retrieving the arousal and valence from brain signals, we can find a precise emotion of the human.

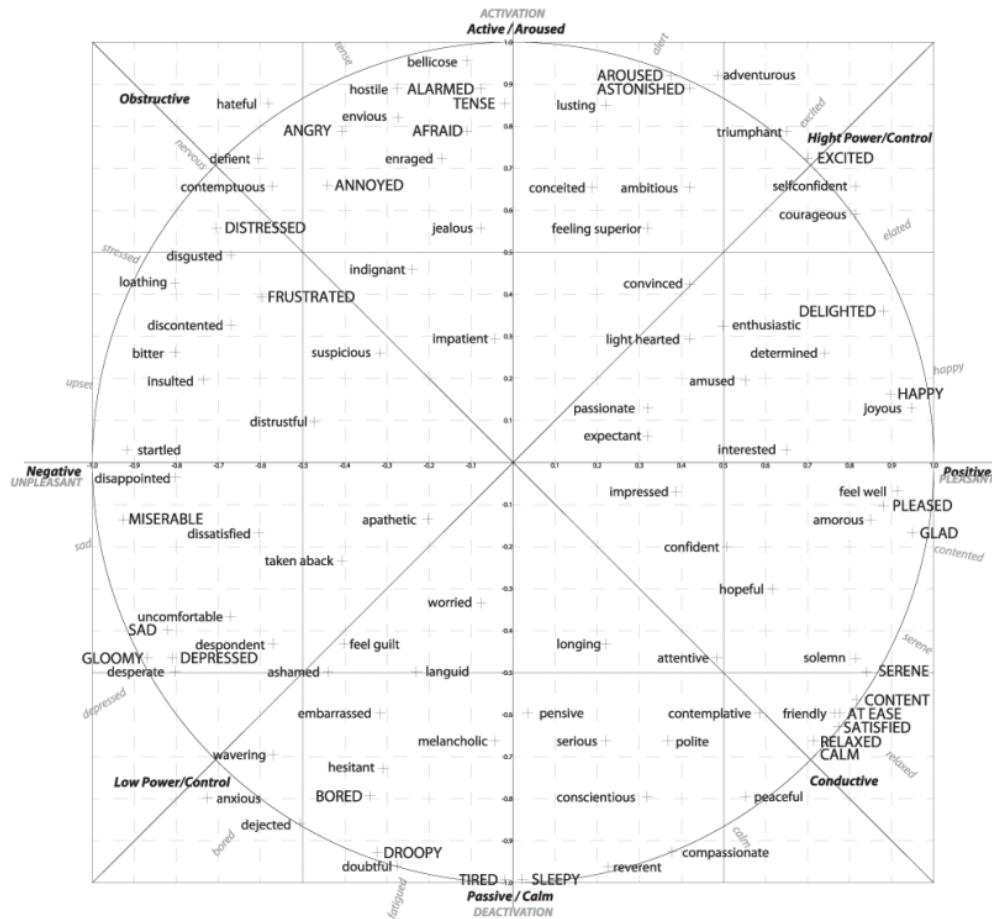


Figure 2. Two-dimension Circumplex space model [26,28-30].

Also, we can see the emotional evolution on the diagram which could help us to study the changes of emotion of people in a time series that shows the reaction of a person to an emotional factor around him/her.

3.2.1 Arousal and valence

The valence shows the quality of the emotion in a range from unpleasant to pleasant, while the arousal shows the quantitative activation in a range from not aroused to excited [3]. We could calculate the arousal and valence by comparing the brain activities in different parts. The high activation of α waves in frontal part of brain and high activation of β waves in right part of brain is correlated to positive emotion. High β waves activity in partial lob when α waves activities is low while the influence of β / α in frontal lobe is increasing at the same time when β waves activities in partial lop is increasing is related to higher arousal [31-33]. Then we use this pattern to calculate the amount of arousal and the value of the valence.

3.2.2 Hardware

Emotion recognition is based on brain signal which is still a new method in research. We organized an experiment where we could gather labeled data with the element that we needed (the experiment will be explained in detail in the following). In the experiment, we have used Emotiv EPOC as a low-cost EEG headset and Google card board Virtual Reality (VR).

3.2.2.1 Emotiv

Emotiv EPOC is a low-cost commercial EEG device [7] with 14 channel wireless EEG. It is not heavy and easily installable. This device returns the value of five principal frequency bands which are

- Delta (0 – 4 Hz)
- Theta (3 – 7 Hz)
- Alpha (8 – 12 Hz)
- Beta (13 – 30 Hz)
- Gamma (30 – 40 Hz)



Figure 3. Emotimap EPOC

The sensors of the device need to be wet and then it should be put on the head in appropriate place, and the dongle of the device that should be connected to the computer. Figure 4 shows the place of the sensors based on international EEG positions.

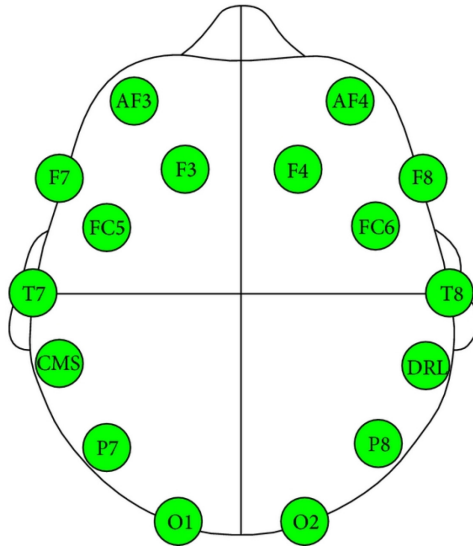


Figure 4. The position of sensors on Emotiv Epoc, Based on international EEG position

3.2.2.2 VR

In the experiment, we isolated the participant and put him in a calm situation. We controlled what he sees by VR (when he wears a VR he could not see but what is shown is the VR and we controlled it) and controlled what he hears by a hand free (he was in a calm room

and hands free was under control). For the VR, we used one Google cardboard virtual reality which is a cheap, light and easy to use the device. This device uses a cell phone to show the ambiance and has no limitation for the model of the cell phone. Figure 5 shows the image of the VR headset.



Figure 5. Google Cardboard VR headset

3.2.3 Formulas

Researches use different formulas and one of our goals was to find the best formulas which make us independent of the hardware. We chose some of the formulas depending on a variety of place of the sensors on the head, and kept the result of all of them to compare them at the end. The headset that we used (Emotiv, explained in section 3.2.2.1) has ability to return the *high* β as well as the *low* β then we calculated all the formulas with β , β_{high} and β_{low} . The β wave could be divided into three sub waves including β_{low} , β and β_{high} . The formulas are named based on the number of sensors which are engaged for calculating the result. For example, arousal $2S_{low}$ refer to the formula which calculates arousal using data of **two sensors** (F_3 and F_4) and using waves α and β_{Low} .

Researchers used different formulas to measure the arousal and valence and published their researches in papers [31,34]. We gathered the formulas that have good results, and we used a formula that used all the sensors all over the head. The reason was that the hardware and the method we used was not the same as them, so we wanted to observe the formulas with our method.

3.2.3.1 Formulas using two sensors

In this formula, we used the data extracted from the $F3$ and $F4$ to calculate the arousal and valence, from now we mention the formulas with two sensors with $2S$ (formula 1 to formula 6). The standard and place of the sensors is explained in section 3.2.2. on Emotiv [31,34] and particularly in figure 4.

$$Arousal_{2s} = \frac{\beta F_3 + \beta F_4}{\alpha F_3 + \alpha F_4} \quad (1)$$

$$Arousal_{2s-H} = \frac{\beta_h F_3 + \beta_h F_4}{\alpha F_3 + \alpha F_4} \quad (2)$$

$$Arousal_{2s-L} = \frac{\beta_l F_3 + \beta_l F_4}{\alpha F_3 + \alpha F_4} \quad (3)$$

$$Valence_{2s} = \frac{\beta F_4}{\alpha F_4} - \frac{\beta F_3}{\alpha F_3} \quad (4)$$

$$Valence_{2s-H} = \frac{\beta_h F_4}{\alpha F_4} - \frac{\beta_h F_3}{\alpha F_3} \quad (5)$$

$$Valence_{2s-L} = \frac{\beta_l F_4}{\alpha F_4} - \frac{\beta_l F_3}{\alpha F_3} \quad (6)$$

3.2.3.2 Formulas using four sensors

In this formula, we used the data extracted from $F3$, $F4$, $AF3$ and $AF4$ to calculate the arousal and valence (formula 7 to formula 12), these formulas use the frontal part of the brain to calculate the arousal and valence. The formulas with four sensors will be mentioned by $4S$ [31,34].

$$Arousal_{4s} = \frac{\beta F_3 + \beta F_4 + \beta AF_3 + \beta AF_4}{\alpha F_3 + \alpha F_4 + \alpha AF_3 + \alpha AF_4} \quad (7)$$

$$Arousal_{4s-H} = \frac{\beta_h F_3 + \beta_h F_4 + \beta_h AF_3 + \beta_h AF_4}{\alpha F_3 + \alpha F_4 + \alpha AF_3 + \alpha AF_4} \quad (8)$$

$$Arousal_{4s-L} = \frac{\beta_l F_3 + \beta_l F_4 + \beta_l AF_3 + \beta_l AF_4}{\alpha F_3 + \alpha F_4 + \alpha AF_3 + \alpha AF_4} \quad (9)$$

$$Valence_{4s} = \frac{\beta F_4 + \beta AF_4}{\alpha F_4 + \alpha AF_4} - \frac{\beta F_3 + \beta AF_3}{\alpha F_3 + \alpha AF_3} \quad (10)$$

$$Valence_{4s-H} = \frac{\beta_h F_4 + \beta_h AF_4}{\alpha F_4 + \alpha AF_4} - \frac{\beta_h F_3 + \beta_h AF_3}{\alpha F_3 + \alpha AF_3} \quad (11)$$

$$Valence_{4s-L} = \frac{\beta_{low} F_4 + \beta_{low} AF_4}{\alpha F_4 + \alpha AF_4} - \frac{\beta_{low} F_3 + \beta_{low} AF_3}{\alpha F_3 + \alpha AF_3} \quad (12)$$

3.2.3.3 Formulas using twelve sensors

In this formula, we used the data from $F3, F4, AF3, AF4, F7, F8, T7, T8, P7, P8, O1$ and $O2$ to calculate the formulas (formula 13 to formula 18) which cover the entire head. The formulas that used twelve sensors were mentioned by $12S$ [31,34].

$$Arousal_{12s} = (\beta F_3 + \beta F_4 + \beta AF_3 + \beta AF_4 + \beta F_7 + \beta F_8 + \beta T_7 + \beta T_8 + \beta P_7 + \beta P_8 + \beta O_1 + \beta O_2) / (\alpha F_3 + \alpha F_4 + \alpha AF_3 + \alpha AF_4 + \alpha F_7 + \alpha F_8 + \alpha T_7 + \alpha T_8 + \alpha P_7 + \alpha P_8 + \alpha O_1 + \alpha O_2) \quad (13)$$

$$Arousal_{12s-H} = (\beta_h F_3 + \beta_h F_4 + \beta_h AF_3 + \beta_h AF_4 + \beta_h F_7 + \beta_h F_8 + \beta_h T_7 + \beta_h T_8 + \beta_h P_7 + \beta_h P_8 + \beta_h O_1 + \beta_h O_2) / (\alpha F_3 + \alpha F_4 + \alpha AF_3 + \alpha AF_4 + \alpha F_7 + \alpha F_8 + \alpha T_7 + \alpha T_8 + \alpha P_7 + \alpha P_8 + \alpha O_1 + \alpha O_2) \quad (14)$$

$$Arousal_{12s-L} = (\beta_l F_3 + \beta_l F_4 + \beta_l AF_3 + \beta_l AF_4 + \beta_l F_7 + \beta_l F_8 + \beta_l T_7 + \beta_l T_8 + \beta_l P_7 + \beta_l P_8 + \beta_l O_1 + \beta_l O_2) / (\alpha F_3 + \alpha F_4 + \alpha AF_3 + \alpha AF_4 + \alpha F_7 + \alpha F_8 + \alpha T_7 + \alpha T_8 + \alpha P_7 + \alpha P_8 + \alpha O_1 + \alpha O_2) \quad (15)$$

$$Valence_{12s} = (\beta F_4 + \beta AF_4 + \beta F_8 + \beta T_8 + \beta P_8 + \beta O_2) / (\alpha F_4 + \alpha AF_4 + \alpha F_8 + \alpha T_8 + \alpha P_8 + \alpha O_2) - (\beta F_3 + \beta AF_3 + \beta F_7 + \beta T_7 + \beta P_7 + \beta O_1) / (\alpha F_3 + \alpha AF_3 + \alpha F_7 + \alpha T_7 + \alpha P_7 + \alpha O_1) \quad (16)$$

$$Valence_{12s-H} = (\beta_h F_4 + \beta_h AF_4 + \beta_h F_8 + \beta_h T_8 + \beta_h P_8 + \beta_h O_2) / (\alpha F_4 + \alpha AF_4 + \alpha F_8 + \alpha T_8 + \alpha P_8 + \alpha O_2) - (\beta_h F_3 + \beta_h AF_3 + \beta_h F_7 + \beta_h T_7 + \beta_h P_7 + \beta_h O_1) / (\alpha F_3 + \alpha AF_3 + \alpha F_7 + \alpha T_7 + \alpha P_7 + \alpha O_1) \quad (17)$$

$$\begin{aligned}
Valence_{12s-L} = & (\beta_l F_4 + \beta_l AF_4 + \beta_l F_8 + \beta_l T_8 + \beta_l P_8 + \beta_l O_2) / (\alpha F_4 + \alpha AF_4 + \alpha F_8 \\
& + \alpha T_8 + \alpha P_8 + \alpha O_2) - (\beta_l F_3 + \beta_l AF_3 + \beta_l F_7 + \beta_l T_7 + \beta_l P_7 \\
& + \beta_l O_1) / (\alpha F_3 + \alpha AF_3 + \alpha F_7 + \alpha T_7 + \alpha P_7 + \alpha O_1)
\end{aligned} \quad (18)$$

3.3 Emotimap

For this research, we created a method that uses the brain EEG data as input and retrieves the emotions by comparing the power of the activities of different waves in different parts of the brain. Then we created a tool that shows the retrieved results of the method. This tool is called Emotimap. In summary, Emotimap is a tool that gets EEG data and

- 1- extracts the current emotion at the time,
- 2- extracts the general emotion,
- 3- monitors the emotional evolution of a person on two dimensions: arousal-valence diagram,

Emotimap works online when connected to the headset and receives the EEG data, Also, it can show the results multiple times as they are saved, to help the users to be able to restudy and precise in details of result, after experiment.

3.3.1 Methodology

Emotimap connects to the headset, receives the raw data and extracts the arousal and valence (the formulas explained in 3.2.3 formulas, calculate the arousal and valence). Raw data is the value of α, β, γ and θ at the time. In the experiment, one goal was to find the best and the most functional formula, so Emotimap calculates and keeps all the formulas.

The reaction of different people to one single emotional factor is different, and we see it in normal life every day. One love story movie makes some people cry, some others just sad and they are some people who makes jokes of that movie, and for people with similar emotion the amount of the emotion (arousal and valence) is totally different. That is why we needed to train our system for everybody separately; I call it *pre-training*. After pre-training, Emotimap

found minimum and maximum of the values and based on that limitation, Emotimap calculates the percentage of the arousal and valence. The values of minimum and maximum is based on the power of brain activities of person which is different person by person. To resume, Emotimap maps the values of the arousal and valence into a new limitation between -100 and 100 (figure 6).

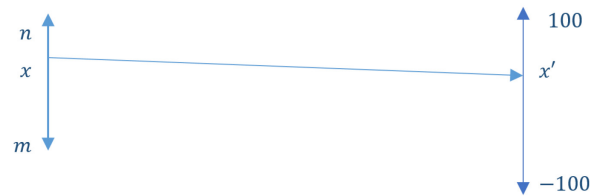


Figure 6. Limitation mapping

For pre-training, we need to put the participant in a situation that makes him/her very emotional, positively and negatively. But as we explained, people get emotional in a different way, and we could not guaranty that we could find the exact minimum and maximum of arousal and valence of people in pre-training. Emotimap is capable to update the range of minimum and maximum and with no interruption continues the operation with new minimum and maximum, if occasionally Emotimap receives data out of range.

We are using a hardware that uses low voltage of electricity then it is possible sometimes to have some noise effect on our values. Emotimap calculates a very big or very small value for arousal or valence that do not repeat very much, Emotimap will take it as noise and removes it from the result. As Emotimap is learning all the time after a while, the result of Emotimap are more precise.

Emotimap shows the emotional evolution, of the participant. This diagram helps us to study the reaction of people to the different emotional factors multiple times. Figure 7 illustrates Emotimap tool which is showing the emotional reactions of one participant off-line.

It allows two options. Firstly, we can connect to the headset and show the emotional reaction of participant online (and save the data in a file) and secondly, we can choose the saved data file to observe the emotional reactions multiple times. Inside the status bar we can see if Emotimap is connected to the headset. Top side of the diagram shows the current emotion as well as the body of the diagram shows the **emotional evolution** of participant.

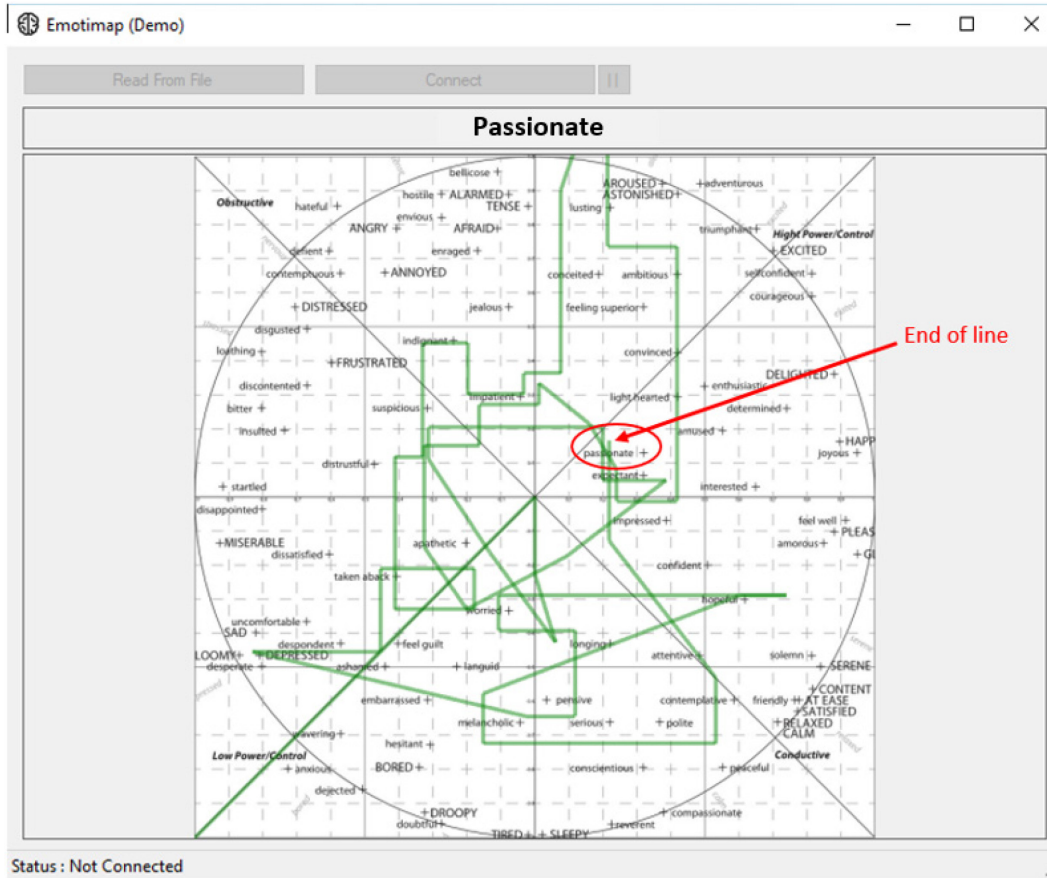


Figure 7. Emotimap shows emotional evolution off-line

Emotimap also recognizes the emotion of participant on real time; this emotion is the nearest emotion on diagram around the end of the line in the diagram, for example, in figure 7, the end of the green line is around **passionant** which is the last emotion detected in emotional evolution and this emotion is mentioned on top of diagram. Everybody could feel multiple emotion in facing with an emotional factor, so the emotion shown in the diagram is the most powerful emotion felt by the participant. For example, when friends panic somebody, the person is scared and excited and happy (as soon as he/she understand it is a joke), there is no border between these emotions, sometimes human experiment different emotions, possibly in the opposite of each other, at the same time. Some of these emotions are stronger than others, Emotimap takes the strongest emotion.

Two emotionally similar people at the same time, facing with similar emotional factor could have different numbers of α, β, γ and θ waves. One important point is that our emotion is

the result of the emotional factor we are faced, with all our memories even what we do not remember, culture and personal experiences of people. The personal part is very strong part of the parameters (figure 8), even one person could feel different, in different time again faced to the same emotional factor.

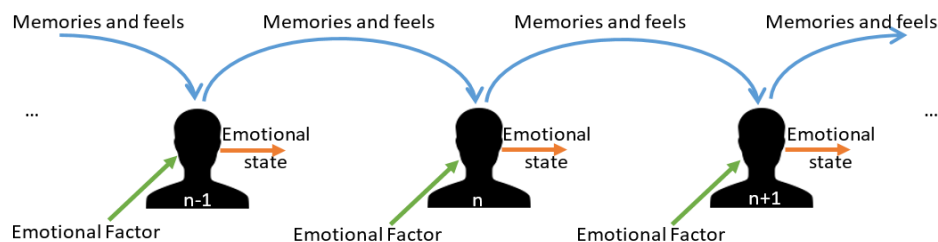


Figure 8. Effect of the memory on the emotional state of person [35]

On the other hand, every person has a feeling that engages him for a longer time; it could be a couple of hours or maybe some months, we called it “general emotion”. For example, one person who is depressed feels depressed generally, but he/she could smile, get angry or scare and these feelings are a current emotion, but behind these emotions, he/she is depressed. Technically it is the most stable recognized emotions when he/she is not in the emotional pick. Emotimap could recognize the general emotion too.

3.3.2 Raw data problematic

Raw data of the EEG headset are the value of the waves α , β , γ and θ which are a decimal number. The brain is controlling any organ inside the body, hearth rate, any movement of hands and feet, mind, thought, imagination and the emotions. The data we extracted from EEG waves is a mix of some parts of these data and probably some noises. Then the result is one series of numbers that change very fast and do not follow any pattern. Some of these changes are very sharp and, some others are very small, like a small shaking of value. But what we need is a stable series of numbers that shows the sharp changes and shows the smoothness diagram, when the feeling of participant is stable.

To do that, in every level we created a list of values and the number of repetitions of every value; then we ignored the values with less than 10 percent of repeatation and our method will use the rest of values to find the minimum and maximum. At the beginning, Emotimap waits until gathering enough data to calculate the minimum and maximum, that request 100

rows of values in this case. Another important point is emotimap does not delete anything, then as Emotimap takes more data some of them that was ignored could be considered again or the opposite.

After then the diagram shows small shakes and sharp changes that are not stable, to ignore that unnecessary changes we filtered data, two times.

3.3.3 Filters

3.3.3.1 Smoother

To avoid the small shakes that do not change the extracted feeling, but make the diagram noisy and unreadable, we ignored theses shaking, and every two points next to each other that are very near will get the value of the first point, the value of this hyper parameter in the experiment is 40 (figure 9). This filter will show the real changes in small scale.

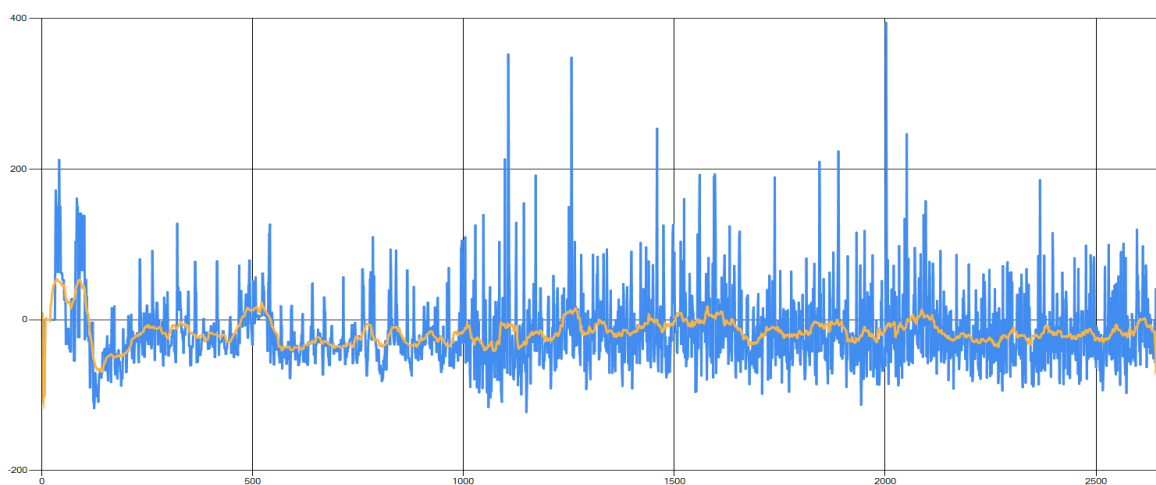


Figure 9. The effect of smoother on raw data, in the value-time diagram. Blue line is raw data, and orange line shows smoothed values

3.3.3.2 Jump Remover

To avoid the feels that passed very fast, which is probably noise, we reduced the data that show very fast and sharp changes that are not stable. It is necessary to pay attention that small changes in values of arousal and valence do not make a change to the recognized emotion. The reason is simple, we used the nearest neighbor method to find emotions and in this method

all points go to the group of the nearest labeled point which means that the points inside the area around labeled point are in the same group, then small changes in arousal and valence do not make any change to the recognized emotion.

At first step, we needed to know when changes in values of arousal and valence will make a change in recognized emotion, then we defined a hyperparameter that kept the minimum distance between every two values (every change more than that could change the recognized emotion). If two sequenced values have a distance more than this hyperparameter we call this part of sequence *break point* and we will go to the next step.

In second step, we wanted to know if the change that just happened is stable, on the other hand, does it continue for a while? We defined a minimum of times of repetition that shows the stability as second hyperparameter. If the changes could not reach the minimum of repetition the change is not stable and all the values after the last break point will change to the last value before break point. In the experiment, the hyperparameters are valued 5 and 10 in order (figure 10).

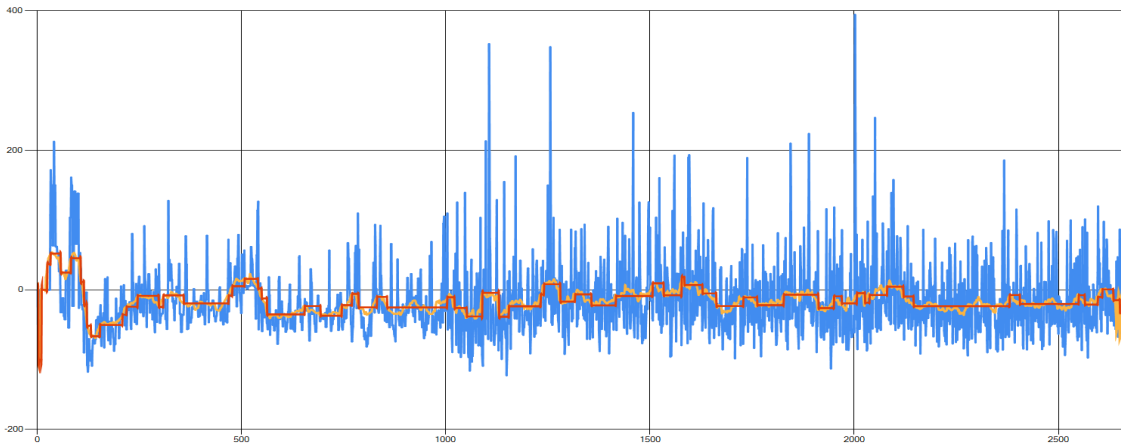


Figure 10. The effect of jump-remover on smoothed data, in the value-time diagram. Blue line is raw data, orange line shows smoothed values, and red line shows the final value

3.4 Experiment

The goal of the experiment is to put the participants in a series of emotional states and extract their emotion using EEG. Emotional states are created in a virtual reality environment by four different emotional factors (Music, 360 degrees films, Images, and text) as explained

above. We had 20 participants, half male and half female in a range of age between 22 and 39 (mean = 30.95 and SD = 5.01), all of them were resident of Montreal with university education degree and from four different origins.

The experiment was situated in an isolated and calm room. Participants worn the VR head set and hands-free. At first, they watched 2 minutes and 16 seconds 360 degrees film, in three parts. The first part is an horror movie, the second part is the view of a firefighters in middle of a house on fire, and finally the last part is a view of passenger of a roller coaster and all these scenes are full of scare and excitatons. One scene of a building in fire is showed in figure 11. In this part, Emotimap is gathering enough data to pre-train the participant data. You can find the protocol of the experiment in appendix 3.



Figure 11. A scene of pre training 360 degrees movie

After that, in a loop, they saw one image that makes them feel negative, and after that, they saw the positive image, 360 degrees film, text or hear music until the end. Between every positive and negative emotional factor, there is a 6th-second rest which is a black scene in silence. The experiment took almost 40 minutes for every participant including filling pre-experiment form and post experiment form. The steps of the experiment are illustrated in figure 12.



Figure 12. Steps of experiment

3.4.1 Software

For this experiment, we have designed and developed two software. One virtual reality application that we created in Unity, able to show the images, 360 degrees film, text and play music. Another software is a control panel, created in C#, connected via a network to the VR and controlling what to show or play, and showing the examiner the participant's emotional state and emotional evolution and emotional factor. The control panel connects to the EEG headset, gathers and saves the data in a file format database (figure 13).

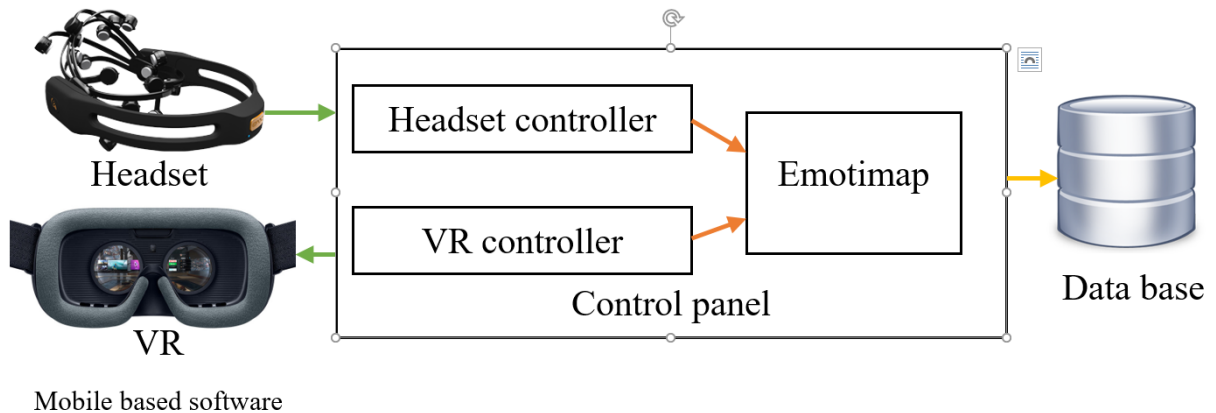


Figure 13. Relation and correlation between the software and hardware of experiment

Inside the control panel, on the top side, we could see the information on the participant and his chosen language, connectivity status and battery level of headset.

The body of the control panel is divided into three parts. Left part is the diagram of Emotimap, where we can see the emotional evolution of participant that is shown in a two dimensions diagram of arousal and valence. Also, we can see the emotional state of participant in the diagram, but to make it easy for user to follow the emotional state we show it on top side

of the diagram for example impatient on figure 14. In the middle, there is a list of emotional factors that is sent or is going to be sent to the VR, this list lets the user know how many emotional factors is sent to the participant and how long it will take to end of the experiment.

On the right side, the examiner can see the image and text that participants see, also, in the list, the examiner can see the last emotional factor sent to the participant (figure 14).

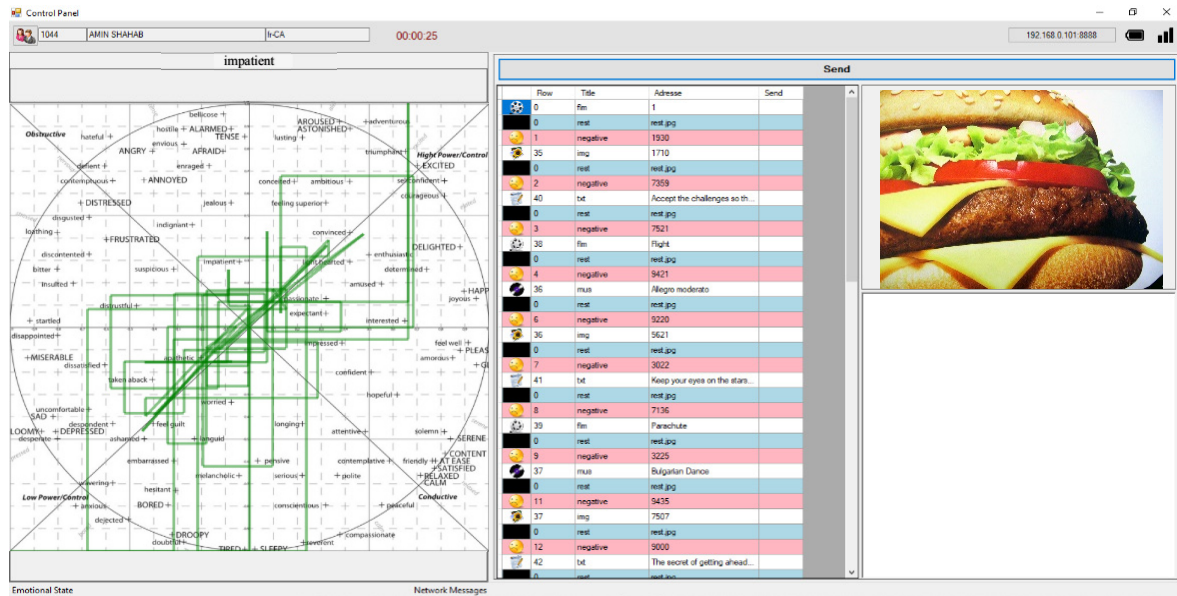


Figure 14. Control panel

3.4.2 Pre-experiment forms

Before the experiment, we explained the steps of the experiment to the participant and they were aware that they are going to see unpleasant images and anytime they could quit the experiment, but if they finish the experiment they will be paid 20\$. Then they read and sign a consent form; you can find this form in appendix one.

Then they filled up the personality test of the big 5; this test determines the characteristics of people into five categories [36]. These categories are

- Extraversion
- Agreeableness

- Conscientiousness
- Neuroticism
- Openness

In Big 5, one question is asked more than one time in using different words or sometime in positive structure and negative structure, then the result of the test is reliable.

We used this test to be able to compare the reaction of the participants when they have similar characteristics. You can find this form in appendix two.

3.4.3 Post-experiment form

After the experiment, participant fills another form where they were asked which emotional factor engaged them more and if they scare of any environment that they have found themselves in the 360 degrees films, to find the reason of the reaction. You can find this form in appendix four.

3.4.4 After experiment conversation

When we were examining the participant, we observed they face and body reaction to the emotional factor that was in the control panel and their emotion detected by Emotimap. When we saw a strange reaction to an emotional factor, we kept it, and after the experiment, we talked to them about their emotion. First, we asked them why they felt like that, and always they had a logic explanation. For example, when one participant was sad as she was watching a very nice and lovely view (illustrated in figure 15), she explained that she knew it is an outstanding landscape, but she had bad memory in a very similar place.

In the middle of the experiment, we saw one or two emotions very repeatedly. When the participant was not on the emotional pick, he/she felt the same emotion. After the experiment we asked them, why they felt like that? They were surprised and certified that we efficiently recognized their mood. We called this general emotion. General emotion is the emotion everybody has in the background of his/her mind, the feeling of a person when he/she is not in the emotional pick. When a person is engaged very hard to a general emotion, he/she does not react to the emotional factor, like a sad person in a party who stay in the corner and does not

participate in the party, or the period that he/she gives attention to the emotional factor is very short, and he/she start feeling like before very fast. We could see clearly these emotions in the Emotimap.



Figure 15. positive emotional factor (image)

4 Results

In the experiment, we have used two groups of emotional factors: negative emotional factor and positive emotional factor in order to make the participant feels bad and good. The emotional factors are four types, images, text, 360 degrees film and music. All the negative emotional factors are based on an image, and positive emotional factor could be any of four different emotional factor types.

We tried to respect the variety of parameters in choosing different emotional factors. For example the 360 degrees films are in different scenes, the color of the scene is different (when two films are from the sea, one of them is under water and is blue, another one is in sea side, and color is khaki).

4.1 Method of assigning emotions to emotional factors

After the experiment, we had the emotional factor and the emotions that participants felt when they were under effect of that emotional factor. All the participants did not exactly felt the same emotions, some part of emotion is common but there were different emotions from person to person. This difference could be because of the noise or it is a real emotion that one person had. We tried to limit the emotions of every emotional factor to the strongest emotions that participant felt as the emotions expected to be created by the special emotional factor.

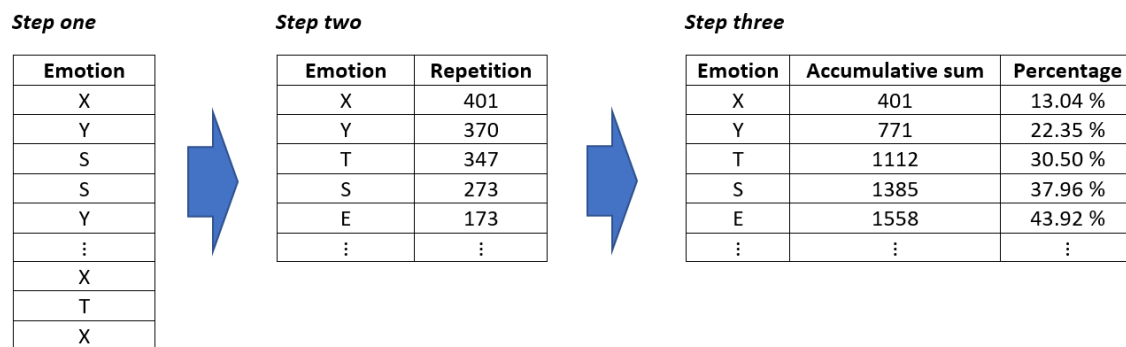


Figure 16. Steps of finding the most powerful emotions created by one emotional factor

To do this, in step one, we made a list of all the emotions felt by all the participant for every emotional factor. Then in step two, we created a list of emotions and the number of repetition of emotions in the list sorted by descending order. In step three, we calculated the accumulative sum and the percentage of repetitions (figure 16).

Finally, all the emotions with the value of accumulative repetitions, less than 80%, (or if there were no emotion with that value then the first emotion in the list) are assigned to the emotional factor as the emotions expected to be created by that emotional factor. Table 1 illustrates a real example, the repetition of tired and sleepy in order with 9 and 5 counts in comparing with apathetic with 888 number of repetitions is not valuable. Column assigned shows the emotions that are assigned to the emotional factor with a tick sign, and the other emotions are shown with cross sign.

Table 1. List of emotions created by an emotional factor and emotions assigned to emotional factor

	Accumulative Repetition	Percentage of Accumulative repetition	assigned
apathetic	888	13.04%	✓
worried	634	22.35%	✓
embarrassed	555	30.50%	✓
distrustful	508	37.96%	✓
longing	406	43.92%	✓
discontent	294	48.24%	✓
pensive	253	51.95%	✓
⋮	⋮	⋮	⋮
happy	33	99.38%	✗
relaxed	15	99.60%	✗
satisfied	13	99.79%	✗
tired	9	99.93%	✗
sleepy	5	100%	✗

In the following diagram (figure 17), we can see the rate of repetitions of emotions created by one emotional factor. The separator (green dotted line) shows the emotions which are assigned to the emotional factor when the percentage of accumulative repetition is less than 80%. Blue bars show the repetition of emotions in the list and orange curve shows the accumulative repetition of emotions in the list.

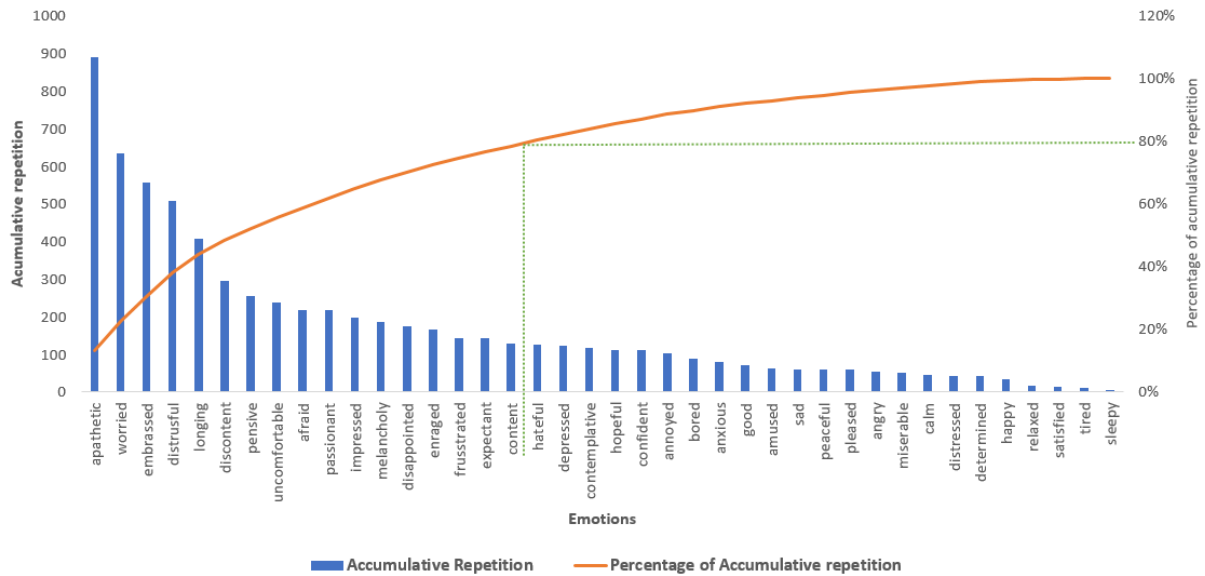


Figure 17. The emotions created by one emotional factor and its accumulative repetition of emotions with their percentage

4.2 Effect of emotional factor

At first, we wanted to know if there are common behavior in reactions to one single emotional factor. So, we extracted the emotion that every participant felt when there were under the effect of the emotional factor and the effective emotion of the participant (with the same method that we assigned the effective emotions to emotional factor, that is making a list of emotions and the number of repetitions of emotions, then creating a list of emotions and percentage of accumulative sum of repetitions of emotions and taking the emotions with percentage less than 80%). We compared these emotions with the emotions assigned to emotional factor to calculate the error rate. We calculated the error rate according three ways.

The first method represents the percentage of emotions assigned to emotional factor that the participant did not feel. In figure 18, we colored it in blue and called it B series. The second method illustrates the percentage of emotions of the participant when he was under the effect of the emotional factor, but these emotions were not assigned to emotional factor, which is shown in orange and called O series. The last method counts the top 80 percent of emotions of the participant when he/she was under the effect of the emotional factor, when these emotions were

not in the list of emotions of emotional factor. This method is just like O series, but we calculate the top 80 percent of the emotions of participant. This method is shown in green and called G series.

According to figure 18, rate error when we count all emotions of the participant is high (blue and orange), the reason is that always people have different emotions, but in the emotional picks, they feel somehow similar emotions.

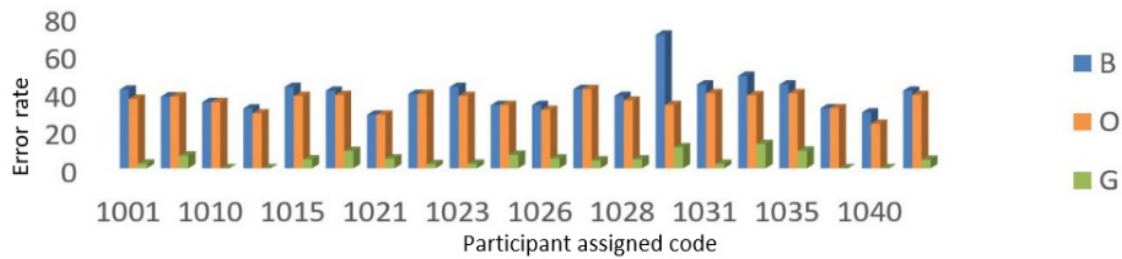


Figure 18. Error rate between emotions that emotional factor created and what participant felt

Table 2 shows the average of error and metric distance of these three methods, as it is mentioned in comparing B, O and G series, an average of error from 46.49% felt down to 19.93 % and then to the 6.32 % which is a good result. The last column shows the metric distance of G series; this parameter shows the distance between the arousal and valence of emotion expected by the emotional factor and what the participant felt. Measuring this distance helps us to know even when the emotions are not the same if the participant emotion was similar, or how near is it to the arousal and valence on the 2D diagram. The result shows that the average of metric distance is 8.63 % and SD is 8.11, these numbers say that normally, emotion expected from emotion felt, is not at all far, participant felt some emotion near to the expected emotion on the 2D diagram.

Table 2. Table of error rate between emotions of participant and emotions normally tagged by emotional factor and its metric distance

Error	B Series	O Series	G Series	Metric distance (G)
Average	46.49 %	19.93 %	6.32 %	8.63 %
SD	17.01 %	13.55 %	6.41 %	8.11 %
No Failure	0.64 %	13.35 %	37.73 %	1.55 %

The last row in table 2 shows the percentage of situations where all the emotions on both sides were the same, meaning there was no error. The rate in B series is very low when it grows up a little for O series, but in G series more than 37 % is with no error, that is a great result.

4.3 Formula comparison

As it is explained in section formula (3.2.3), we could use different formulas to extract the emotions from the brain activities. Then one of our goals was to compare the formulas to clarify what is different between these formulas and which one works the best. Then we kept all the arousal and valence created by different formulas. The formulas could be divided in two groups

- 1- The number of sensors
- 2- The use of β wave ($\beta, \beta_{low}, \beta_{high}$)

Figure 19 illustrates the similarity between the formulas depending on the number of sensors. As it is shown, the most similarity goes to the formulas with same sensors and between β_{low} and β but it is at most about 40% of similarity. And it is going to be worth when the we compare the formula with different sensors. In figure 19, formula axis shows two formulas names that we are comparing. For example, first column at left is $2S - 2S_h$ which shows the percentage of similarity of formula $2S$ and formula $2S_h$ ($2S$ with β_{High}). To make diagram readable, we colored bars based on the first formula of comparing (e.g. blue when first formula is $2S$).

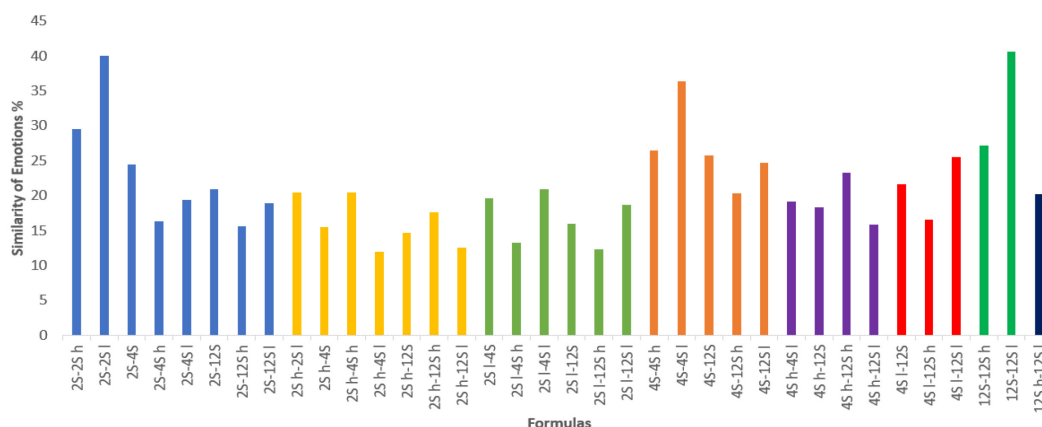


Figure 19. Similarity between the formulas depending on the number of sensors

To understand if there is a difference when extracting two different but near emotions or two emotions totally different we extracted the percentage of metric distance between the formulas (figure 20).

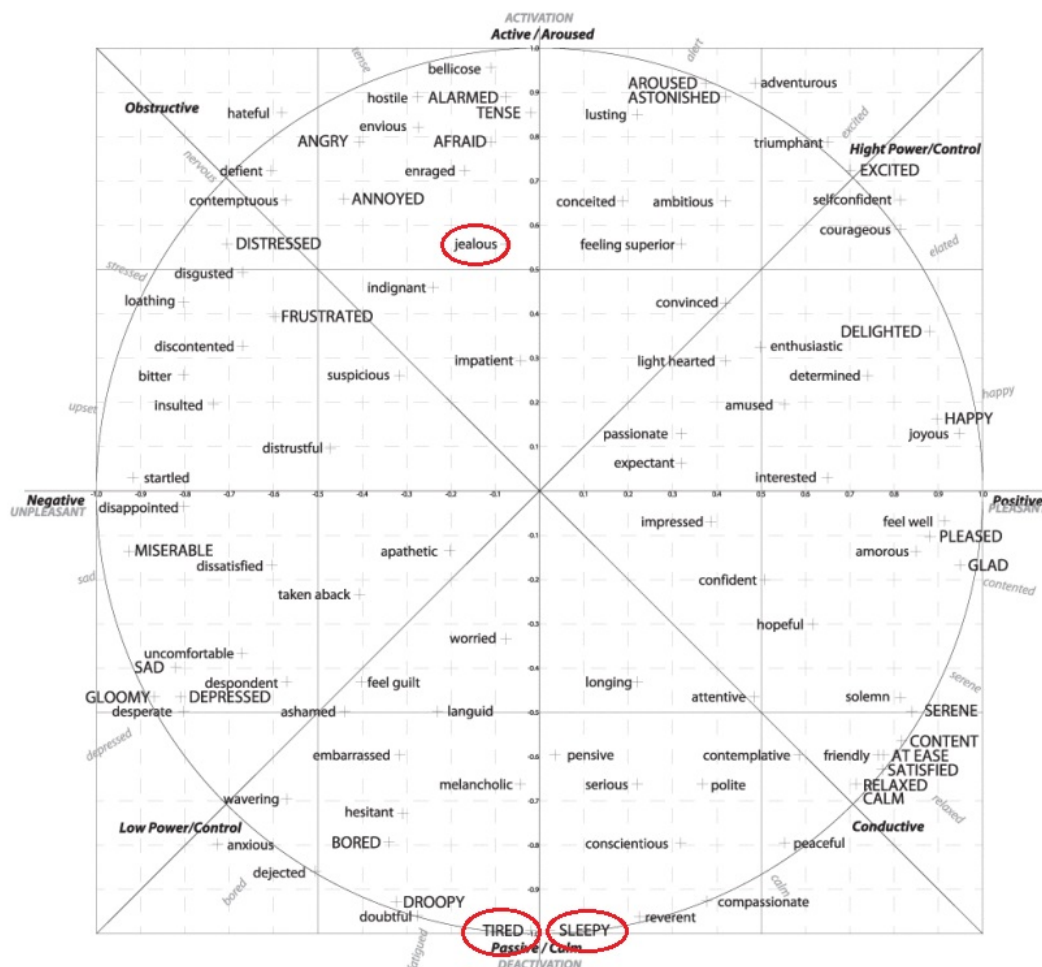


Figure 20. Position of emotion - Comparing the different emotions depends on position

We generated one report that shows the metric distance between the emotions; figure 21 shows that the average of distance between formulas is between about 20 and 60 percentage. The results are so different that we could not replace the formulas, but we can see that the minimum difference is between the formulas with same sensors when they use β and β_{low} witch the formulas with different sensors shows a big distance.

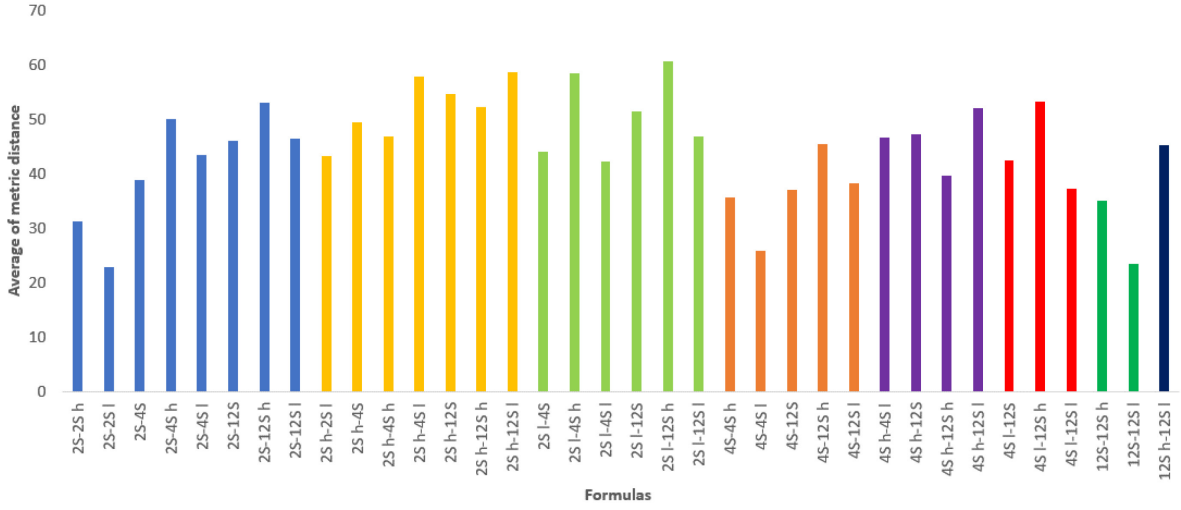


Figure 21. Average of metric distance between the formulas depends on arousal and valence on 2D diagram

After that, we compared the formulas depending on the number of sensors and β , β_{low} and β_{high} to understand the reason of metric distance between formulas. In figure 22, we mapped the values of formulas in a time series. Results show that the formula that used β_{low} are more powerful in picks which means they are bigger values in picks, and formulas with β_{high} are less strong in picks and are smaller. On the other hand, the formula with β_{high} can predict a change of detected emotion sooner and formulas with β_{low} follow the change of detected emotion a little bit later.

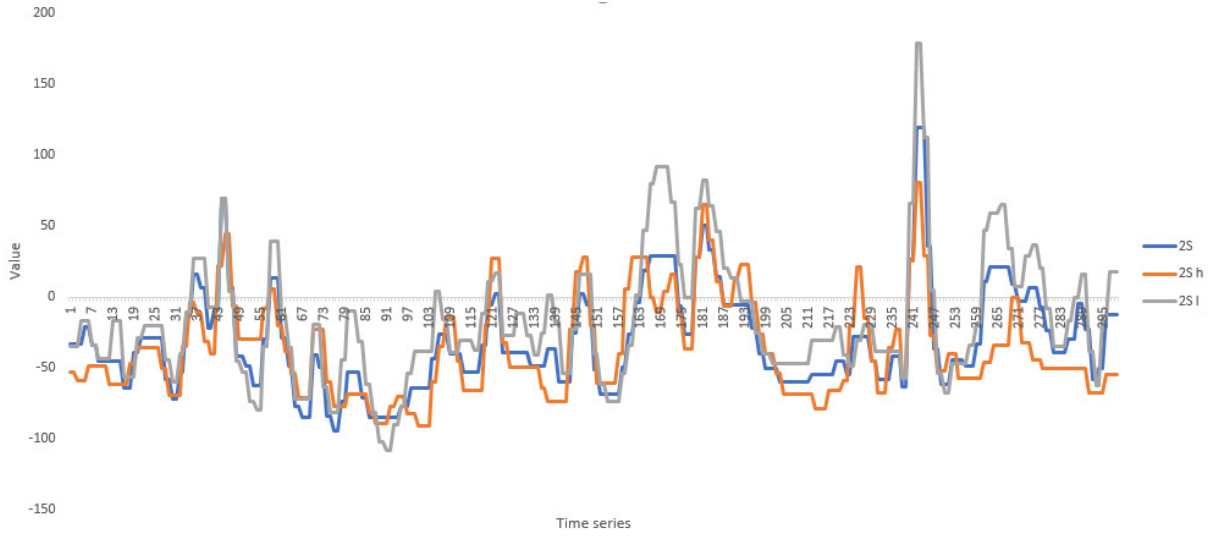


Figure 22. Comparing the formula using β , β_{low} and β_{high}

On the other hand, when we compared the formulas with a different number of sensors, we found that the formulas with 12 sensors follow the changes very weak, and do not follow the strong picks. The number of sensors over the head reduces the sensibility of formula. Formulas with four sensors are more sensible in picks, and the formulas with two sensors are the most sensible (figure 23).

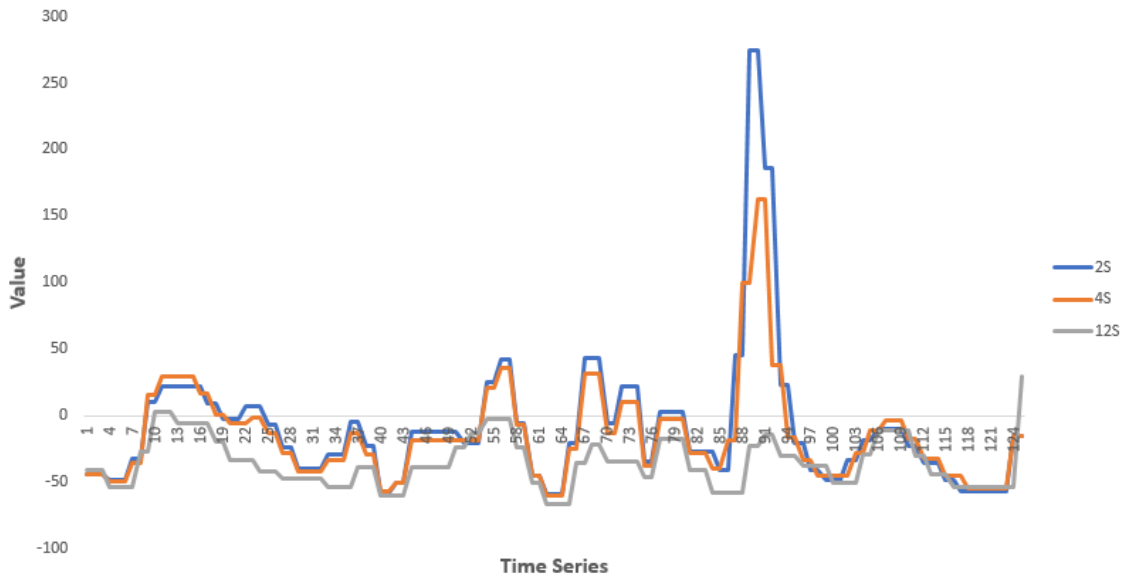


Figure 23. Comparing the formulas depending on the number of sensors

4.4 Big Five

Before every experiment the participant filled a big five form which is a method to categorize the people based on five characteristics factors. These factors are extraversion, agreeableness, conscientiousness, neuroticism, and openness. To do that we calculated the emotional reactions of the participant and make a list of them sorted by the similarity of emotions they had against the emotional factors. Then we used the order and add the values of big 5 results to the list. Then we could consider the characteristics of people who react similarly or not. Then we considered them the result of the big five tests. The result is shown in figure 24; the participant id is sorted depending on the similarity in their reaction to the emotional factor.

In the diagram, we show the list of twenty participants and the values of five parameters of big 5. Participants are sequenced by the similarity of their reactions in experiment, meaning that every two participants next to each other in diagram, has the most similarity and as they are far their reaction is different. For example, participant one and two are the most similar and are the most different by participant twenty.

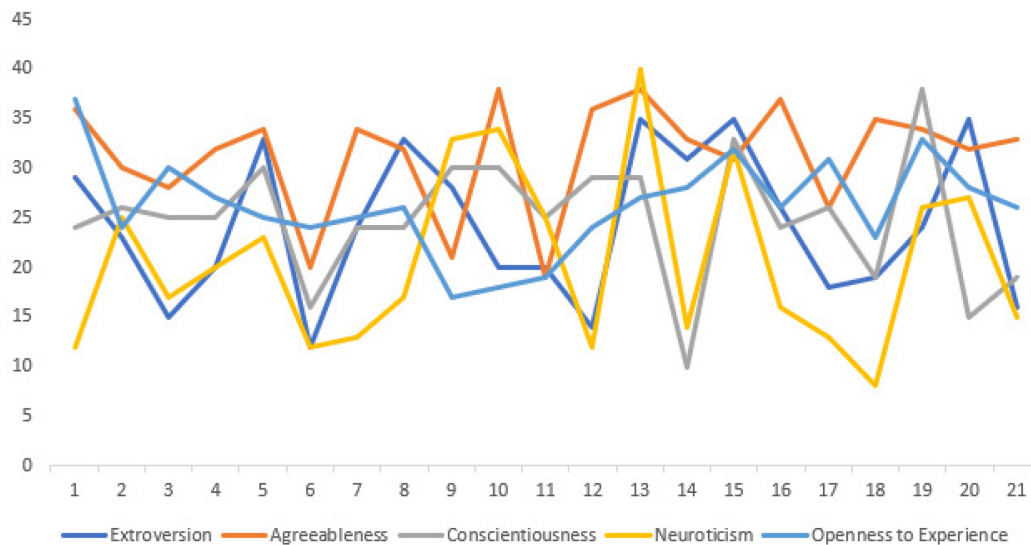


Figure 24. Comparing the characteristic state of participant with similarity of their reaction to the emotional factors

The diagram clearly shows that there is no relation between their characters and similarity of their reaction to the emotional factors. Clearly, there is no logic pattern of changes of none of the big 5 parameters. The values of parameters of big 5 go up and down in limit range with any special behaviour. The reason is that two people with very close characters have different life history and memories, and as we explained before, the memory has a great effect on the human's feeling by pposition to different emotional factors.

4.5 General emotions

When we were creating Emotimap, we saw some fix emotions in monitoring the emotions of everybody. That made us search for the reason. One theory was that it was a bug, but it was different person by person. Then we followed another theory and we talked to the participant. The second theory is that human always feels an emotion, sometimes it is strong, and sometimes it is not strong, sometimes it passed fast and other times the feeling stays with people even for years. When we started to talk to the participants about their moods, how do they generally feel these days, it was the same feeling as Emotimap showed. This is the mood and the emotion of people when there are not under the effect of a strong emotion previously felt in their life which stays with them for a long time. As much as this feeling is strong, a person does not engage with the emotional factor; we call it general emotion.

The emotional reaction of participant to emotional factor is like

- At first, they feel their general emotion,
- when they face up with emotional factor, it takes time to react,
- for a while, their emotion is a reaction to emotional factor (they are on pick),
- then their emotion goes back to their general emotion.

The time that they react to emotional factor and they stay on reaction depends on how their general emotion is strong. As much as they general emotion is strong, they go to the pick longer and stay on pick shorter.

To find the general emotion of everybody we need to extract the participant's emotion when he/she is not engaged with any special emotional factor, when he/she is not on an emotional pick. Then we need to take short first period when the participant was under effect of emotional factor or when the participant is not any more engaged with emotional factor. It is not predictable that emotional factor engages the participant for how long.

In the experiment, the control panel kept the information of emotional factors and the time they were sent to the participant. Then we cut the data by these timings when every cut includes the emotions of participants under effect of any emotional factor. Every time we trigger an emotional factor, it takes a while to be effected by the emotional factor and goes to a pick, the emotions before this pick being the general emotion of participant. We took some first emotions at the beginning of any cut as general emotion when the participants are not still engaged with emotional factor. Then we show first 40%, 50% and 60% as a symbol in a range of 35% to 60% of accumulative of the percentage number of irritated emotion during of the experiment, in the next step we compared how many percentages of these emotions exist at the beginning of emotional time. The error rate and the situation with no failure are shown in Table 3.

Table 3. Error rate of detected general emotion

First n% of most repeated emotion	40%	50 %	60%
Average	5.00	3.50	7.31
SD ¹⁰	22.36	11.82	10.99
No Failure	95 %	90%	65%

As it is shown in table 3 and figure 25, for about 40% of the most repeated emotion we could reach 95 % of correct recognition of general emotion. This rate falls as we enlarge the share of the most repeated emotion. In figure 25, we can see that the rate of correct recognition of general

¹⁰ Standard deviation

emotion is a maximum of 35% as the limit of the most repeated emotion, and it starts to fall slowly and continually when it passes 41%.

The possibility that no emotion exists in the cut is less than 35% of accumulative sum of repetition of emotions, on the other hand, less value does not change the maximum, so we ignore it.

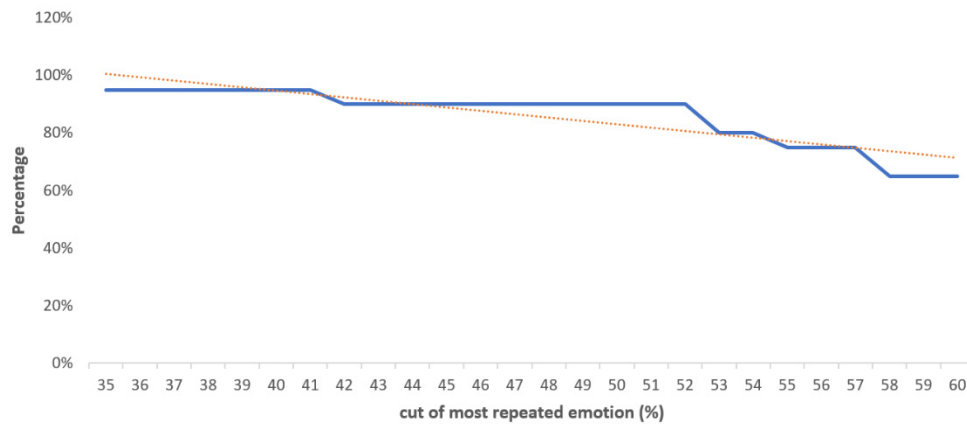


Figure 25. Rate of general emotion recognition with no error depends on the cut of most repeated emotion (%)

5 Conclusion

The objective of this research was to extract and monitor the current emotion and the general emotion of human in order to help the humanity with health, entertainment, etc. To do this we designed and created Emotimap, a tool that connects to a EEG headset and collects the brain activities data, filters and transforms them into a meaningful data where we can extract the emotion of people based on arousal and valence and monitor the correct emotion, general emotion and the emotional evolution of people on a two dimensions diagram.

This study showed that everybody is experiencing more than one emotion at a time. These emotions could be very complex to recognize even for the person. Also, everybody feels two types of emotions; an emotion that one person senses when he/she is not experiencing an emotional pick. We called it **general emotion** and person usually feels it for a long time (it could stay with a person even for years). General emotion could engage strongly a person when the emotional factor could engage a person hardly and for a short period. On the other hand, every person could have different emotions depending on the situation and the ambiance around him that could be strongly or weakly engaged, for a short or long period. This emotion is the **current emotion** of the person. Current emotion depends on the emotional factor around the person and his/her general emotion, and the strongest parameter is the life history and memory of a person. Research shows that memory is so effective that even people with similar characters, react differently to a similar emotional factor. Comparing the formulas shows that frontal part of the brain shows the emotional pick strongly. And the strongest formula is the formula with two sensors of *F3* and *F4*.

The experiment showed that Emotimap is a very powerful and reliable tool that shows the emotional states of people. We tested Emotimap when a participant who was a real fan of soccer watched a soccer match and we recorded the film of match and the emotional evolution of participant. After that we played the movie, the participant explained step by step all the emotions and why he felt like that, even that emotion was not expected at that moment. Emotimap shows the general emotion and current emotion of people precisely and is very useful in a big variety of usage. When a psychologist visits a patient, if he/she knows about the general emotion of patient, also be aware of the emotional reaction of patient again the question and

emotional factor, then the doctors are somehow watching the emotion of patient, just like when a doctor watch a x-ray of a bon of patient. The amount of information that the doctor could get in a short time is huge. Maybe we could say that Emotimap is an x-ray machine of the emotions.

The ability of Emotimap to recognize and shows the general emotion is critical. There is some job position that could affect on human life, a pilot, a surgeon, a police office, school bus driver and lots of other job positions, carries a heavy responsibility on their shoulder. If we could make sure that they are in a good emotional state to do their tasks, we could reduce the personal failure, at least in this kind of jobs. Also, we could find out when they need help and by helping them as soon as possible, have a healthy society.

Babies, unconscious patient and a retarded and sometimes elder people could not explain their needs. We could use Emotimap to find out how they feel, what problem they have, so we can help them. This help is positive in two sights, first one is they need help and helping people is a great job, the second is, as much as we have healthier individual, our society will be healthy, people will be more motivated and healthy society make the individual happier and healthier. Also, it reduces the cost of government in different parts like health, entertainment, etc.

We have two goals as the future work, the first one is to make Emotimap as much as possible more precise and enlarge the number of emotions that Emotimap could extract. Second goal is to find if there is correlation between γ and θ waves activities and α and β waves behavior, to use to extract the general and current emotions of participant faster and more precisely.

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Appendix one: consent form

FORMULAIRE DE CONSENTEMENT

Titre de la recherche : Étude des réactions émotionnelles et cérébrales au but de réduction des émotions au moyen d'environnement de Réalité Virtuelle.

Chercheur : *Amin Shahab, Étudiant MSc, DIRO, Université de Montréal*

Directeur du Laboratoire : *Claude Frasson, Professeur, DIRO, Université de Montréal*

A) RENSEIGNEMENTS AUX PARTICIPANTS

1. Objectifs de la recherche.

Ce projet de recherche vise à étudier les réactions émotionnelles et cérébrales au but de réduction des émotions au moyen d'environnement de Réalité Virtuelle. Nous allons ainsi enregistrer les données physiologiques du participant au fur et à mesure qu'il est en train d'expérimenter notre système d'apprentissage Emotimap.

2. Participation à la recherche

Votre participation à cette recherche consiste tout d'abord à remplir un formulaire pour connaissance caractéristique initial. Ensuite vous expérimentez un système qui vous montre des images, des films, des textes ou qui vous fait entendre des musiques (les images peuvent comprendre des images émotionnelles sensibles, vraiment tristes ou neutres). Enfin vous remplirez un autre formulaire de déclaration d'émotion ressentie.

Ceci implique d'enregistrer le signal physiologique à savoir l'activité cérébrale (EEG). Les enregistrements se feront à l'aide de capteurs non intrusifs. L'expérience se déroulera dans un local du département d'informatique de l'Université de Montréal et durera ~1h. Vous bénéficierez d'un montant de 20\$ après votre participation à cette expérience.

3. Confidentialité

Les renseignements que vous nous donnerez demeureront confidentiels. Chaque participant de l'étude se verra attribuer un numéro d'identification. Aucune information permettant de vous identifier d'une

façon ou d'une autre ne sera publiée. Ces données seront conservées durant sept ans, conformément à la politique habituelle de l'Université de Montréal. Après ce délai, elles seront totalement détruites.

4. Avantages et inconvénients

L'utilisation des capteurs physiologiques est indolore et sans risque. En participant à cette recherche, vous pourrez contribuer à l'avancement des connaissances d'émotion par les activités cérébrales et ses potentiels. Vous bénéficierez d'un montant de 20\$ après votre participation à l'expérience.

5. Droit de retrait

Votre participation est entièrement volontaire. Vous êtes libre de vous retirer en tout temps par avis verbal, sans préjudice et sans devoir justifier votre décision. Si vous décidez de vous retirer de la recherche, vous pouvez communiquer avec l'assistant de recherche, au numéro de téléphone indiqué à la page suivante du formulaire. Si vous vous retirez de la recherche, les renseignements qui auront été recueillis seront détruits et vous n'aurez pas à rembourser le 20\$ reçu lors de votre participation à l'expérience.

B) CONSENTEMENT

Je déclare avoir pris connaissance des informations ci-dessus, avoir obtenu les réponses à mes questions sur ma participation à la recherche et comprendre le but, la nature, les avantages, les risques et les inconvénients de cette recherche.

Après réflexion et un délai raisonnable, je consens librement à prendre part à cette recherche. Je sais que je peux me retirer en tout temps sans préjudice et sans devoir justifier ma décision.

Signature : _____ Date : ____ / ____ /2017 _____

Nom : _____ Prénom : _____

Je déclare avoir expliqué le but, la nature, les avantages, les risques et les inconvénients de l'étude et avoir répondu au meilleur de ma connaissance aux questions posées.

Signature du chercheur _____ Date : ____ / ____ /2017 _____
(ou de son représentant)

Nom : **Shahab**

Prénom : **Amin**

Pour toute question relative à la recherche, ou pour vous retirer de la recherche, vous pouvez communiquer avec Amin Shahab, assistant de recherche, au numéro de téléphone suivant : [REDACTED] ou à l'adresse courriel suivante : amin.shahab@umontreal.ca

Toute plainte relative à votre participation à cette recherche peut être adressée à l'ombudsman de l'Université de Montréal, au numéro de téléphone [REDACTED] ou à l'adresse courriel ombudsman@umontreal.ca. **(L'ombudsman accepte les appels à frais virés).**

Un exemplaire du formulaire de consentement signé doit être remis au participant s'il le demande

Appendix two: Big 5 form

	Disagree	Neutral		Agree	
I am the life of the party.	0	0	0	0	0
I feel little concern for others.	0	0	0	0	0
I am always prepared.	0	0	0	0	0
I get stressed out easily.	0	0	0	0	0
I have a rich vocabulary.	0	0	0	0	0
I don't talk a lot.	0	0	0	0	0
I am interested in people.	0	0	0	0	0
I leave my belongings around.	0	0	0	0	0
I am relaxed most of the time.	0	0	0	0	0
I have difficulty understanding abstract ideas.	0	0	0	0	0
I feel comfortable around people.	0	0	0	0	0
I insult people.	0	0	0	0	0
I pay attention to details.	0	0	0	0	0
I worry about things.	0	0	0	0	0
I have a vivid imagination.	0	0	0	0	0
I keep in the background.	0	0	0	0	0
I sympathize with others' feelings.	0	0	0	0	0
I make a mess of things.	0	0	0	0	0
I seldom feel blue.	0	0	0	0	0
I am not interested in abstract ideas.	0	0	0	0	0
I start conversations.	0	0	0	0	0
I am not interested in other people's problems.	0	0	0	0	0
I get chores done right away.	0	0	0	0	0
I am easily disturbed.	0	0	0	0	0
I have excellent ideas.	0	0	0	0	0
I have little to say.	0	0	0	0	0
I have a soft heart.	0	0	0	0	0
I often forget to put things back in their proper place.	0	0	0	0	0
I get upset easily.	0	0	0	0	0
I do not have a good imagination.	0	0	0	0	0
I talk to a lot of different people at parties.	0	0	0	0	0
I am not really interested in others.	0	0	0	0	0
I like order.	0	0	0	0	0

I change my mood a lot.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am quick to understand things.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I don't like to draw attention to myself.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I take time out for others.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I shirk my duties.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I have frequent mood swings.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I use difficult words.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I don't mind being the center of attention.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I feel others' emotions.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I follow a schedule.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I get irritated easily.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I spend time reflecting on things.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am quiet around strangers.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I make people feel at ease.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am exacting in my work.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I often feel blue.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am full of ideas.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Appendix three: protocol of the experiment

Protocole Expérimental

Shahab, Frasson (février 2017)

Installation :

1. Utiliser chaise roulettes
2. Charger le logiciel (Emotimap)
3. Installer l'Emotiv et google cardboard
4. Mettre en ligne le formulaire Google ('Big V', 'Pre-session form' et 'post-session form')

Installation matérielle (~10-15 min)

1. **Formulaire de consentement** : faire lire et signer le formulaire de consentement aux participants.
2. **Formulaire 'Pre-session form'**: faire remplir le formulaire 'Pre-session form' aux participants.
3. **Forme d'enregistrassions** : faire remplir la forme d'information personnelle dans Emotimap.
4. Demander aux participants d'éteindre leurs téléphones.
5. **Réalité virtuelle** : Placer Google Cardboard, Verifier que participant soit allaise et VR est visible
6. **EEG** : Placer et calibrer le casque Emotiv EEG.
7. **Explication** : expliquer tous les niveaux d'expérimentation à participant
8. Proposer aux participants d'utiliser leurs écouteurs.

Emotimap

Calibration (~2 min)

Faire écouter une musique pour 1 :57 pour avoir une taille suffisant des données d'Émotive pour entraîner Emotimap

Faire voir une page noire et dans silence

Test (~35-45 min – 40 facteur d'émotion négatif)

- 1- Faire voir des facteurs d'émotion négatif. (7 second)
- 2- Après chaque une, faire voir ou écouter un des facteurs d'émotion positif (la music, l'image, le texte, le film 360 degré).
- 3- Faire voir une page noire un silence pour relaxer. (3 second)

Répéter jusqu'à dernière facteur d'émotion et à la fois Emotimap interprète des données d'Emotiv et les montre sur le diagramme de Roussel's Circumplex.

Facteur d'émotion négatif sera montré 7second, et la page noire silence sera montré 3 second, mais pour les facteurs d'émotion positif, il n'y a pas temps fixe, moi, je suivie révolution émotionnelle de participant sur le diagramme, et j'attende pour un changement sensible ou pas pour longtemps pour continuer expérimentation.

Temps pour facteur d'émotion négatif est fixe (7 sec) parce qu'il y a trois types des participant

- 1- Très sensible
- 2- Normale
- 3- Peut sensible

Après 7 sec, pour les gens peut sensible et quelque fois normal, on commence à faire attention à d'autre chose, alors on ne peut pas mesurer notre facteur d'émotion positif Et temps pour facteur d'émotion positif est flexible, parce que on a besoins de trouver quel facteur affect plus tôt et quel plus efficace, et c'est pour quel type des gens.

Après le test (~10-15 min)

1. Arrêter Emotimap.
2. Arrêter Emotiv.
3. Arrêter Google Cardboard.
4. Retirer tous les senseurs.
5. Éteindre le téléphone portable.
6. Prendre une copie de sauvegarde des données d'Emotimap.
7. Mettre en ligne les formulaire Google 'post-session form', 'Big V'.
8. Faire remplir le formulaire 'Post-session form' par le participant.
9. Faire remplir le formulaire du Big V par le participant.
10. Faire remplir le formulaire de paiement par le participant.
11. Payer le participant.
12. Expliquer l'objectif de l'expérience.
13. Demander de ne pas parler aux probables futurs participants du déroulement de l'expérience.

Appendix four: post experiment form

1- Normally you consider yourself ...

Sleepy	Tired	To fear	Angry	Calm	Relax
Content	Depressed				

2- Before experimentation you were

Sleepy	Tired	To fear	Angry	Calm	Relax
Content	Depressed				

3- Every emotional factor had how much effect on you?

	Lots (negative)	A little (negative)	noting	A little (positive)	Lots (positive)
Picture (negative)	0	0	0	0	0
Picture (positive)	0	0	0	0	0
Music	0	0	0	0	0
Text	0	0	0	0	0
Film	0	0	0	0	0

4- give a rate to each emotional factor that show how much it could make you feel better.
(-5 feel bad, +5 feel good)

[illegible]

5- What type of emotion factor could keep your attention more? (0 less, 5 more)

	0	1	2	3	4	5
Picture	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Music	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Text	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Film	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

6- in middle of the experiment, is there anything that take your attention away?

Not at all Rarely Sometimes Often all the times

7- How you feel comfortable with any of the following?

	Not at all	Not at all	Not at all
Flight	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
height	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sea	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
animals	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

8- Your idea about the experimentation...

Appendix five: paper

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Using Electroencephalograms to Interpret and Monitor the Emotions

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Abstract. Detecting the real-time human emotions became recently one important issue in Artificial Intelligent (AI). Numbers of research on emotional facial expressions, the effect of emotion on heart rate, eye movement and the evolution of emotions with the time show the interest of this topic. This paper presents a method for observing the human's emotional evolutions (sequence of emotions) based on brain activities in its different parts. The Emotiv EPOC headset collects the data of Electroencephalograms (EEG) of the participant to calculate the arousal and valence. After training the system with headset output data, the noise and brain's data other than emotional information will be cut out according to two levels of filtering. Finally, mapping the result (arousal and valence) with two dimensions circumplex space model presents the real-time emotional evolutions of the participant. Real-time emotional evolutions show all the picks of positive and negative feelings, moreover, analyzing the EEG data will allow recognizing the general emotions, which are the strongest routine senses of the participant. Comparing the unexpected reaction, the time taken by general emotion and feelings in picks, give us a tool to observe the health situation of the people and on the other hand, is an instrument to measure the mood of the people against a video game, news and advertising.

Keywords: Artificial Intelligence, Emotion, Sentiment Analysis, Virtual Reality, Arousal, Valence, Opinion Mining.

1 Introduction

Every day we see the quick changes in lifestyle which are the result of the advanced facilities, ease in life and new medical solutions, for humanity. However, this development leads people to a new and modern lifestyle, among noises and air pollutions [1], that could make a mental problem. Emotions and resulting from emotions are unobservable parts of human being, and it makes this kind of research more complicated. Recently, the number of investigation on sentiments analysis and also named opinion mining that are methods based on detect real-time emotions and feeling of human, in both aspect of academic and commercial is growing [2,3]. The researchers used different applications to identify emotions, such as facial expression [4-

6], heart rate variation, skin conductivity and respiration [7,8], although these methods are not reliable, because of lots of reason. For example, when facial expression system is detecting person's emotion using his/her face with natural frown eyebrows, or a person who smiles whenever is nervous, or when we use a heart rate variation system to detecting person's emotion who has blood pressure problem, cannot work precisely. For these reasons, researchers are progressively interested in using EEG as a reliable source to identify the emotional situation of human [4,9]. EEGbased system was designed to be used by disabled people [9] but reliability and excitement of controlling the environment just by the power of thinking, is going to make it the next generation of wearable computer in a variety of applications, such as

- A better choice than controller or Kinect in VR and gaming [10,11].
- Designing software and problem-solving system [10,12].
- Marketing, transport, and health [13,14]

In this paper, we analyze the emotion of participants when they are watching 360 degrees movies, an image or a text as well as when they are listening to the music in a virtual reality (VR) environment. Emotiv EPOC extracts the brain participant EEG data. Mapping the arousal and valence, calculated by the value of the brain waves of EEG data, on the two dimensions circumplex space model, return one feeling. By comparing the time series of emotions of participants when they are under the effect of an emotional factor and compare the time series of emotions of one participant. During the experiment, we tried to (1) find the evolution of emotions, (2) compare the formulas, (3) find the general emotion of participant. This paper is structured as following: section 2 explains the emotional evolutions, section 3 explains the experiment and the method used to interpret the data, and in section 4 the results obtained will be discussed.

2 Emotional Evolutions

The most complex and unreachable part of human being is the mind, and fortunately, very soon, researchers find out that there is a close interrelationship between brain waves and the psychological state of the person [3,15,16] and it became a way to catch people's emotion. Reading emotion of individuals is crucial, and it could help lots of people to live a better life. The first task of psychologists is understanding the mental situation of a patient; the patient

should talk until the doctor analyzes him/her, and this would be facilitated if the patient could explain how does he/she feel. For another example, if the system could analyze the emotional state of the person facing critical jobs related to human lives, like a pilot or a surgeon, whenever his/her mind is not enough ready and focused, the person and his/her colleagues could be alarmed. Usually, the team trusts their leaders, and they could hesitate to interrupt him/her until it is unfortunately too late.

The goal of this research is to detect the emotional state of a participant in different emotional situations, then to show their emotional evolutions on two dimensions circumplex space model. Emotional evolution is the sequence of emotional changes of a human. We create a software called Emotimap to interpret the EEG to show the human's emotional state and evolution of the emotions. In this paper, we will talk about

1. The effect of emotional factors on participants (monitored by Emotimap).
2. The methods of calculating the arousal and valence and comparing them.
3. General emotions in the evolution of emotions (interpreted by Emotimap).

3 Experiment

The objective of this experiment is to put the participant in a sequence of emotional states and detect their emotions using their brain activities. The emotional states are produced by four kinds of emotional factors (360 degrees film, image, text, and music) in a virtual reality environment.

3.1 Subjects

The subjects are 20 and include 10 males and 10 females in the age range between 22 – 39 (mean = 30.95 and SD = 5.01) all resident of Montreal with four different origins.

3.2 Experimental Procedure

The subjects participated in the experiment individually; every experiment takes almost 40 minutes include filling the pre-experiment and post-experiment forms. The experiment is divided into four steps illustrated in figure 1.

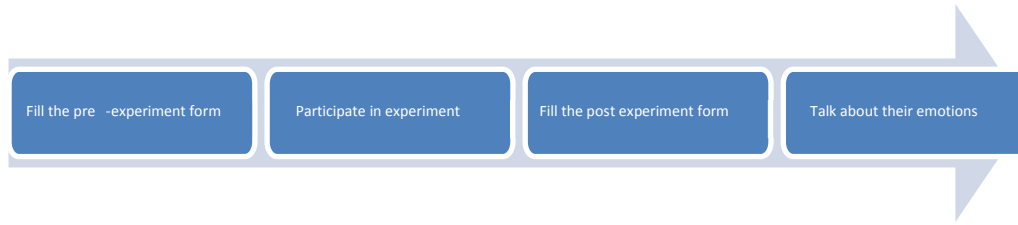


Fig. 1. The steps of experiments

In step one, every participant is assigned to one unique key, and he/she fills up the big five personality test which is a test that categorizes the people by their characters [17]. Step two is the main part when the subject participates in the experiment, we will detail it in following. In step three, the participant fills up the form about his/her feeling and positive or negative effect of every emotional factor. The goal of this form is to find out if there is a logical reason when a subject has a different emotion from the feels that emotional factor should normally create. In the last step, we discuss with the participant about their feelings. In the middle of the experiment, we observed what a participant sees, hears and their emotional evolution in Emotimap, and we look at their face and body reaction. In all the experiments, we observed a strange and unexpected feedback from the participant.

Software. The experiment uses two software. The first one is the virtual reality mobile base software, and the other one is a windows desktop that connects to the mobile based software and controls it, at the same time, logs into the Emotiv headset to collect the EEG data, also calculates the emotions and keeps the data in a data base. Figure 2 illustrates the procedure of experiment.

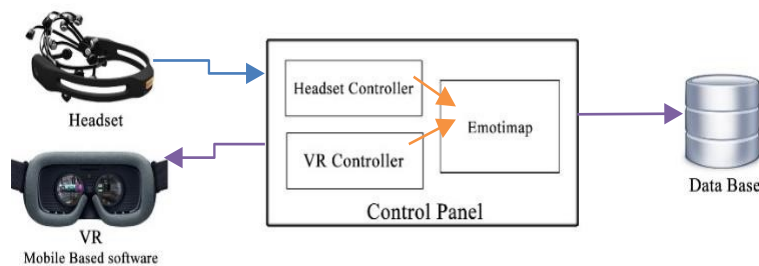


Fig. 2. Experiment software relation

Headset. In this experiment, we use Emotiv EPOC headset which is a fourteenchannel EEG headset. This headset can return the value of α , β_{low} , β_{High} , γ and θ of any single sensor.

VR. The participant uses Google Cardboard VR, which is not expensive, easy to use and supports different models of cell phone. Whenever the control panel (the Windows desktop software) sends a command to the mobile base VR software, the VR reads the command and follows the orders to display images, 360 degrees films, messages and play music.

Control panel. Control panel is the core of the system which (1) connects to the Emotiv to collect the EEG data, (2) interprets the result and (3) control what VR is showing and playing. After the beginning of every experiment, the control panel shows a 360 degrees film for 97 seconds to pre-train the participant individually, then it shows 7 seconds rest. The rest displays quiet black surroundings; we chose a black color because in the VR the sharp light bothers the eyes. Then in a loop to the end of the emotional factors, the system shows one negative emotional factor which makes the participant feeling negative (7 seconds). Then in continue one of the positive emotional factors include an image (15 seconds), text message (20 seconds), 360 degrees film (50 seconds) and music (50 seconds).

Emotional factor. Emotional factors are the elements we used to effect on the emotion of the participants. We needed an emotional factor to trigger negative emotions and positive ones. For negative emotional factor, we used images from IAPS (International Affective Picture System) [18] which is a standard database of images used in studies about emotions. For positive emotional factor, we have four categories.

- Images (positive): we used IAPS, with some added images.
- Text: we used the quote of scientist, philosophers, and politicians. Every quote in three languages (English, French, Farsi). The participants talk at least, one of these languages natively or in advanced and they just pay attention to the concept.
- 360 degrees film: we used YouTube to find 360 degrees film with different parameters such as color, ambiance, etc.
- Music: we selected instrumental music with one primary instrument to avoid the effect of the different instrument sound (the feeling that sound of the violin makes is different than the sound of the saxophone) when the music track follows the variety in mode, scale, tempo, etc.

Emotimap. Emotimap is the tool that we have developed. It receives the data of the EEG headset, independently of model and brand, and interprets the data to calculate the arousal and valence. Emotimap uses the nearest neighbor method to find the current emotion of participant and shows it on a two dimension circumplex space model (arousal and valence) [2]. Figure 3 shows the Emotimap in the left part of the control panel. Emotimap shows the evolution of emotions from the beginning of the experiment and currently detected emotion is showed on top of Emotimap. The diagram of Emotimap (two-dimensions circumplex space) is taken from Georgios Paltoglou et al. [2]. List of the emotional factors that control panel sends to VR is shown in the middle. In the right side, we can see what the participant see or hear.

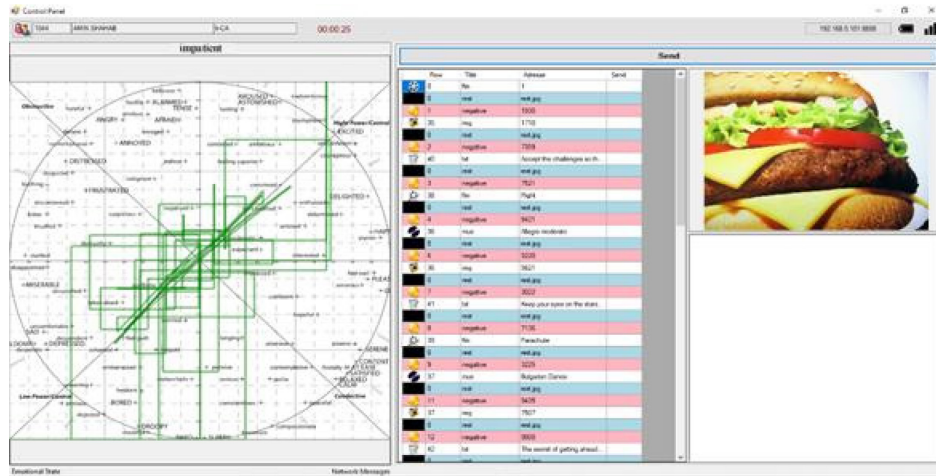


Fig. 3. Control panel, send the emotional factor to the VR and let the examiner see the emotional state of a participant in Emotimap at left and what he/she see and hear at right.

Arousal indicates the value of emotion varying from unpleasant to pleasant, and valence demonstrates the amount of quantitative activation varying from calm to excited [19]. Arousal and valence are the results of comparing the brain activity of human in different parts of the brain. We use the formulas (explained in the following part) to calculate the arousal and valence. Brain manages all the internal organs such as heart, lung, glands and their hormones while the human is thinking, watching, remembering and saving the memories. To extract the pure data of emotions we use two level of filtering (explain in following).

Formulas. Based on the ratio of activation of α and β waves in different parts of brain there are formulas that calculate the arousal and valence [20], in the experiment we kept the values of all of them to compare. We have three categories of formulas with two EEG sensors (2s: F_3, F_4), four EEG sensors (4s: F_3, F_4, AF_3, AF_4) and twelves

EEG sensors (12s: $F_3, F_4, AF_3, AF_4, F_7, F_8, T_7, T_8, P_7, P_8, O_1, O_2$), based on international EEG positions [5,21], and when it is mentioned low or high, that means the formula uses β_{low} or β_{high} . Formulas (1) and (2) in order are the arousal and valence with 12sensors, to calculate other formulas, remove the sensors which are not in its category.

$$Arousal = \frac{\beta F_3 + \beta F_4 + \beta AF_3 + \beta AF_4 + \beta F_7 + \beta F_8 + \beta T_7 + \beta T_8 + \beta P_7 + \beta P_8 + \beta O_1 + \beta O_2}{\alpha F_3 + \alpha F_4 + \alpha AF_3 + \alpha AF_4 + \alpha F_7 + \alpha F_8 + \alpha T_7 + \alpha T_8 + \alpha P_7 + \alpha P_8 + \alpha O_1 + \alpha O_2} \quad (1)$$

$$Valence = \frac{\beta AF_4 + \beta F_4 + \beta F_8 + \beta T_8 + \beta P_8 + \beta O_2}{\alpha AF_4 + \alpha F_4 + \alpha F_8 + \alpha T_8 + \alpha P_8 + \alpha O_2} - \frac{\beta AF_3 + \beta F_3 + \beta F_7 + \beta T_7 + \beta P_7 + \beta O_1}{\alpha AF_3 + \alpha F_3 + \alpha F_7 + \alpha T_7 + \alpha P_7 + \alpha O_1} \quad (2)$$

Filters. We have access to data of the brain cortex. The brain is governing all areas of the body all the time. Human being emotions are complicated which means that one person in a short period of the time has more than one feeling and some of them are stronger than the others. For example, when a person sees a celebrity, he/she is happy, excited, shocked and sometimes nervous. Then Emotimap reduces the small changes in emotional evolutions time series and attention to keep the stronger feels, using two filters.

- Smoother: ignores small shift to avoid the unnecessary movement. The position of the arousal and valence on Emotimap, are always shaking, when this movement is in a small area, and detected emotion does not change too much, so to avoid the complexity and to increase readability, Emotimap ignore this shaking.
- Jump-remover: reduces the small changes, by avoiding sharp variation when is not stable, that means we do not keep the feelings which pass very fast.

4 Results

In the experiment, we look at participants and observe their face and body reactions to the emotional factor and the feeling that Emotimap recognizes. After that, we had talked to them and ask them to explain how they felt while they saw or heard the emotional factor when they had an unexpected reflex; the most exciting part was that participants felt exactly like what Emotimap showed, and they had a reason to feel like that. For example, when one of the participants watched a breathtaking green landscape, Emotimap detected sadness; participant explained that it is a lovely and beautiful image, but she had bad memories in a similar place. In every experiment, we saw examples like that, or sometimes the whole of the experiment was under the effect of some emotions, explained in general emotion section. The reason is that nobody has a white empty mind that reflects the emotion of a scene or music as a mirror,

everyone has unique memories and life story which strongly affect on his/her emotional state (figure 4).

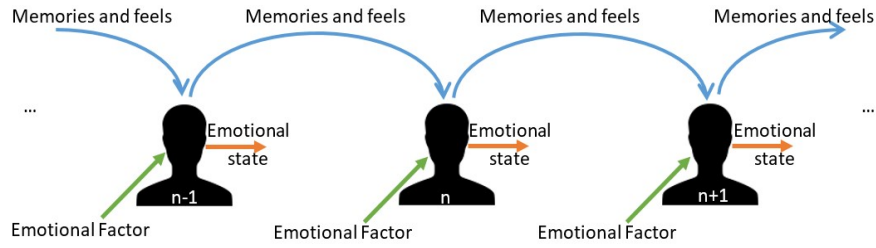


Fig. 4. The emotional state of people depends on the emotional factors around them, and their memories, effect of memory is much stronger than the emotional factors.

4.1 Typical Effect of the Emotional Factor

Effect of Emotions. We calculate the error rate of what participants feel the emotion that emotional factor creates. To find the emotions of one emotional factor, we take the percentage of the accumulative sum of the descending sort of count of emotions of all the participants when they were under effect of emotional factor. Then we take all the emotions with accumulative sum under 70% or if there were no emotion, we took first emotion. (figure 5)

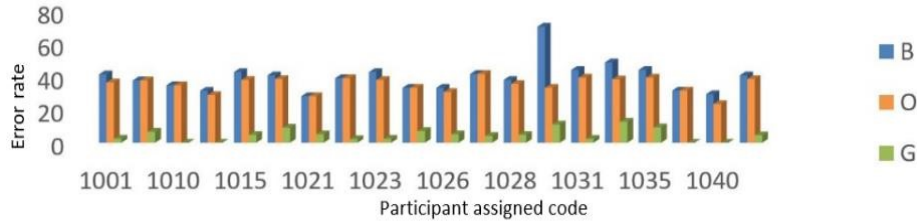
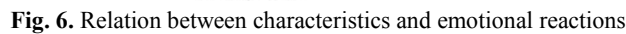


Fig. 5. Error rate of the emotions of emotional factors and what the participant feels

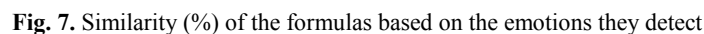
B series (Blue bar) represents the percentage of the number of emotions of an emotional factor which is not in participant's emotion, plus the contrariwise, divided by total numbers of the emotions on both sides. O series (Orange bar) shows the percentage of the numbers of participant emotions which is not in emotional factors divided by the total of the feelings of participant's emotions. G series (Green bar) illuminate O series, but just count the accumulative sum of percentage less than 70% of participant emotions and if there were no item, count the first emotion. According to Table 1, B series display almost 50% failure, although in O series, failure average drops to 19.93%, but it is not reliable rate. G series with 6.32% average of error is stable. The fourth column shows the metric average of distance.

Failure	B series	O series	G Serie	Metric dist.
Average	46.49 %	19.93 %	6.32 %	8.63 %
SD	17.01 %	13.55 %	6.41 %	8.11 %
No failure	0.64 %	13.35 %	37.73 %	1.55 %

The Relation Between Emotional Reaction and Characteristics. Before the experiment, all the participants fill a Big five form. Figure 6 shows the similarities of characteristics of participants when the emotional reaction to the emotional factor was similar. As much as the participant id is closer, their reaction is more similar. According to the diagram, there is no relation between personal character and emotional reflex.



Researchers use different formulas to calculate the arousal and valence. As explained in section formulas, we use three categories of them to compare. We tried to find the similar formula, based on the detected emotions, illustrated in figure 7. The most similar formulas are the formulas in the same category when they use β and β_{low} , brain waves which are less than 45 percent.



We compared the reaction of formulas according to the time. Figure 8 shows that formulas that use frontal sensors are more reliable and between the formulas in the same category, the formula with β_{high} are stronger in picks.

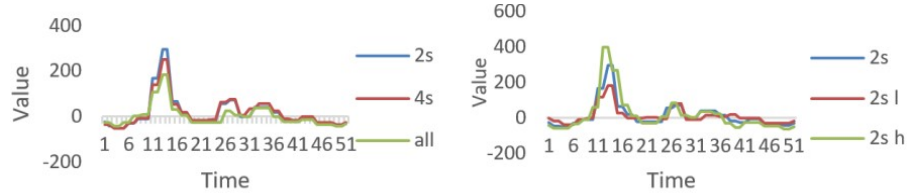


Fig. 8. Compare the formulas, based on their reaction on emotion picks

4.3 General Emotions

In the middle of the experiment, whenever the participant did not engage with the emotional factor, Emotimap showed some emotions, unique for everybody. After experiment when we asked them why they felt like that, they were surprised that we detected their emotions and confirmed the Emotimap result, we called that, general emotion. General emotion could help the humanity to diagnose, to measure the ability to take responsibilities for a critical task, etc.

Usually, general emotions are powerful when the person is not on the emotional pick. At the beginning of emotional cut when the participant is not yet engaged. To detect the general emotion in real time, we get the most repetitive emotion of all the test. To validate it, we get first 40%, 50% and 60% percent of accumulative of the percentage count of irritated emotion during of the experiment. Then we count how many percentages of the emotions exist at the beginning of the emotional cut. The error rate result is presented in table 2.

Table 2. Error rate of detecting general emotion			
	40%	50%	60%
Average	5.00	3.50	7.31
SD	22.36	11.82	10.99
No failure	95%	90%	65%

The result shows we can detect the general emotion for 95% which is a great note when we get 40% of most repeated emotion as the general emotions.

5 Conclusion Future work

In this paper, we went over a method to detect the current emotion and a way to identify general emotion of people and compare the different formulas. We planned one experiment to verify our methods used in Emotimap as a tool that detects current and general emotion of individuals. After the experiment, we could extract the repeated emotions, called general emotion, and after filtering the EEG data, Emotimap could recognize the current feeling. The result shows the importance of the background memories on the current feelings. Also, we could detect the current emotion with 6.41 % of error with the average of 8.11 % of the metric distance that means, even in error case, Emotimap noticed an emotion close to the real one. Also, Emotimap could detect correctly 95% of the general emotion. Finally, the outcome of the formula comparing shows the equations that use frontal sensors are more reliable.

There are so many topics to look at as future work. At first, we will study if there is another relation between the emotions detected (current and general) and the pattern of the γ and θ waves. Secondly, we will work on a combined formula to use the different ability of every formula to find more powerful and precise one.

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