BRAINWAVE ANALYSIS IN VIRTUAL REALITY BASED EMOTIONAL REGULATION TRAINING

by

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To my parents

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ABSTRACT

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Title: Brainwave Analysis in Virtual Reality Based Emotional Regulation Training
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Emotional regulation is how people manage their emotions especially anxiety, anger, and frustration, which are all negative emotions. It is critical to health, academic achievement, and work performance to have proper emotion regulation skills. In order to facilitate participants to manage emotions, we developed a series of training programs by using HTC© Vive™ headset and Neuracle. The HTC Vive is to improve immersion in presence to lead to more effective training, and the Neuracle is using Electroencephalography (EEG) techniques for reading user's brainwave signals which provide real time input for the training programs. We focused on analyzing if emotion, which was reflected in brainwave signals, had changes when participants were exposed to positive/negative stimuli. The testing results indicated that there were noticeable changes in brainwave signals to stimuli. The findings from the testing provide a solid foundation to use brainwave signals as real-time input in our game development for improving emotion regulation skills in the future.

1. INTRODUCTION

1.1 Background

Emotions play an essential role in people's daily lives. Not only can they bring psychological and physical changes but they also have influence on a person's behavior. Recently, growing attention has been paid to apply Virtual Reality (VR) games in studying emotional regulation, anxiety disorder, attention deficit hyperactivity disorder, autism spectrum disorder, post-traumatic stress disorder, and substance abuse [1].

1.1.1 Emotional regulation

Emotional regulation (ER) involves attempts to maintain, increase, or decrease the experience and expression of pleasant and unpleasant emotions [2]. Simply speaking, emotional regulation is the process by which individuals exert influence on the experience, occurrence and expression of emotions. Emotional regulation involves the changes of latency, occurrence time, duration, behavior expression, psychological experience, physiological response and so on. It is a dynamic process. Gross pointed out that there were three aspects to emotional regulation that need to be considered [2]. Firstly, emotional regulation not only reduces negative emotions, in fact, emotional regulation concludes the enhancement, maintenance and reeducation of positive and negative emotions. Secondly, just like emotional arousal, emotional regulation sometimes is conscious and sometimes unconscious. Thirdly, emotional regulation is not absolutely good or bad, it is good in one scenario but may be bad in another scenario.

Gross broke the process of emotion generation into four stages: situation, attention, appraisal, and response [2].

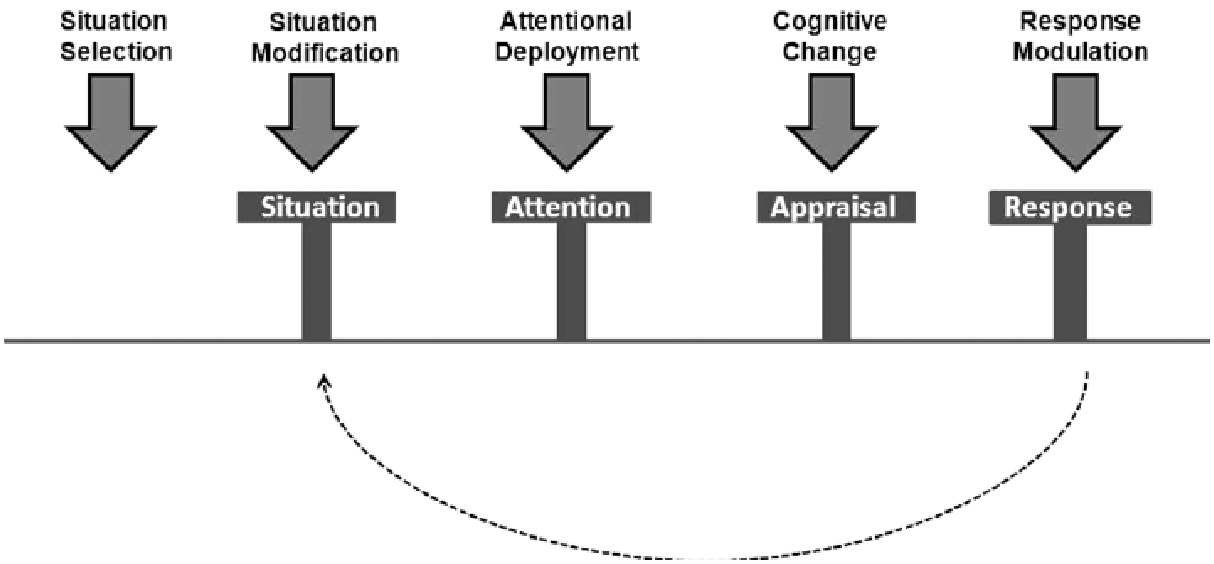


Figure 1. Gross and Thompson’s (2007) process model of emotion [2]

When individuals approach or avoid certain people, events and occasions to regulate their emotions it is called situation selection. This is a kind of emotional regulation strategy that people often use first. Individuals often use this strategy to avoid or reduce the occurrence of negative emotions and increase the opportunities of positive emotional experience. Situational modification refers to coping with problems or primary controlling emotional events, trying to change situations. If an individual is in an awkward situation, the person will try to change embarrassing things into neutral or positive images. Attentional deployment is concerned with one or more aspects in many situations, which include both making efforts to stay focused on a particular topic or task and keeping attention away from the original topic or task. This project was based on Gross’s research results mentioned previously as a design model. We focused on the situation modification stage and training participants’ emotional regulation ability through changing situation.

Emotional regulation is greatly important to physical and mental health. Good emotional regulation can promote physical and mental health. Both Beck and Seligman believe that some certain cognitive strategies, such as neglect of cognitive evaluation, can prevent or alleviate depression [3]. According to Gross's study, emotional regulation can reduce emotional behavior and emotional experience, while reducing negative emotions such as anxiety, depression and anger which affect people adversely and emotional regulation is beneficial to physical and mental health.

On the contrary, bad emotional regulation is not good for physical and mental health. For example, long-term depression of grief and crying can easily lead to respiratory diseases, inhibition of love can cause bronchial diseases or cancer, and not expressing emotions can accelerate the deterioration of cancer. The depression of anger is closely related to the incidence of cardiovascular disease and hypertension.

1.1.2 Virtual Reality

Virtual reality technology is a computer simulation system which can create the experience of the virtual world. It uses computer to generate a simulation system of 3D dynamic interactive, multi-source information fusion. Entity behavior replica immerses users in the environment. Human-computer interaction is no longer centered on 2D computer screens and traditional input/output devices.

As virtual reality (VR) quietly changes people's way of working and personal lifestyle, it also changes the way people are treated in times of discomfort. First, it is revolutionary data visualization. Information about physical systems and organs is now being modeled for medical training purposes, for developing surgical strategies, and for implementing various virtual programs. VR models of various disease trajectories are also used to assess the therapeutic potential and possible outcomes. Second, virtual reality is merging people and facilities around the globe into interconnected virtual centers, providing the best health care to patients in remote areas, and fostering collaboration among world-class teams of experts. Third, the use of VR to help patients in psychosocial therapy means learning about new behaviors or pain after re-learning skills, following stroke or severe trauma, whether physical or emotional.

Virtual Reality is increasingly being used in fields such as education, entertainment, mental health and so on. There are mainly two types of virtual reality display systems: Cave Automatic Virtual Environment (CAVE) system and Head-Mounted Display (HMD) [4].The CAVE needs to be contained within a larger room. The viewer, whose headgear is synchronized with the projectors, can walk around an image to study it from all angles. Sensors within the room track the viewer's position to align the perspective correctly [5] . HMD such as HTC Vive and Oculus Rift, is portable and cost-effective. Both types of devices are capable of producing a sensation of presence and are being used in health related areas. In our research, we used HTC Vive to display the 3D virtual environment.

Figure 2. Cave system [6]

1.1.3 Electroencephalogram

Electroencephalogram (EEG) is an electrical activity that is usually recorded on the scalp of the brain and generated by the discharging of neurons within the brain [7] . A majority of scholars assumed that post-synaptic neuron potential is the major components of Electroencephalogram at present. Electrodes are mounted in resilient caps enable data to be collected from the same scalp location of all respondents.

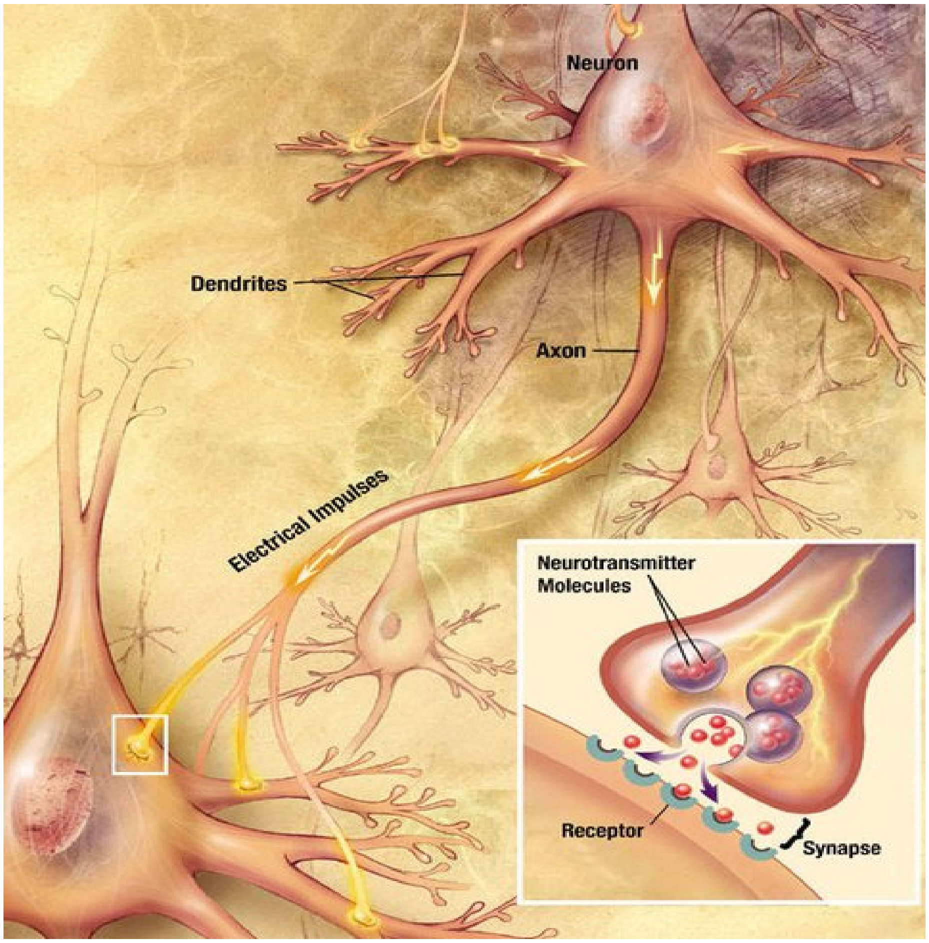


Figure 3. Electrical activity within neurons [8]

Electroencephalography measures the electrical activity which is produced by the synchronized activity of thousands of neurons and provides millisecond time-resolution with high precision [9]. Since the voltage fluctuations measured on the electrodes are very small, the recorded data is digitized and sent to the amplifier. The amplified data can then be displayed as a sequence of voltage values.

EEG allows researchers to study the psychological mechanisms behind perception and behavior by analyzing event-related brain potentials (ERPs) and frequencies. EEG provides high-resolution, real-time data that captures fast, implicit processes, rather than revealing them through self-reporting [10].

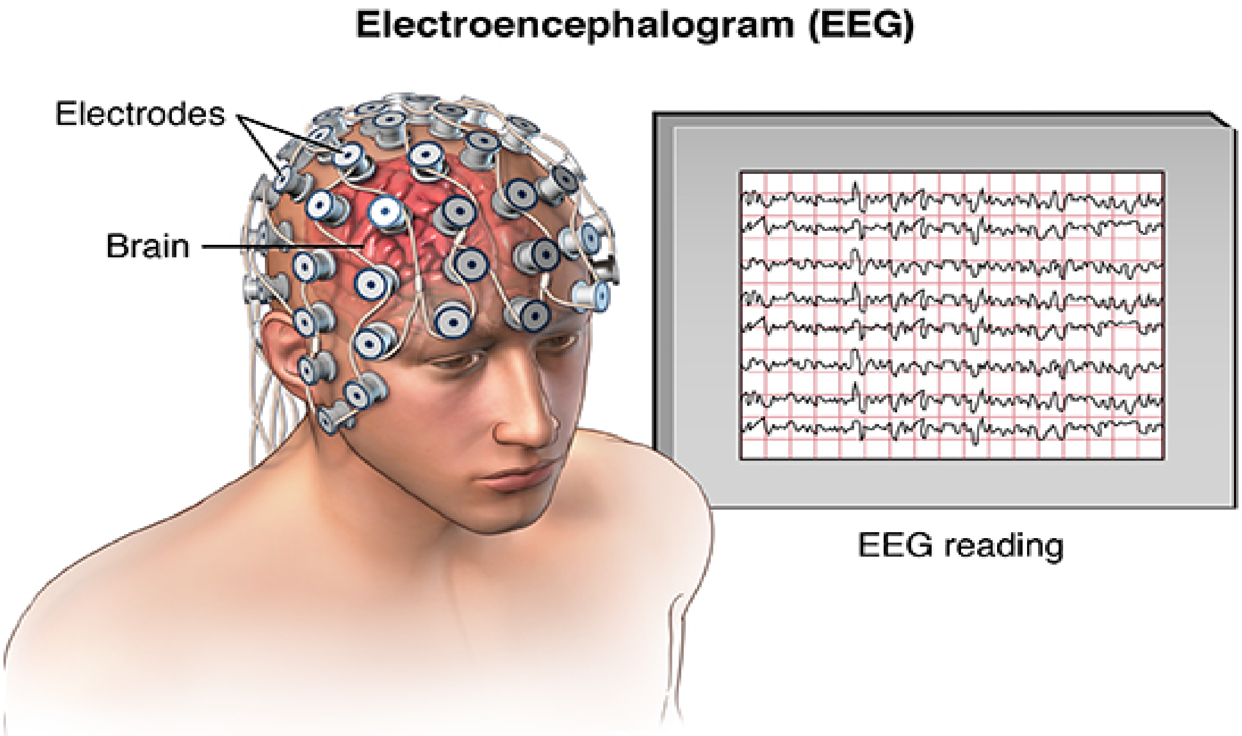


Figure 4. EEG reading [11]

1.1.4 Event-related potential

Event-related potential (ERP) is an index of brain activity revealed by systematic changes in electrical activity, primarily produced by cortical neurons. ERPs are electrical potential associated with a particular event. ERP refers to many cognitive activities related to stimulation or response, which are useful for measuring fast and implicit cognitive activities because they allow researchers to examine brainwave fluctuations instantaneously and with high temporal accuracy. Therefore, researchers may study ERP that occurs before the stimulus is recognized and track changes in response over time.

EEG waveforms have positive and negative voltage deflections, which can be called waves or peaks. If a waveform is reliably derived from a particular stimulus, associated with a particular cognitive process, and has a circumscribed scalp distribution, then it is referred to as an ERP component. ERP components are usually named according to the direction of deflection and the latency (milliseconds). The letter "P" precedes the positive component. The letter "N" precedes the negative component [10]. For example, a positive deflection component occurring about 300 milliseconds after the start of stimulation is named p300. Similarly, the negative deflection component occurring about 100 milliseconds after the start of stimulation is named N100. In general, the time of an ERP component is relative, not precise, and may be affected by various experimental factors. This means that the third positive deflection may be marked as p300 even if it occurs after 400 milliseconds. P300 is a component of frequent research that occurs 300-800 ms after the onset of stimulation which is related to novelty processing.

Classical ERPs include P1, Nl, P2, N2 and P3 (P300). P1, N1 and P2 are exogenous (physiological) components of ERPs, which are affected by the physical characteristics of stimulation; N2 and P3 are endogenous (psychological) components of ERPs, which are not affected by the physical characteristics of stimulation but related to the mental state and attention of the subjects.

1.1.5 Emotion EEG feature analysis

Brain wave is a kind of spontaneous rhythmic nervous electric activity. When the human brain works, it generates its own brain waves. Its frequency range varies from 1 to 30 times per second which can be divided into different activity bands, delta (1-3 Hz), theta (4-7 Hz), alpha (8-13 Hz), beta (14-30 Hz), and gamma(>35Hz). Alpha activity has more power compared with beta and gamma activities so that alpha is the easiest to see in an EEG signal [12].

Delta wave’s frequency ranges from 1 to 3 Hz and the amplitude is 20 to 200 mV. This band can be recorded in the temporal and parietal lobes when a person is in infancy or immature intellectual development, and an adult is extremely tired and lethargic or under anesthesia.

Theta wave is particularly pronounced in adults with frustration or depression and in psychiatric patients. But this wave is the main component of the electroencephalogram in adolescents.

Alpha waves are the basic rhythm of normal human brain waves. If there is no additional stimulation, its frequency is quite constant. The rhythm is most obvious when a person is awake, quiet and closed his eyes. When he opens his eyes (stimulated by light) or receives other stimuli, the alpha wave disappears immediately. Alpha activity is most prominent during relaxation and is inversely related to brain activity.

Beta wave shows when mental tension and emotional excitement or excitement occur. As a person wakes up from a nightmare, the original slow-wave rhythm can be immediately replaced by the rhythm.

Gamma activity is related to object maintenance, memory, and various cognitive processes.
When people are happy or meditating, the exciting beta, delta or theta waves are weakened at the moment, and the alpha waves are relatively strengthened. Because the waveform is closest to the biorhythm of the EEG in the right brain, the state of human inspiration appears.

1.2 Review of literature

Researchers at Boston Children's Hospital have developed video games intend for youths with Attention Deficit Hyperactivity Disorder (ADHD), anxiety disorders, or just for learning how to control their emotions more effectively [13]. This video game can track the child's heart rate on the screen. As the player's heart rate rises, the game becomes more and more difficult. In order to continue playing without adding obstacles, the child must calm himself down and lower his heart rate. Dr. Kahn says these games can help children build muscle memory. So once they can lower their heart rate repeatedly, the psychological response to calming themselves down becomes more and more natural.

Researchers at the University of Cincinnati delivered a 10-week cognitive behavioral-based therapy to improve social skills in a group of juvenile offenders by using virtual reality. Susan Henneberg pointed out that using virtual environments can offer participants a safe, “no loss” environment during treatment [13] [14] [15]. Juvenile offenders are usually more likely to be provocative, hostile, resentful, destructive, and engage in impulsive, risky behavior. There are usually more risk factors for them to develop their social skills in a real environment. Therefore, it is safer for juvenile offenders to train their social skills in virtual reality than actual situation.

In recent years, some researchers combined both virtual reality technique and the electrical activity of the heart ─ Electrocardiography (ECG) in the training programs development. For example, Rodríguez developed a series of VR games in his research training the ability of emotional regulation in adolescents. They reported that their games are effective in training and evaluating emotional regulation because there is a decrease of frustration level after playing their training games [16]. Compared to ECG, Electroencephalography (EEG) is another measurement to provide emotional information. Rodríguez developed a virtual park for assessing brain activations associated with emotional regulation during virtual reality mood induction procedures. He put a series of sad pictures from IAPS database in his virtual park and participants had to unscramble sentences such as “Life seems sad and senseless to me”. Participants wore an EEG headset named Emotive EPOC to acquire their EEG signal. Then they had to choose the picture which they thought best represented the meaning of the sentences from four options and the cycle was repeated five times. This research concluded that sadness induction is associated with emotional regulation strategies [17]. Besides, Tarrant used a 360 degree video photography to show a VR nature environment for leading participants to do a mindfulness meditation and they acquire EEG data with a 19-channel EEG electrocap. Through analyzing Alpha and Beta power, he reported that virtual reality therapy for anxiety reduction is effective [18].

Inspired by the related research, we developed a series of VR games using HTC Vive together with a portable wireless EEG acquisition system to improve participant’s emotional regulation skills. The thesis focused on analyzing if emotion, which is reflected in brainwave signals, has changes when participants are exposed to virtual environment positive/negative stimuli. The testing results indicated that there were noticeable changes in brainwave signals to stimuli. Therefore, it is reasonable to use brainwave signals as real-time input in our game design for improving emotion regulation skills in future development. The emotion regulation strategies will be added along with the environment setup.

2. METHODOLOGY

Our software development is to implement interactive training programs in 3D virtual environments while reading real-time brain signals from the EEG hardware. At present, we developed three scenes: forest, grassland and beach. We integrated Virtual Reality scene and EEG acquire system together by using serial port communication so that the scenes can be changed with brain waves.

2.1 Research equipment

2.1.1 HTC Vive

The HTC Vive, shown in Figure 5, was utilized in immerging users into virtual reality environments. The two base stations can get the signal from the headset and controllers to track the motion of the player. The headset uses “room scale” tracking technology, allowing the users to move in 3D space and use motion-tracked handheld controllers to interact with the environment.

Figure 5. HTC Vive [19]

The Neuracle wireless EEG acquisition system in the project is from Neuracle shown in Figure 6, Figure 7, and Figure 8 [20], which is a neural technology company that provides professional solutions for both neuroscience and clinical neurology community worldwide. The EEG acquisition system collects the electrical signals from the epidermis of the human's head and transmit them to the computer through Wi-Fi wireless module for data display and storage. After configuring the relevant accessories of the wireless EEG acquisition system, the system can receive signals such as sound, light and keys pushing, and record and store the activities' information of the electrical signals of the human head epidermis under different conditions (sound, light, keys) at the same time. Considering emotion regulation is affected by fields from the previous relevant research, we recorded and analyzed the electrode Fz, F4, F3, F7, T8, Pz, P3, P4, and the reference was Cz. The positions of these electrodes were based on 10–20 system or International 10–20 system that is an internationally recognized method to describe and apply the location of scalp electrodes in the context of an EEG exam [21].

2.1.2 EEG Cap

Figure 6. Trigger box for transferring marker to router

Figure 7. Neuracle wireless EEG cap

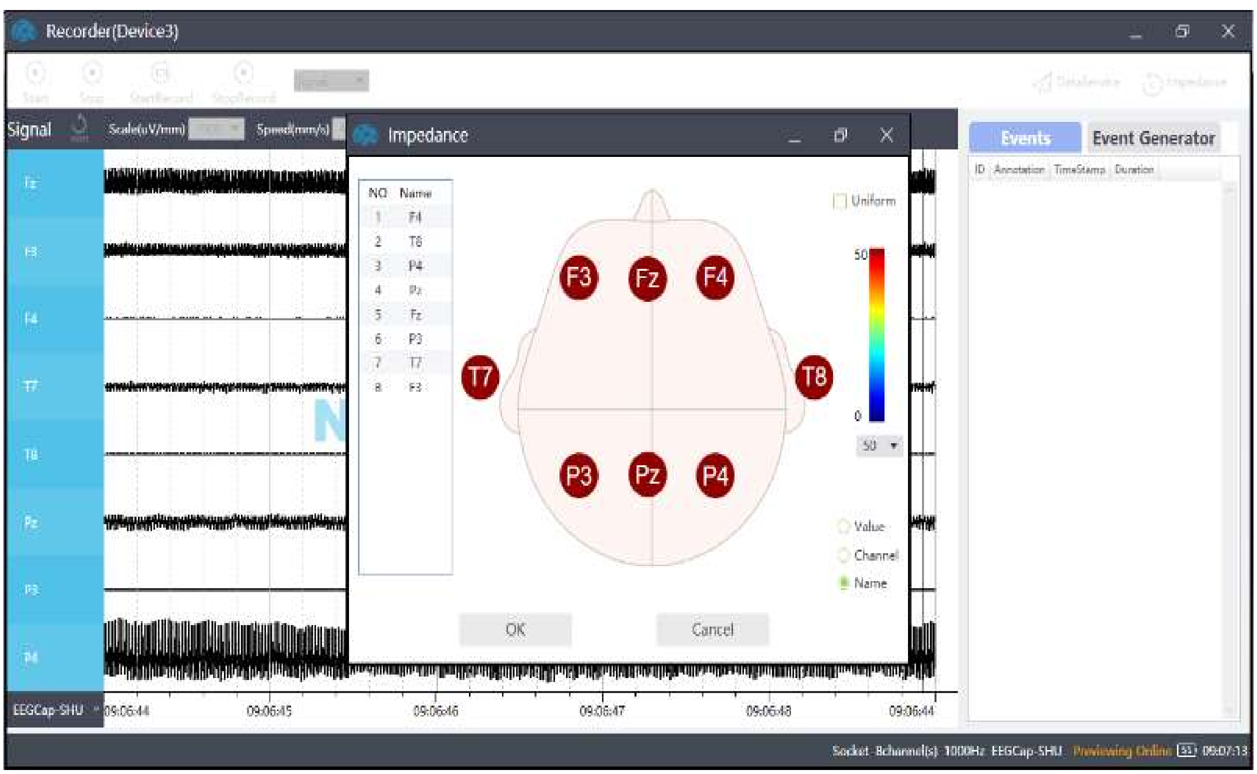


Figure 8. The interface of EEG recorder

The VR training games were developed with Unity3D, which is a comprehensive multi-platform game development tool developed by Unity Technologies [22]. It is a fully integrated professional game engine. To play the games, the participant is required to put on the wireless headset so that the brain signal can be acquired. The user also needs to wear the HTC Vive headset to feel present in the virtual reality scene. Two controllers from HTC Vive allow the user to interact with the virtual reality environment.

2.2 Serial port communication

In the project, serial port is used in communication between Unity3d and MATLAB. The collected raw data from EEG recorder would be sent to MATLAB and then Alpha waves can be extracted through Fast Fourier Transform. The energy value obtained in MATLAB is sent by using serial port from MATLAB to unity.

SerialPort class in System.IO.Ports namespace is used at the bottom of serial communication in Unity3D. SerialPort.ReadLine() method is used to read serial data. The system reads serial data by loops and stores it in the queue named inputQueue. Then it detects whether there is a message in the queue by loop in the update of Unity3d. If there is one, the message will be out of the queue. The above content is implemented by SerialComm plug-in. In my project, I mainly used SerialControllerCustomDelimiter script. The script sends the received data to SampleMessageListener script. SampleMessageListener parses the hexadecimal data and makes the elements in the scene perform corresponding actions according to the corresponding commands, such as weather change, animal generation, etc.

2.3 Project scenarios

The project includes three scenarios which are shown on a menu interface after the game is initiated. Users can choose which scenes they want to enter, respectively: Forest, Grassland, and Beach. Each scene has a start and an end button. When the user presses the start or end button with a controller, a hexadecimal string would be sent from Unity3d to the EEG recorder via a serial port. Before the start button appears in all the scenes, there is a 10 seconds warm-up process. At this point, a text appears in front of the user, telling the user that this is a warm-up process. Participants need to relax themselves and press the confirmation button to start warm-up. The 10 seconds collected alpha wave average energy would be set as the initial value after starting the game. There are three scenes developed as follows:

2.3.1 Forest

We analyzed the brainwave signal changed in one of the training games: the virtual forest scene. The forest theme was selected as a background scene based on the categories defined from International Affective Picture Rating System (IAPS) [23]. Two screen snapshots of the virtual forest is shown in Figure 9 and Figure 10.

The virtual forest scene created an immersive forest traveling experience for participants. Once entering forest scene, participant would see a big menu item in front of them. After understanding the game rule through introduction, participant could click the start button by pressing the trigger of the controller. Participants could also view the virtual forest in different angles. We developed fifteen different virtual animals in the forest scene. These animals were divided to three groups: negative, neutral, and positive because each of categories arouses a different emotional response of participants. The categories were defined according to the references from the IAPS. For example, the wolf is labeled as “Negative” because it could bring the sense of nervousness, depression and fear. When people see a cute and unaggressive animals like the rabbit, relaxed and happy states can be aroused. Therefore, rabbit was tagged “Positive”. Some animals do not provoke a positive or a negative reaction such as horses, these animals are tagged “Neutral”. In the experimental setup, each kind of virtual animal appeared randomly in the virtual forest four times in the program, and lasted for ten seconds each time. There were ten seconds pause between the changes. The flowchart is shown in Figure 11. Once a virtual animal showed up in the scene, the computer serial port would send a signal number to the EEG data receiver indicating the animal’s category, while EEG data was recorded at the same time. After the whole process was finished, the data was analyzed by using the EEGLAB in MATLAB.

Figure 9. Virtual forest without virtual animals

Figure 10. Virtual forest with virtual animals

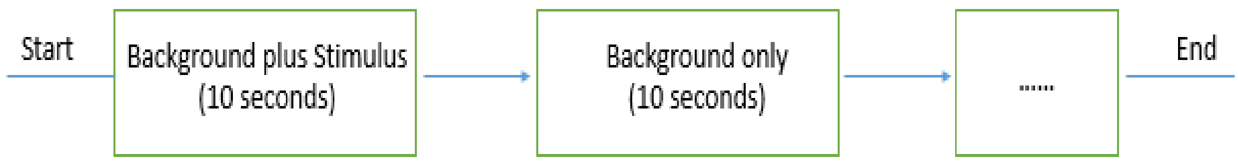


Figure 11. The flowchart of the experiment procedure

2.3.2 Grassland

Participants can see a boundless grassland, blue sky, white clouds and a crowd of birds in this scene. This scene is mainly focused on environmental change. There are three different types of weather. When participants enter the grassland scene, they will experience different weathers. For example, clear sunny sky “positive”, cloudy “neutural” and storm “negative”. Different weathers and some disturbances will show up according to participants’ Alpha energy change. If participants’ Alpha wave averge energy value in 10 seconds is below initial value, within the next 10 seconds, the weather will change to “Negative” weather and “Negative” disturbances like crows and other objects of that nature. The “Negative” disturbances will continue to show up until the partinicipants’ Alpha value is higher than the initial value. When the environment is changed or disturbances appear, a mark will be sent to the EEG recorder data client to distiguish different weather change and disturbances. In addition, this feedback system would record the total time that the Alpha value was higher than the intital value. Particiants can have an intuitive concept for their emotional regulation training results.

Figure 12. Screen snapshots of the virtual "grassland"

2.3.3 Beach

The beach scene is developed for relaxing participants. This scene shows a glorious tropical beach. The sparkling waves flicker gently against the glittering white sand beach. The brilliant sunlight shines from the beautiful blue sky, and the birds fly high above. Participants can enjoy a private beach and relax themselves completely in the scene on the beach as long as they wear the VR equipment, put on the earphones and sit on the beach, away from everything. There are several relaxation options on the beach: lie down and guide meditation, listen to music that is quiet and relaxing, and people can also import their personal music library, podcast and meditation course or simply take a relaxing look around and listen to the sounds on their idyllic beach. Better still, this scene adds double play mode so that it allows two participants to enter this scene together. The system will record their EEG data so that it can be analyzed for both people participating in the same scene.

Figure 13. Screen snapshots of the virtual “beach”

2.4 EEG data analysis

2.4.1 EEG feature extraction - Relative energy

The feature extraction of signals is the basis of detection, classification and recognition. EEG feature extraction refers to the signal characteristics that can best reflect a certain state of the subjects, which are extracted from the collected EEG signals according to the problems to be studied. Because of the rhythm of EEG, the most common feature is the power spectrum of EEG in different frequency bands. We studied the EEG spectrum on the basis of the energy of each rhythm and its relative energy.

For a continuous-time signals, the signal energy in the signal x(t) is

$$E = \int_{-\infty}^{\infty} |x(t)|^2 \, dt$$

For the relative energy analysis of EEG, we only need to calculate the relative energy of each rhythm according to the above method and then calculate the total percentage of relative energy which will be the relative energy we need.

$$P_i = E_i / \sum_i Ei$$

2.4.2 Fourier transform

The EEG signals are acquired in the time domain and must be converted to the frequency domain by using Fourier transform before analyzing these band [24]. The Fourier principle shows that any time series or signals of any continuous measurement can be expressed as an infinite superposition of different sinusoidal signals. The Fourier transform algorithm created according to this principle uses the directly measured raw signal to calculate the frequency, amplitude and phase of different sinusoidal signals in the signal in an accumulated method. Researchers can use the power spectrum to represent all the frequencies shown in the dataset, collapsed over time [25]. The definition of Fourier transform as follow:

$$F(\omega) = F[f(t)] = \int_{\infty}^{-\infty} f(t) e^{-j\omega t} \, dt$$

2.4.3 Fast Fourier Transform

In practice, Fast Fourier Transform (FFT) is often used to complete Fourier transform. An analog signal can convert digital signal after analog-to-digital conversion [26]. After FFT, N sampling points will have corresponding N FFT results. In order to simplify FFT operations, we usually take N to the integer power of 2. Assuming the sampling frequency is Fs, the sampling point is N, after FFT, the frequency of a point n (n start from 1) is Fn=(n-1)*Fs/N; the modulus of the point divide N/2 is the signal amplitude under the corresponding frequency; the phase of the point is the signal phase at the corresponding frequency. Fourier transform is suitable for the analysis of stationary signals. However, the EEG signal is non-stationary and time-varying signal. We can divide the signal into many segments by windowing method. So we can think that in each segment of the signal, it is continuous and stable. We can use Fourier transform to analyze the frequency domain. In this paper, fast Fourier transform is used to calculate Alpha wave.

3. RESULTS

3.1 Design purpose

In our testing, we recruited three participants to test our “Forest” program. As the testing results from all participants were consistent, one example result was used to show the performance. We used “1” as Negative, “2” as Neutral, and “3” as Positive. Figure 14 shows the brain waves under these three stimuli.

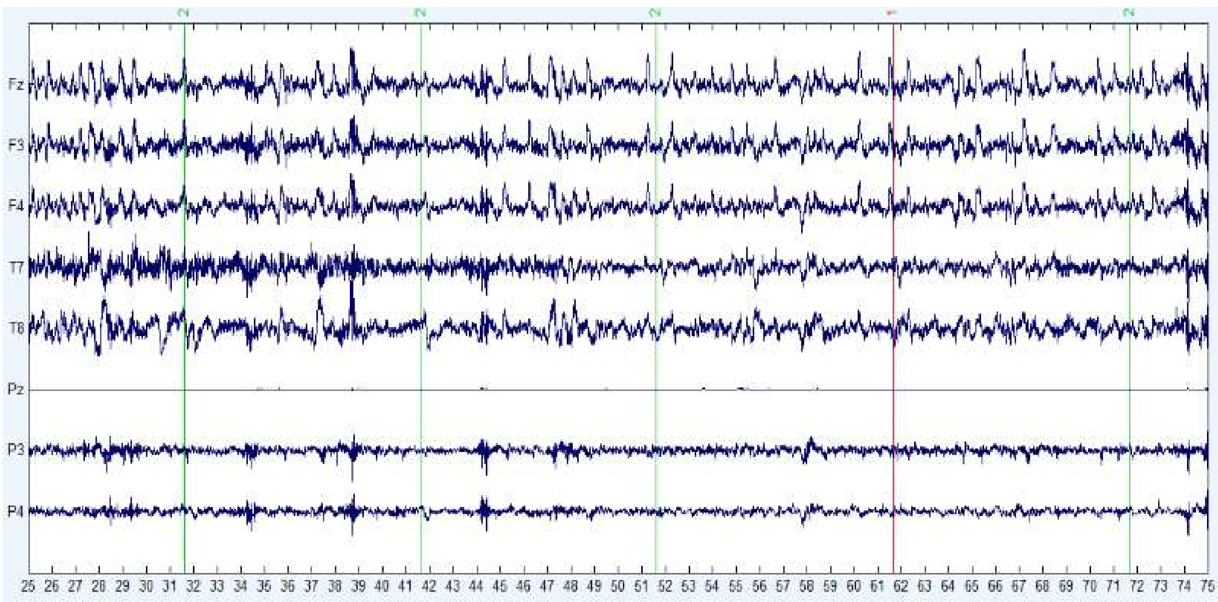


Figure 14. The interface of EEG recorder software

From the alpha waves graphs in the Figure 15, Figure 16, and Figure 17, it showed that under “positive” and “neutral” stimulus, the amplitude of the alpha waves was larger than the “negative” stimulus. That meant under these two situations, participants were more relaxed to the “positive” stimulus than the “negative” stimulus, which was what we expected. However, it was not obvious of the differences between the “positive” and “neutral” stimuli. We assumed that there were similar effects for participants under the two current stimuli. In the future we will conduct more research and define “positive” and “neutral” stimuli that could be distinguished more clearly.

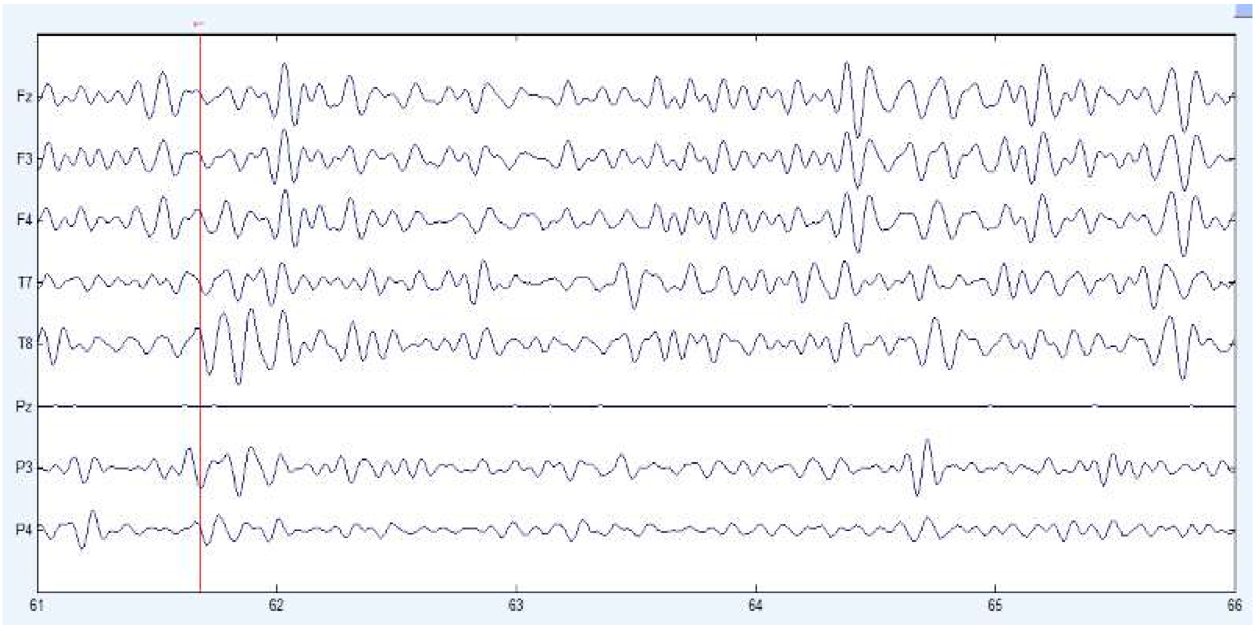


Figure 15. Alpha waves under “Negative” stimulus

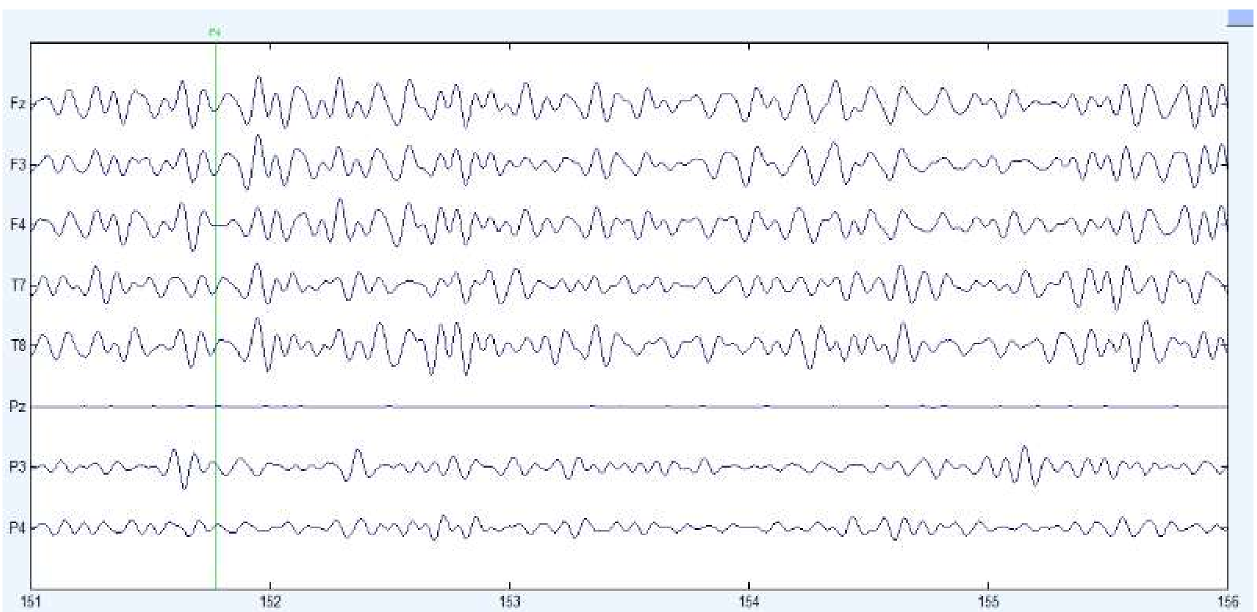


Figure 16. Alpha waves under “Neutral” stimulus

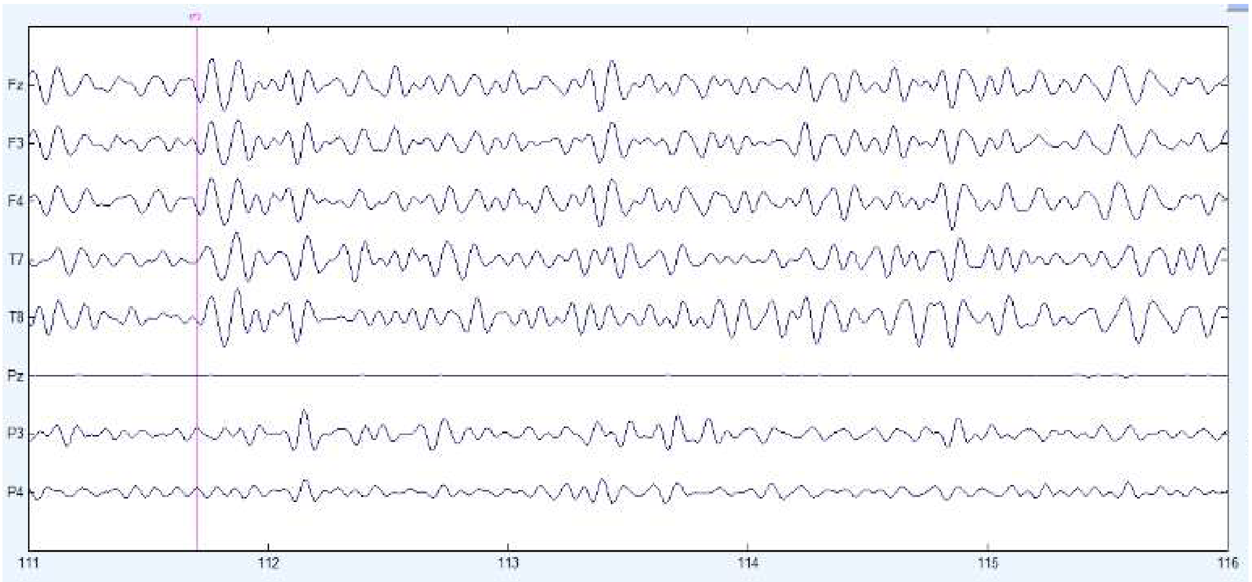
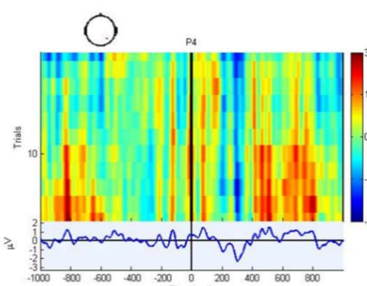


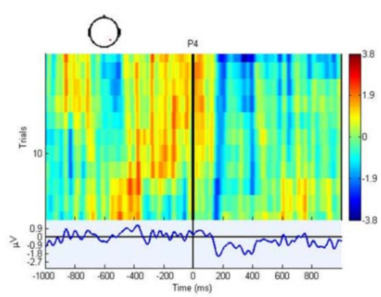
Figure 17. Alpha waves under “Positive” stimulus

The graphs below Figure 18(a - x) demonstrate the Event-related potentials (ERP) of channels (Fz, F4, F3, F7, T8, Pz, P3, P4) comparison under different stimulus. Event-related potential was measured from brain responses that were the direct result of specific sensory, cognitive or motor events. [23]N400 waveform was defined as a negative deflection below the pre stimulus baseline, starting around 250 milliseconds and peaking around 400 milliseconds. [27]The P300 has a positive-going amplitude (usually relative to a reference behind the ear or the average of two such references) that peaks at around 300 milliseconds. [28]

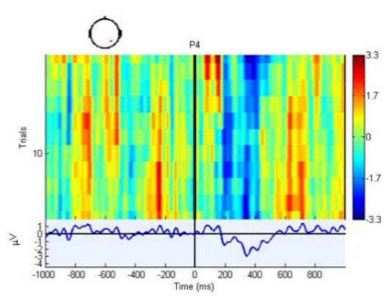
P4 Channel:



a. p4 under 1 stimulus



b. p4 under 2 stimulus

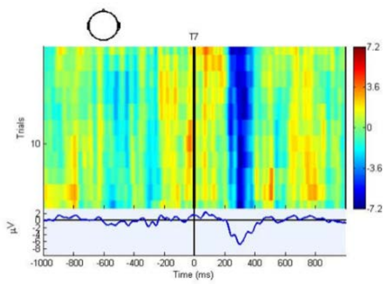


c. p4 under 3 stimulus

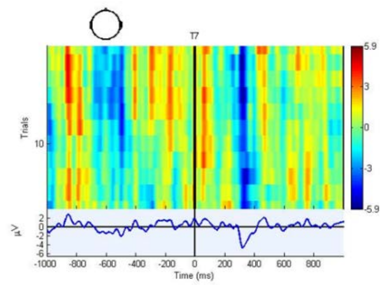
Figure 18 (a - x). Event-related potentials of channels (Fz, F4, F3, F7, T8, Pz, P3, P4)

Figure 18 continued

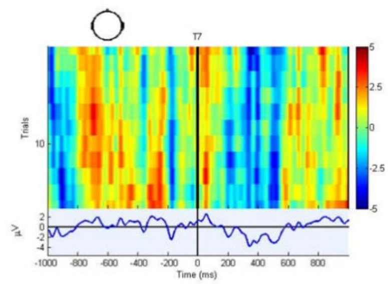
T7 Channel:



d. T7 under 1 stimulus

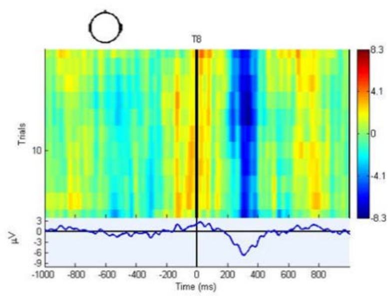


e. T7 under 2 stimulus

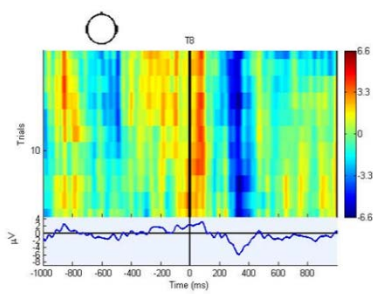


f. T7 under 3 stimulus

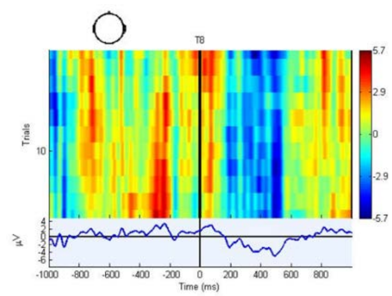
T8 Channel:



g. T8 under 1 stimulus

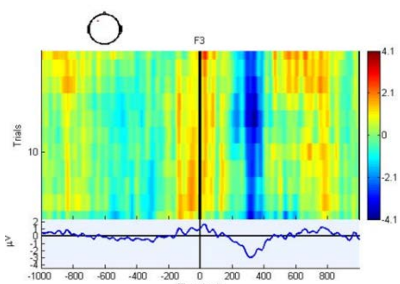


h. T8 under 2 stimulus

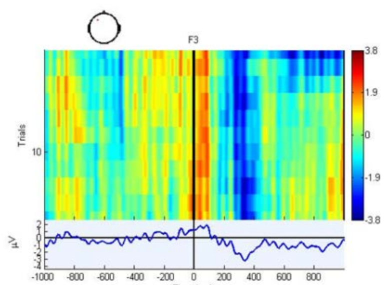


i. T8 under 3 stimulus

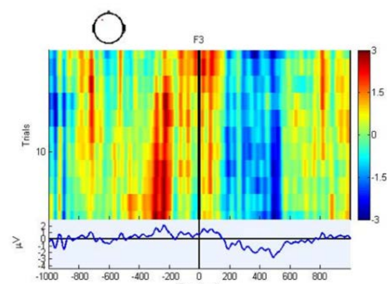
F3 Channel:



j. F3 under 1 stimulus



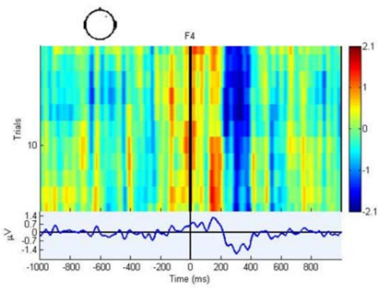
k. F3 under 2 stimulus



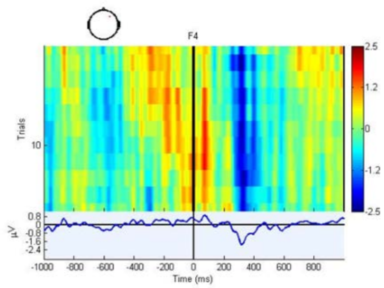
l. F3 under 3 stimulus

Figure 18 continued

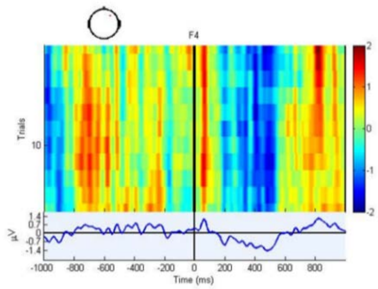
F4 Channel:



m. F4 under 1 stimulus

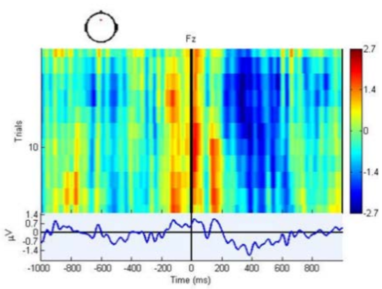


n. F4 under 2 stimulus

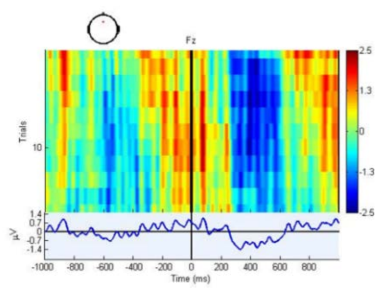


o. F4 under 3 stimulus

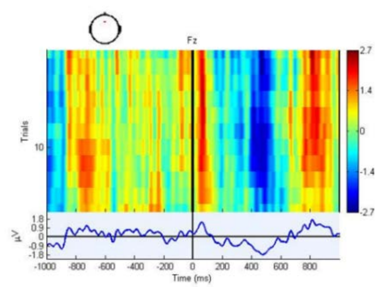
Fz Channel:



p. Fz under 1 stimulus

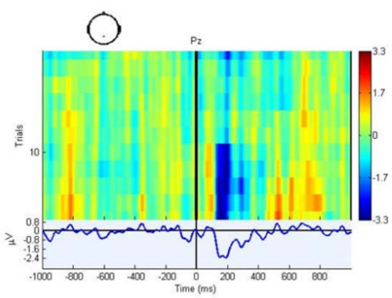


q. Fz under 2 stimulus

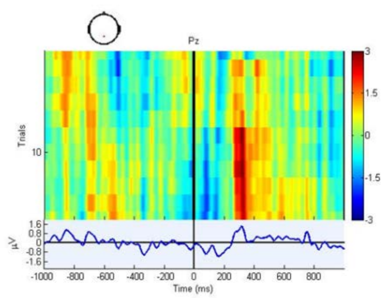


r. Fz under 3 stimulus

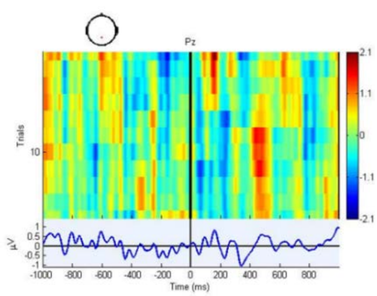
Pz Channel:



s. Pz under 1 stimulus



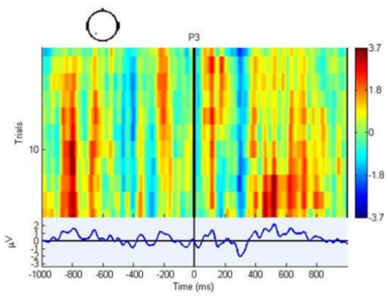
t. Pz under 2 stimulus



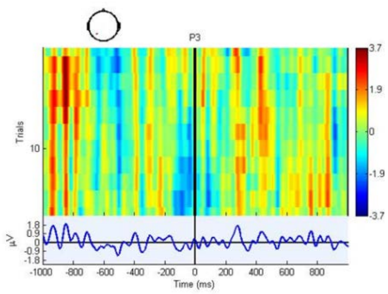
u. Pz under 3 stimulus

Figure 18 continued

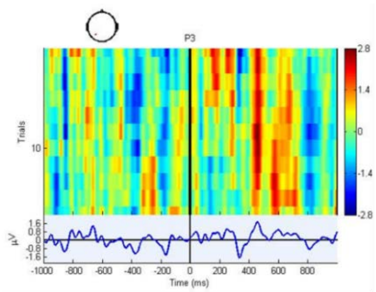
P3 Channel:



v. P3 under 1 stimulus



w. P3 under 2 stimulus



x. P3 under 3 stimulus

As shown in the eight groups of pictures in figure 16, it was obvious there were negative peeks at about 400ms, which meant N400 was obvious in this study. Under the second stimulus, there were positive peeks at about 300ms in some electrodes, such as Pz and P3, but not for all. We assumed that in the virtual reality, subjects feel more immersive than when the environment is negative rather than positive.

3.1 Comparison of ERPs at electrode of different stimulus.

3.1.1 Channel ERPs at electrode positions Fz F3 F4 T7 T8 Pz P3 P4 of "1" stimulus

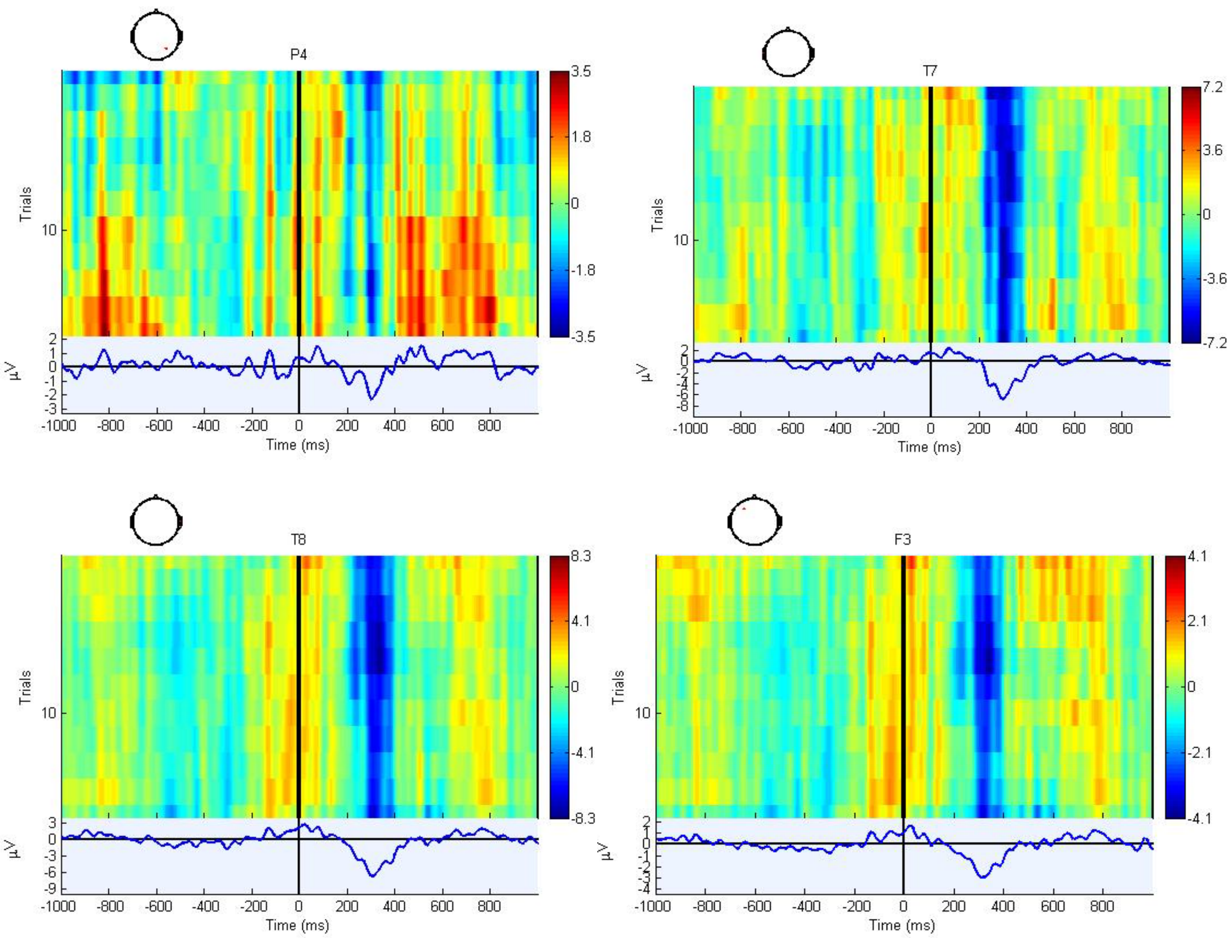
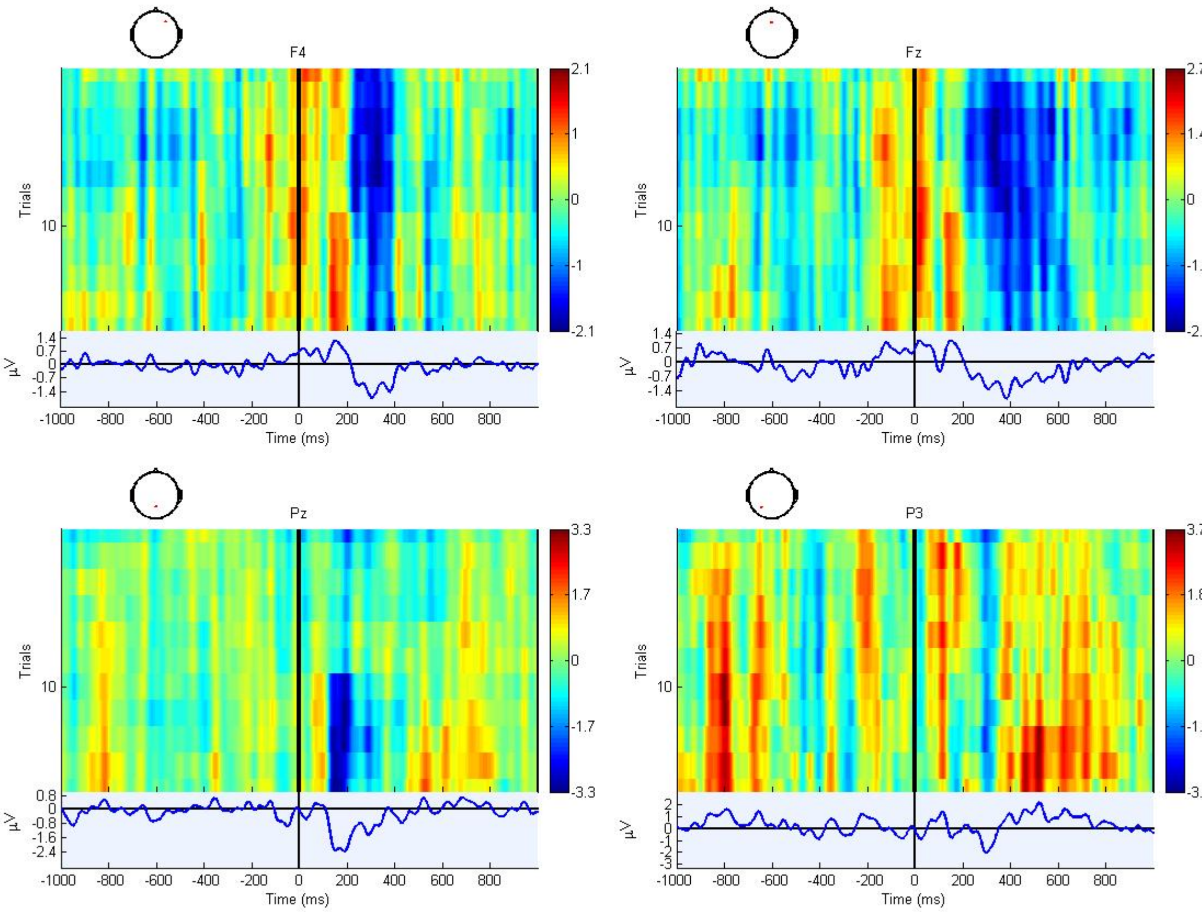


Figure 19. Channel ERPs at electrode positions Fz F3 F4 T7 T8 Pz P3 P4 of "1" stimulus

Figure 19 continued



3.1.2 Channel ERPs at electrode positions Fz F3 F4 T7 T8 Pz P3 P4 of “2” stimulus

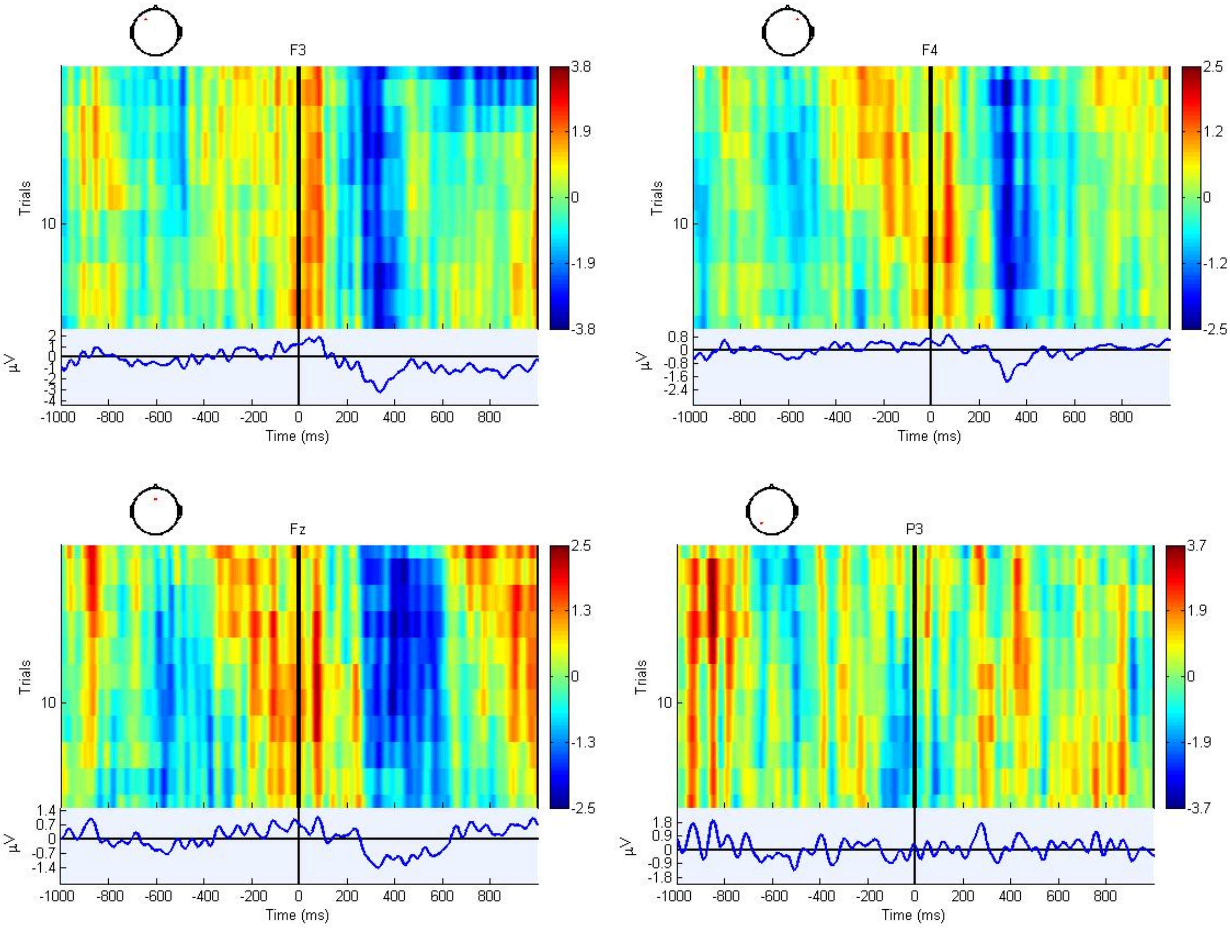
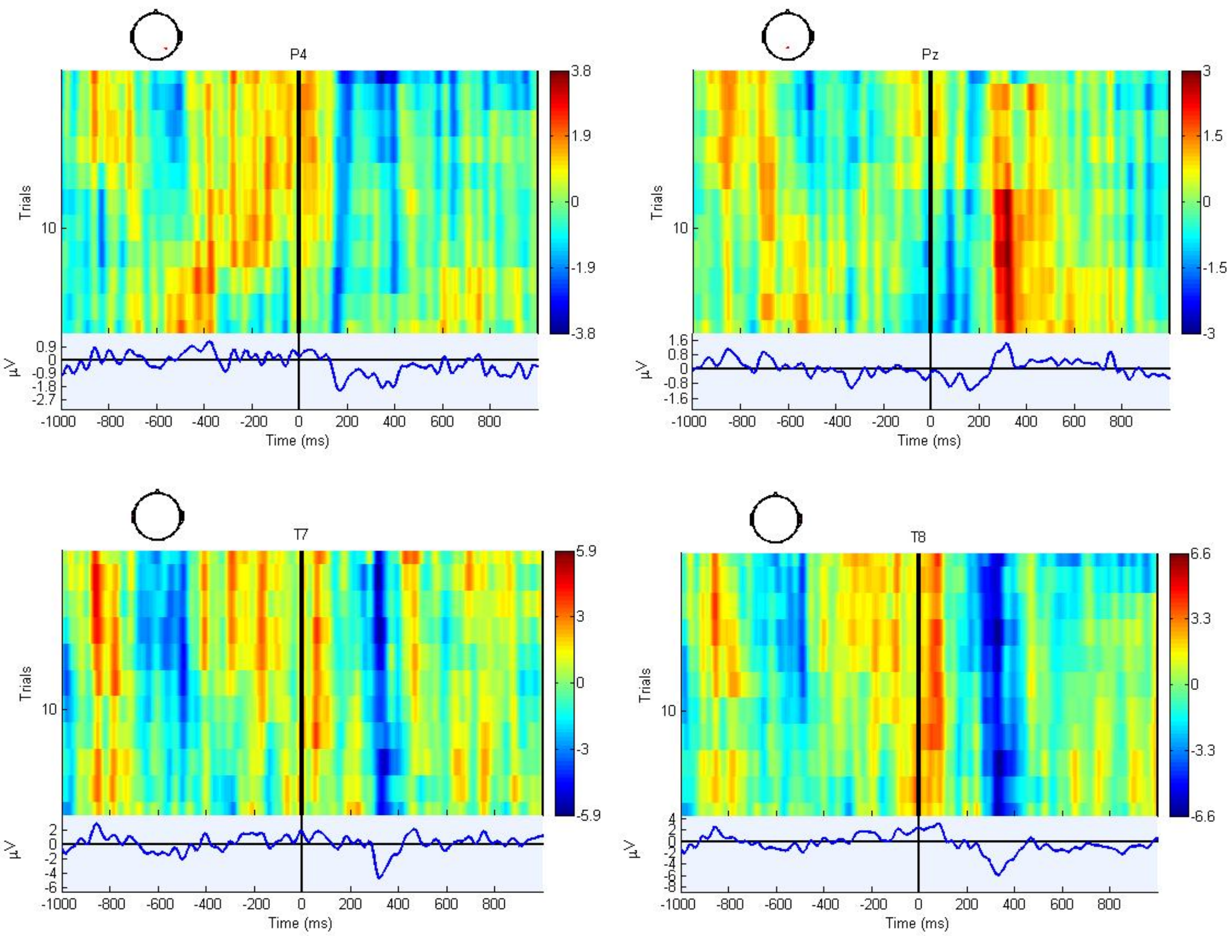


Figure 20. Channel ERPs at electrode positions Fz F3 F4 T7 T8 Pz P3 P4 of “2” stimulus

Figure 20 continued



3.1.3 Channel ERPs at electrode positions Fz F3 F4 T7 T8 Pz P3 P4 of "3" stimulus

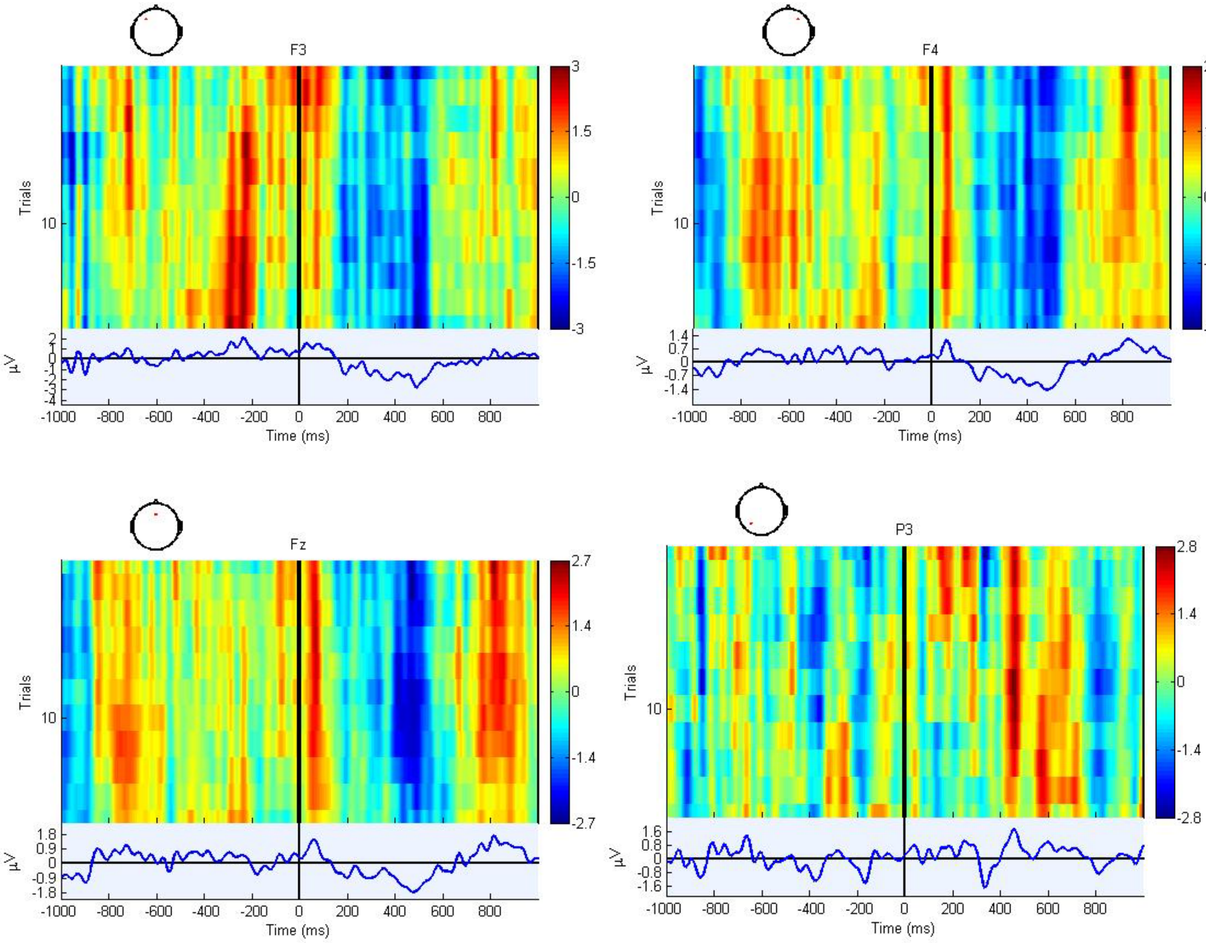
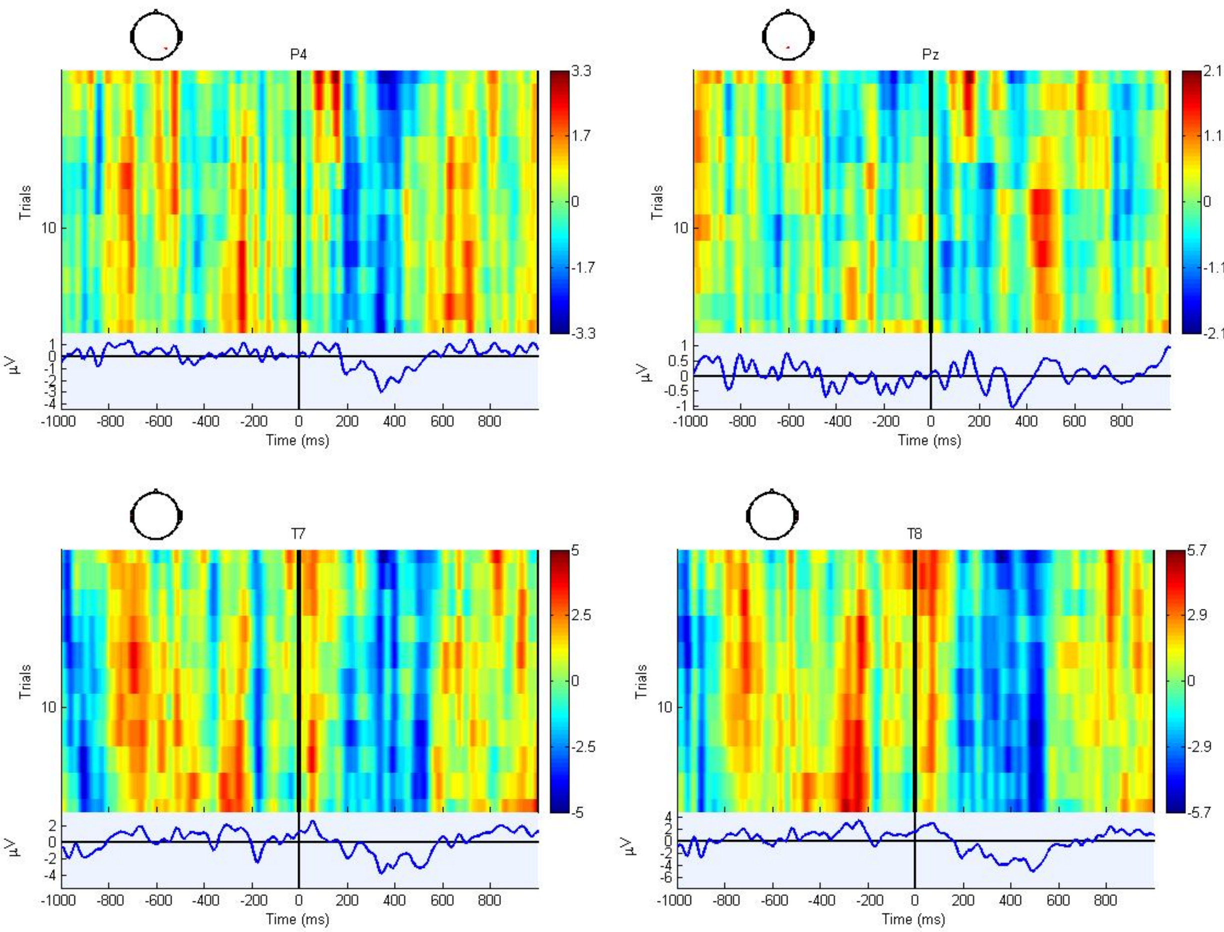


Figure 21. Channel ERPs at electrode positions Fz F3 F4 T7 T8 Pz P3 P4 of "3" stimulus

Figure 21 continued



As shown in the three groups of pictures above, it is obvious there are negative peeks in these pictures at about 400ms, which means N400 is evident in this study. And under the second stimulus, there are positive peeks at about 300ms in some electrode, such as Pz and P3, but not for all. We assumed that in the virtual reality, subjects feel more immersive than when the environment are negative rather than positive.

3.2 Comparison of channel ERPs

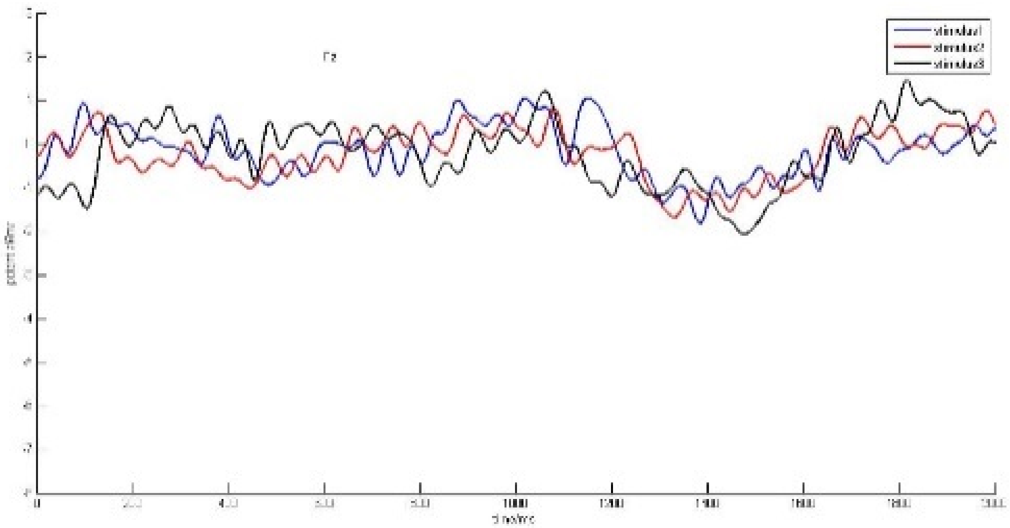


Figure 22. Channel ERP in Position “Fz”

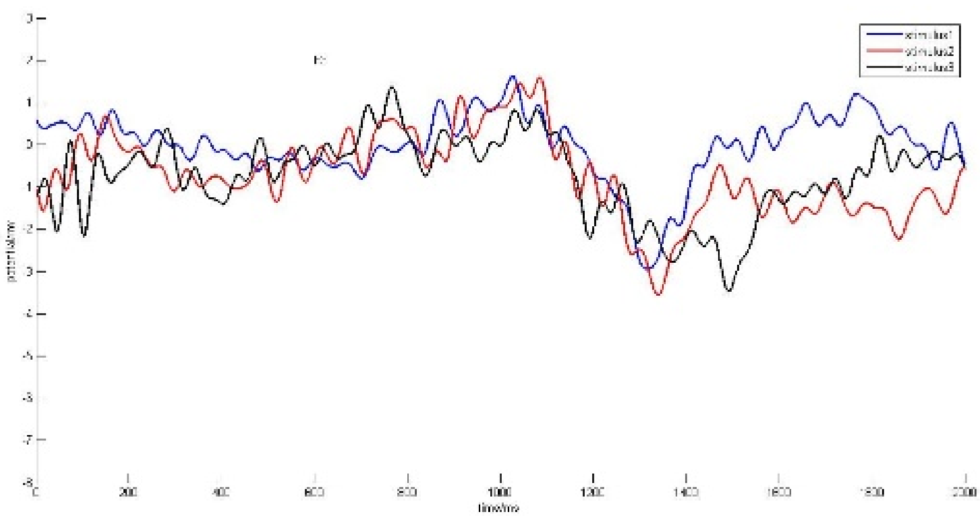


Figure 23. Channel ERP in Position “F3”

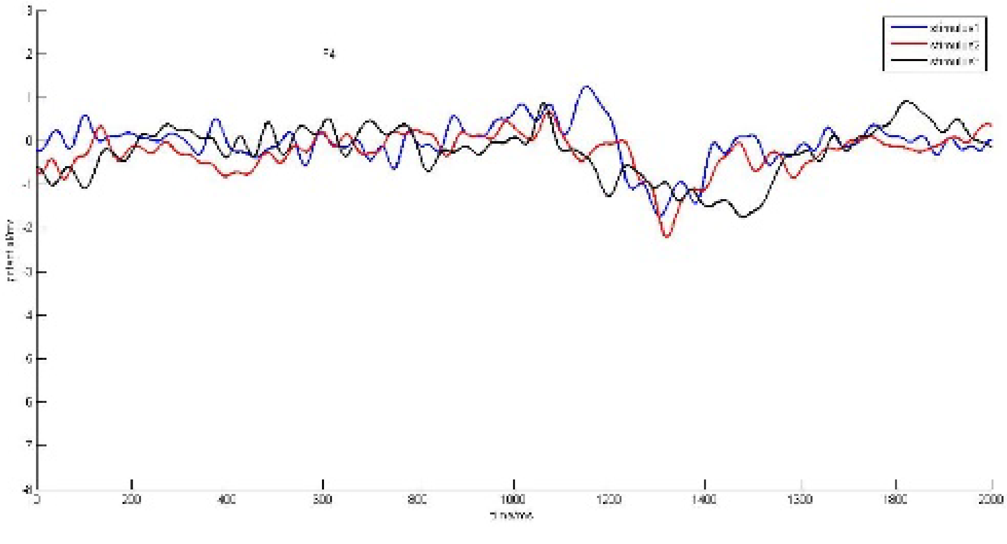


Figure 24. Channel ERP in Position “F4”

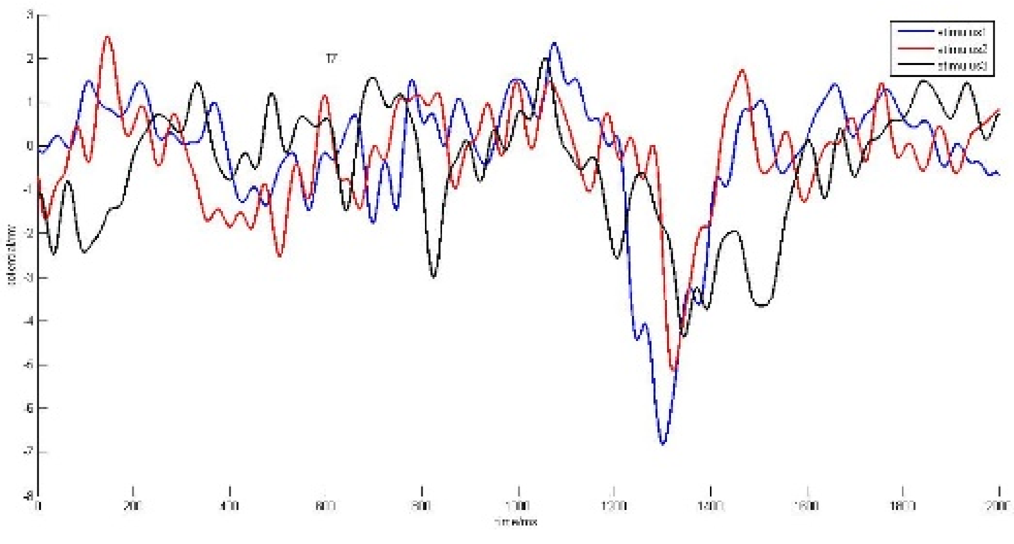


Figure 25. Channel ERP in Position “T7”

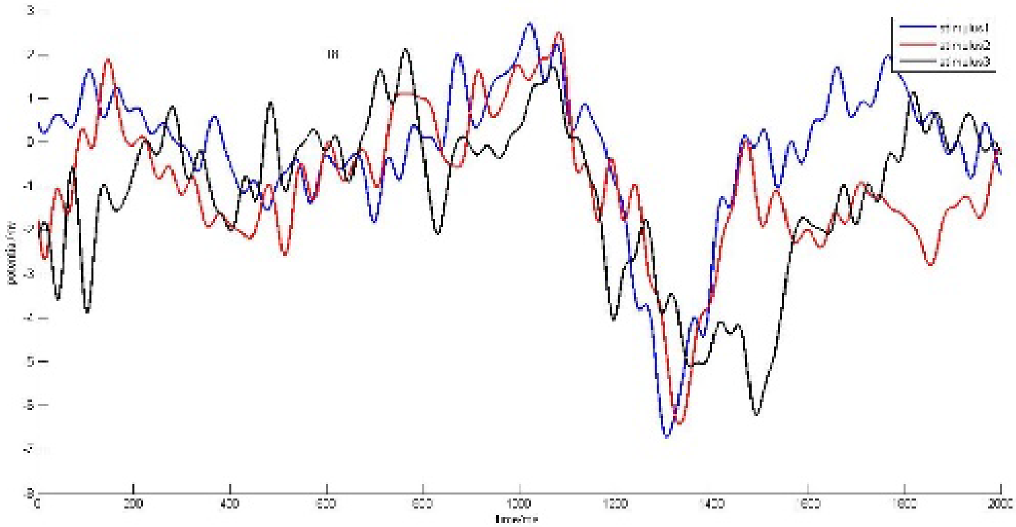


Figure 26. Channel ERP in Position “T8”

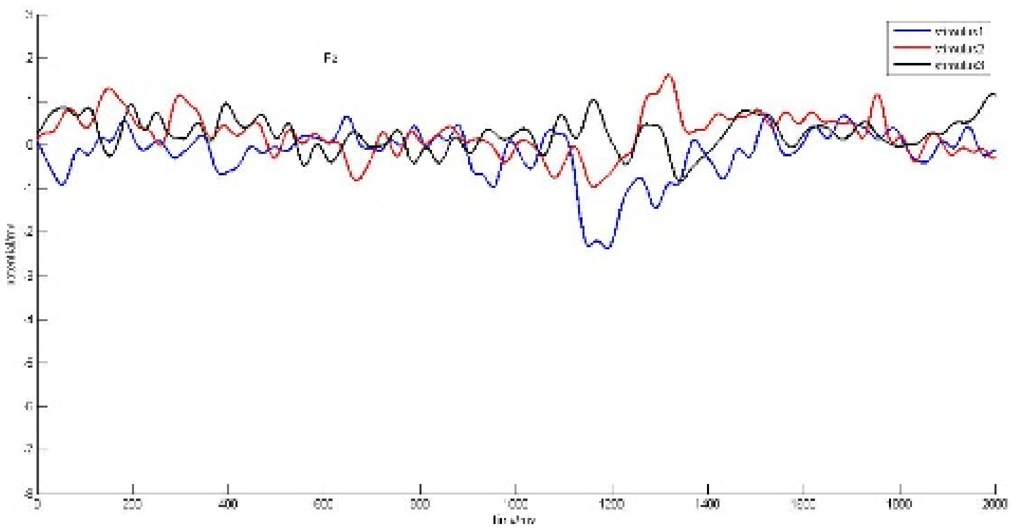


Figure 27. Channel ERP in Position “Pz”

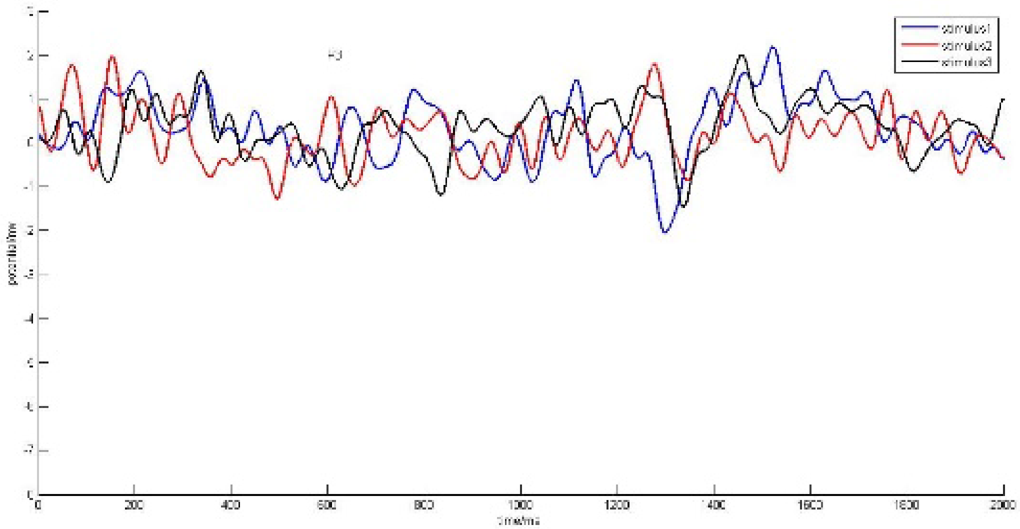


Figure 28. Channel ERP in Position “P3”

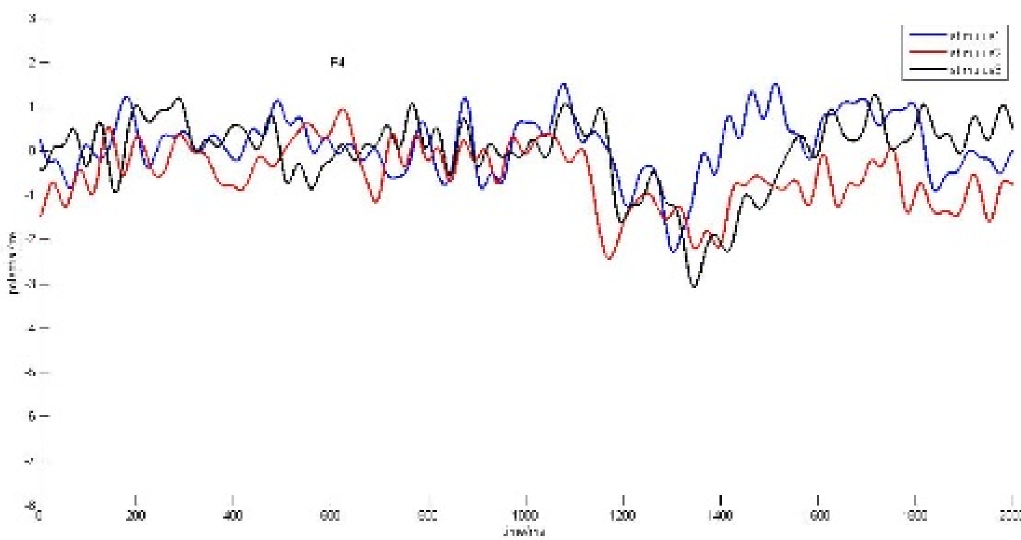


Figure 29. Channel ERP in Position “P4”

The channel ERP image Figure 22 - Figure 29 shows electrodes T7 and T8 play an important role in decreasing potentials at 1200ms to 1400ms. Considering the result we get from the comparison of ERPs at electrode of different stimulus, we assume that temporal lobe is the key filed in processing negative environment in virtual reality.

The three graphs Figure 30, Figure 31, and Figure 32 below show the comparison of ERP of different stimulus.

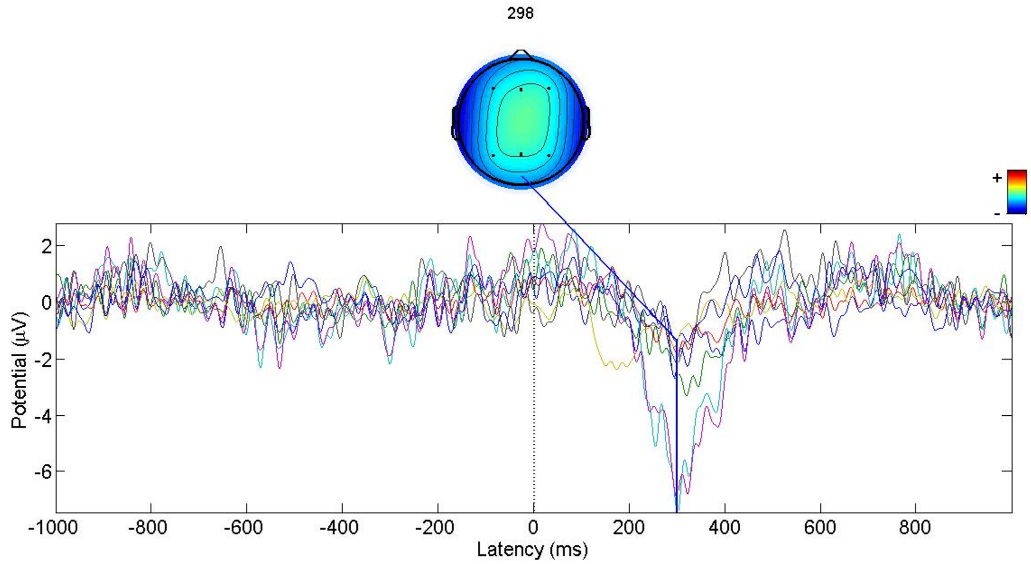


Figure 30. a negative peak showed up around 300ms under negative stimulus

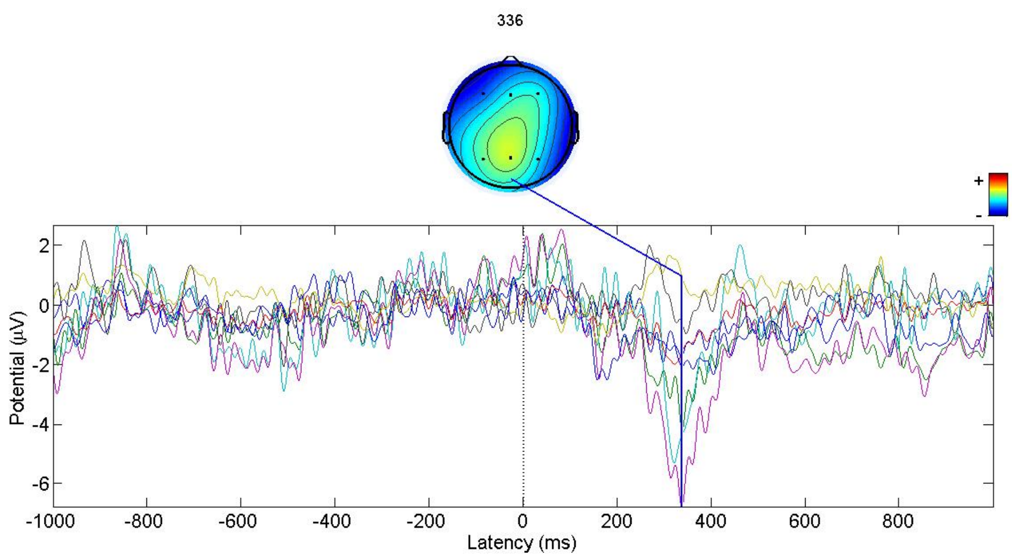


Figure 31. a negative peak showed up between 300-400ms under neutral stimulus

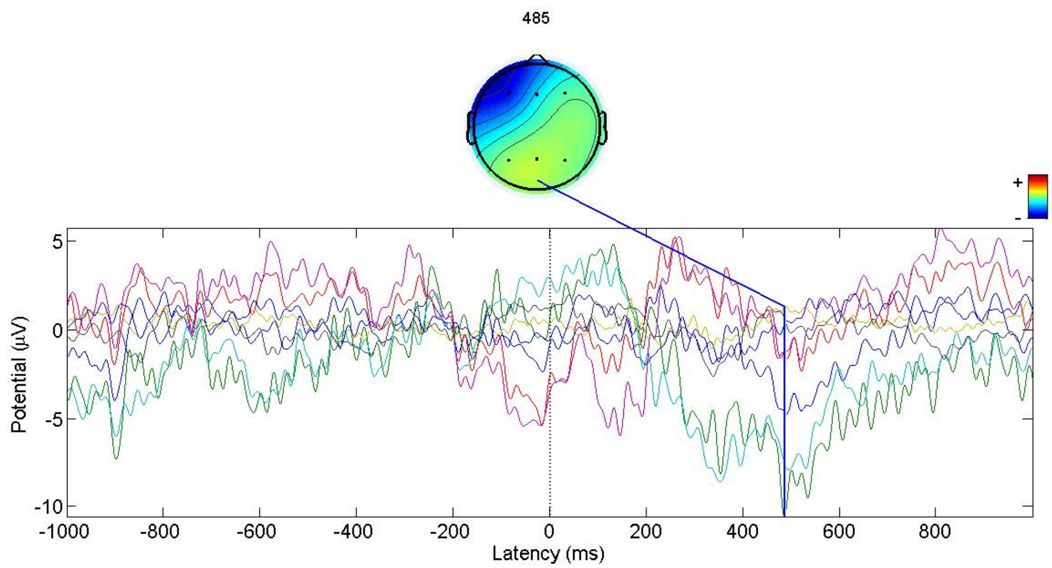


Figure 32. a negative peak showed up between 300-400ms under positive stimulus

From the spectral plot results shown in Figure 30, Figure 31, and Figure 32, it could be seen that no matter what kinds of stimulus, there was always a negative peek. A negative peak showed up around 300-400ms under negative and neutral stimulus but not for positive stimulus. In theory, there is a positive peak around 300ms. However, the “positive” and “neutral” stimuli did not bring noticeable changes in our virtual environment. This result was not consistent with research from prevalent research [28]. From our preliminary research, we assumed two major reasons for this inconsistency. One reason was that the results from [28]were concluded based on the stimuli using 2D pictures instead of 3D virtual environment. There might be differences between 2D and 3D scenes in event-related potential for participants. The second was concluded based on our questionnaire survey analysis. Participants had a different understanding on the “positive” and “neutral” categories, therefore the virtual animals we defined in these two categories did not bring appropriate stimuli to the participants. It led to the confusing results in our brainwave signal analysis. To address this problem, we will improve the definition of these two categories in the future development.

4. CONCLUSIONS AND FUTURE WORK

The paper described a pilot study in the development of VR based training programs for improving emotional regulation skills. We developed a virtual forest while adding virtual animals from "positive", "neutral", and "negative" categories as stimuli to analyze if EEG brainwave signals, indicating emotion waves, had noticeable changes. We proved that N400 showed up at 400ms after "negative" stimulus. Though there were changes to "positive" and "neutral" stimuli, the results were neither as expected nor unnoticeable. According to the questionnaires we surveyed, we concluded that the reason was that our categories of "negative" and "neutral" were not defined distinctively. We would improve it in the future.

A grassland scene was developed for training participants' emotional regulation ability. The scene would be changed according to participants' Alpha energy value automatically. At present, the training loops and serial port communication has been already finished, but we still need to use the equipment from Shanghai University to finish the research and get results. Besides, we will add more disturbs in this scene so that participants can be tested from all kinks of perspectives in the future.

A beach scene was developed for relaxing and meditation which gives users a way to release stress and negative emotions by entering a cozy world. We have added double-play mode in this scene so that we can analyze the results from two different participants under the same scene. In the future, we would import the analyzed EEG results into a dynamic graph in the virtual scene so that users would have an intuitive understanding about their emotional change.

In the field of psychology, some researchers and therapists conduct research and treat patients through compiling and telling stories. Due to the time constraints in the project, we could not finish develop an interactive virtual environment following a story script. In the future, more story based virtual training modules will be developed for better emotional regulation training.

When we developed the training modules, we focused on regulating emotions in general. In the future, we will concentrate on specific groups and develop more effective training modules targeting to the specific groups.

The testing results from “Forest” scene suggested that immersive virtual environments have obvious influence on m the EEG brainwave signals, which in turns reflect participant’s emotions. Therefore, we have a good basis to believe that it may become an effective methodology in regulating emotions using virtual reality based games with EEG signal as real-time input. In addition, the games can be developed with more interactions from users, multiple player mode can be introduced, and different difficult levels can be implemented to attract player’s attention and improve their participation.

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