Exploring Design of Experiments to Collect and Analyze Brain Signals Induced by Attention in Immersive Environments

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[**Abstract]** Immersive environments and technologies have become increasingly prevalent in recent times. Sustaining adequate attention during the learning processes in immersive environments is essential for optimal and productive educational performance. Experiments can be performed to develop efficient and effective teaching methods by examining brain signals that relate to attention. Consequently, this research was conducted to explore the design of experiments to collect and analyze brain signals induced by attention in a variety of immersive environments. Participants were asked to take part in two distinct common and validated tests measuring visual attention: the *Anne Treisman Test* and the *Eriksen Flanker Test*. The data obtained from the experiments showed that generated brain signals enabled consistent monitoring of neural activities, thus providing a standard and confirmed platform for conducting a wider scope of research in future experiments related to attention in immersive environments.

[Keywords] brain signals, electroencephalogram (EEG), attention, immersive environments

Technical Terminologies and Definitions: The following terminologies are provided to assist readers in their comprehension of this research article. Virtual Reality (VR) immerses users in a fully artificial digital environment. Augmented Reality (AR) overlays virtual objects on the real-world environment. Mixed reality (MR) not just overlays but anchors virtual objects to the real world. An electroencephalogram (EEG) is a recording of electrical signals produced by brain activity using electrodes (e.g., small metal discs) attached to the scalp. Please see Appendix I depicting different waveforms, frequencies, charts and colors, descriptions, and interpretations utilized in this research article.

Introduction and Concise Literature Review

Immersive technologies have become increasingly widespread in recent times (Makransky, Terkildsen & Mayer, 2019; Keum, Lee, Lee & In, 2018; Allcoat & Mühlenen, 2018; Coe - students with disabilities, n.d.). The most familiar to most people is virtual reality (VR), which is defined as "an artificial environment which is experienced through sensory stimuli provided by a computer and in which one's actions partially determine what happens in the environment" by *Webster's Dictionary*. Access to VR, augmented reality (AR), and mixed reality (MR) is not only limited to just VR headsets or sophisticated computer systems and setups; these immersive technologies are being integrated into modern smartphones and other devices. Examples of AR can be seen in the popularity of applications such as the mobile game *Pokémon GO,* where people catch virtual creatures from their couches. Potentially, these technologies are becoming more integrated into our daily life. It has now become a curiosity to understand how these technologies affect the brain and the potential benefits and consequences of these technologies. A report of a study in the *National Center for Education Statistics* (Coe - students with disabilities, n.d.) asserted that there are significant correlations between EEG (electroencephalogram) readings and the type of stimulant used. This study also revealed that the activity of high *Beta* brainwave signals has a strong relationship with the EEG signals obtained with the headgear. Furthermore, the results suggested that EEG gear can adequately and reliably capture, analyze, and even predict brain activity, depending on the kind of stimuli used on the subject. In another experiment (Hou, Liu, Sourina, Tan, Wang & Mueller-Wittig, 2015), the stress level was measured by collecting EEG signals. Typically, brain signal analyses use methods such as the power spectrum feature, fractal dimension feature, and statistical feature. The power spectrum feature is the most commonly used method to analyze stress-related EEG data. In short, this feature divides the EEG signals into *Delta* (0.5–4 Hz), *Theta* (4–8 Hz), *Alpha* (8–12 Hz), *Beta* (12–30 Hz), and *Gamma* (above 30 Hz).

In another article (Peng, Hu, Zheng, Zhao, Chen & Cai, 2013), those with chronic stress were found to have higher leftprefrontal power. This study validated the use of EEGs in the discrimination between those with chronic stress and those with moderate to low stress. Furthermore, a study (Gwizdka, Hosseini, Cole & Wang, 2017) showed the effectiveness of eye-tracking and EEG readings while subjects were reading and making decisions. However, with EEG and eye-tracking combined, there was an improvement in performance. The researchers concluded that this was evidence that a viable product could be made based on this: "There is potential for practical application of such techniques." While there are ample scholarly research reports supporting the notion that immersive environments may optimize learning, there are a few reports providing a contrary assertion (Makransky, Terkildsen & Mayer, 2019).

Preliminary results of *Assessing emotional responses induced in virtual reality using a consumer EEG headset* (Horvat, Dobrinić, Novosel & Jerčić, 2018) showed that statistically significant correlations between valence and arousal ratings of pictures and EEG bands were present but highly personalized. In another article, *Fractal dimension methods to determine optimum EEG electrode placement for concentration estimation* (Siamaknejad, Liew & Loo, 2019), the Higuchi and Katz algorithms were used to conclude that the P3 location was the best position to measure concentration with an EEG, although the P8 location was a close second (P3 and P8 electrode positions are shown in varieties of maps at (Electrode maps of EEG, n.d.). The Higuchi and Katz algorithm performed best when trying to determine clear distances between relaxation and concentration states. A group of researchers (Brouwer, Neerincx, Kallen, Leer & Brinke, 2011) successfully demonstrated a method to induce stress in individual participants using VR. A support vector machine (SVM) (Liu, Chiang & Chu, 2013) was then used to calculate and analyze the EEG signals and report if the subject was attentive. The results revealed that this method for measuring attentiveness was 76.82% accurate. Another group of researchers (Ismail, Hanif, Mohamed, Hamzah & Rizman, 2016) concluded that basic emotions activate specific regions of the brain and elicit certain brainwaves. This could be relevant in many different scenarios, from doctors treating patients more effectively to criminal interrogations. Furthermore, researchers (Park, Park, Shin & Choi, 2021) gathered information showing that attentiveness can be obtained by observing the *Theta* band and by implementing audio and visual stimulations when inattentiveness is detected by EEG. Yet another research (Keum, Lee, Lee, & In, 2018) concluded that it is possible to measure the degree of immersion using EEG brainwaves, but there is a need to address external noise.

The potential benefits of the studies reported here include providing a way to view how immersion technologies could be used to maximize attention and retention in a variety of environments (Beebe, Rose & Amin, 2010; Scherer, Muller, Neuper, Graimann & Pfurtscheller, 2004; Li, Li, Ratcliffe, Liu, Qi & Liu, 2011; Belle, Hargraves & Najarian, 2012). This could theoretically provide a basis for better ways to teach and a basis for the probable consequences of using these devices over a certain period. This investigation was conducted to explore the design of such experiments to collect and analyze brain signals induced by attention in immersive environments. Moreover, this study was designed to assess the hypothesis that immersion technologies support more attentive focus than other mediums.

The specific goal was to create a process to focus specifically on attention and to analyze any changes when using different forms of immersion technologies. Attention can be measured with several methods; however, the specific tool to measure attention during this research was electroencephalography or EEG (Noachtar, Binnie, Ebersole, Mauguiere, Sakamoto & Westmoreland, 1999). EEG is a process of measuring electrical activity in the brain by using electrodes that are placed on the scalp and are used to plot out the electrical activity created by neuron clusters (Jun & Smitha, 2016; Mustafa & Magnor, 2016). EEG is normally used by the medical field to assess brain-related phenomena. However, it can also be used to measure attention, emotional states, and other factors related to the brain (Ismail, Hanif, Mohamed, Hamzah & Rizman, 2016; Park, Park, Shin & Choi, 2021; Suzuki, Ito, Ishii & Dohsaka, 2019; Zhang, Gao & Chen, 2011; Cuingnet, Chupin, Benali & Colliot, 2010).

Research Question
Does the purposed design of experiments to collect and analyze brain signals induced by attention in immersive environments generate optimal attention waves within the Beta wave range, asserted to have a strong correlation with attention and focus?

Research Design Methodology

Participants
As a preliminary exploration and in consideration of the extensive complexity of the proposed research, sixteen (n=16) university community members, both female and male, ages 18 to 67 of diverse disciplines from two campuses of the university served as participants in this research. There were disproportionately more males than females (12-4). Participants were provided basic exposure to all instruments and measurements in all experiments.

Instruments and Measurement
An essential part of the design of the experiments was to explore and identify an EEG device that was uncomplicated to use and would provide consistent and reliable data. Furthermore, the authors sought to narrow down EEG devices that were comfortable to use for participants and could be set up accurately and quickly. The most all-encompassing device and software were the EMOTIV-14 channel EPOC X device and EMOTIV PRO software. This allowed the setup for measurement to be shortened to around 10 minutes, and it could be taken off and placed on another participant very quickly. Several tests were conducted with this device to assess its ability to deliver reliable and consistent EEG data. After assessing its ability on multiple participants, three experiments were conducted with three different stimuli to assess their effect on the participants. This data was then exported for additional processing and analysis.

Instruments (Hardware and Software) Specification:

- *EMOTIV-14 Channel EPOC X EEG Headgear*
  - *14 Channels: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4*
  - *Wireless Bluetooth 5.0*
  - *Sample Rate 2048 internal down-sampled to 128 SPS or 256SPS*
  - *Bandwidth: 0.16 – 43Hz, digital notch filters at 50Hz and 60Hz*
  - *Filtering: Built-in digital 5th order SINC filter*
  - *Resolution: LSB = 0.51μV (14 bits mode), 0.1275μV (16 bits mode)*
  - *Dimensions: 9 x 15 x 15 cm, Weight: 170 g*
  - *Saline-soaked felt tips for electrodes*
- *Z-Space Laptop*
- *Android Smartphone*
- *Intel i9 Mid-tower Desktop PC with Nvidia GPU*
- *EMOTIV Cortex Applications:*
  - *EMOTIV PRO*
  - *EMOTIV ANALYZER*
- *MATLAB*

- *EEGLAB*

Assumptions Consideration

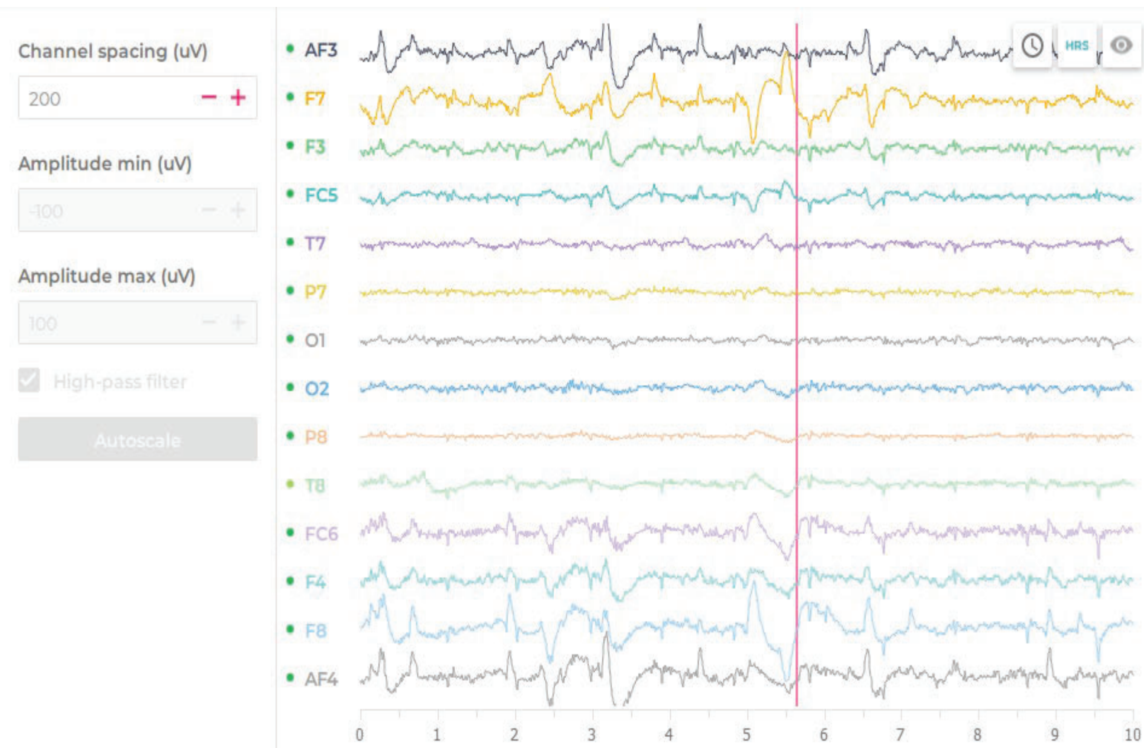
Human brains have billions of neurons, and their combined electrical signals generate oscillations known as brain waves. Both *Alpha* waves (8-13 Hz frequency) and *Beta* waves (14-30 Hz frequency) are assumed to have a strong correlation with attention, particularly in the parietal cortex. Some researchers consider 18.5 Hz to be an optimal frequency for focus and concentration. For simplicity of design and commonality, *Gamma* waves (30-140 Hz) are not interpreted in this study. *Gamma* waves are associated with a higher level of focus, inspiration, and higher learning activities.

Procedure for Experiments

The researchers conducted several tests with each of the EEG devices on different participants to obtain variability for baseline conditions. To ensure consistency when setting up the EEG, the felt tips were placed in several different conditions, including dry, soaked for two minutes, and dampened by placing several drops of saline solution onto each felt pad before application. The most consistent results for connection quality and EEG signal quality were obtained by using several drops of saline solution, rather than having them dry or soaked. The raw EEG data collected is shown in Figure 1.

Figure 1

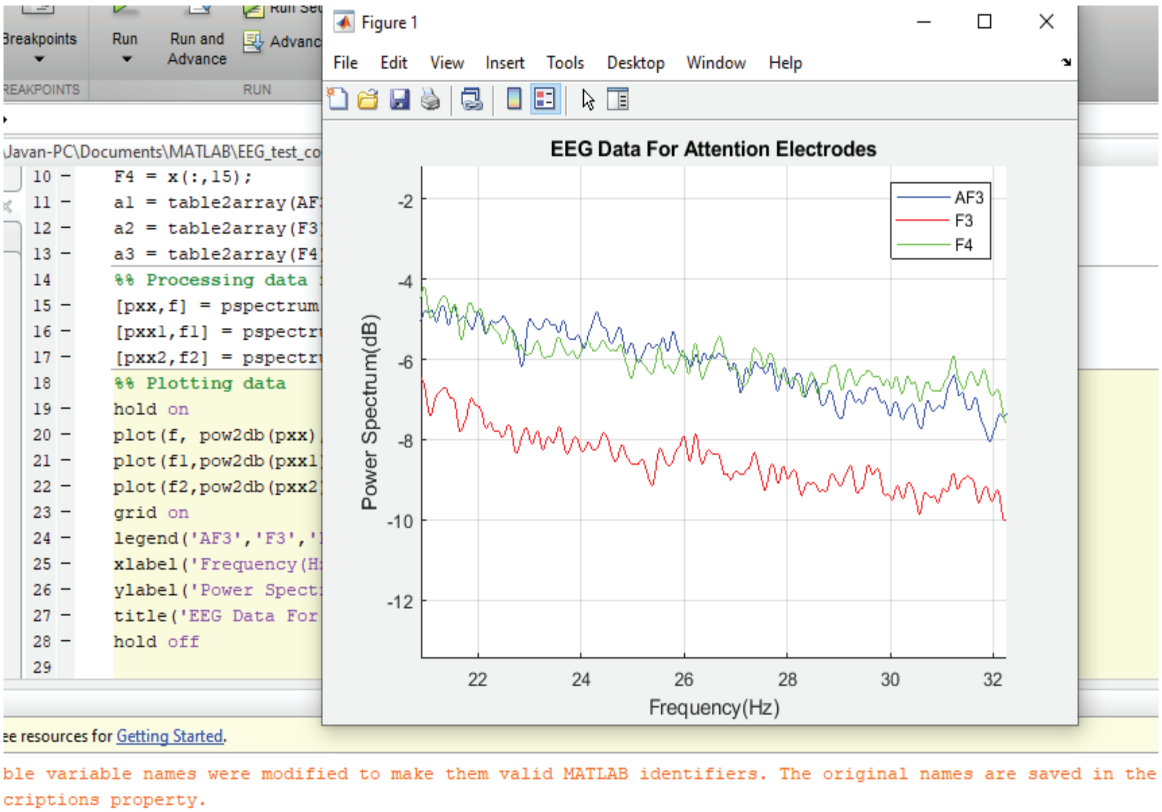
Raw EEG Data Collected - The Most Reliable and Consistent Raw Data for Connection Quality and EEG Signal Quality Were Obtained by Using Several Drops of Saline Solution



Three EPOC X devices were tested to acquire the ideal conditions for connection. The group of researchers conducted several tests with each of the EEG devices on different participants to obtain variability for baseline conditions. It was observed that one of the EEG devices was more consistent than the other two, as shown in Figure 2.

Figure 2

EEG Data Simulated in MATLAB Showed that One of the Three EPOC X Devices Were Tested for Obtaining Variability for Baseline Conditions More Consistent than the Other Two Devices



The setup conditions were repeated several times to verify the method. After the results were monitored over several weeks with consistent results, this was observed to be the superior and ideal method for setup. The most prominent psychological test, the visual attention *Anne Treisman* test, was also conducted in this project, as shown in Figure 3.

Figure 3

A Participant is in Preparation for the Visual Attention Anne Treisman Test, A Prominent Psychological Test

Figure 4

Eriksen Flanker Test was Administered to a Participant after Establishing a Sufficient Connection for Testing

Activity at different frequencies during events at electrode F3 is shown in Figure 5, and raw unfiltered EEG data during events at the F4 electrode position are shown in Figure 6. To begin each trial, a baseline was established with participants' eyes opened and closed for 15 seconds each. A baseline signal serves as a control sample to properly analyze signals while the subject is exposed to various stimuli. After establishing a sufficient connection for testing and EEG signal quality, each participant was given the *Eriksen Flanker* test, as shown in Figure 4. This test places a single specific letter into a string of letters on a screen, and the participant chooses which single letter is being flanked by the press of a button.

Figure 5

Activity at Different Frequencies during Events at Electrode F3

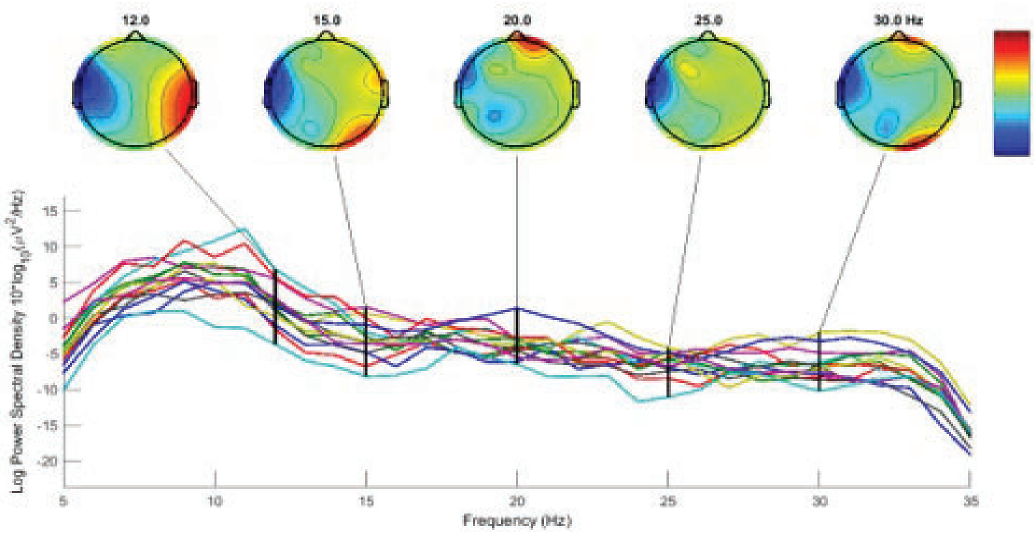


Figure 6

Raw unfiltered EEG Data during Events at the F4 Electrode Position

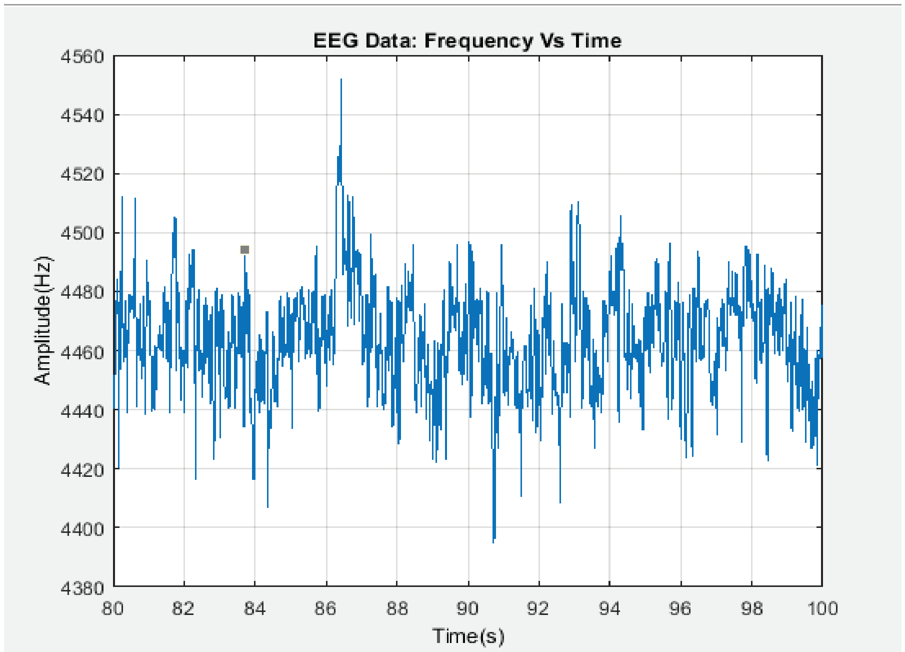
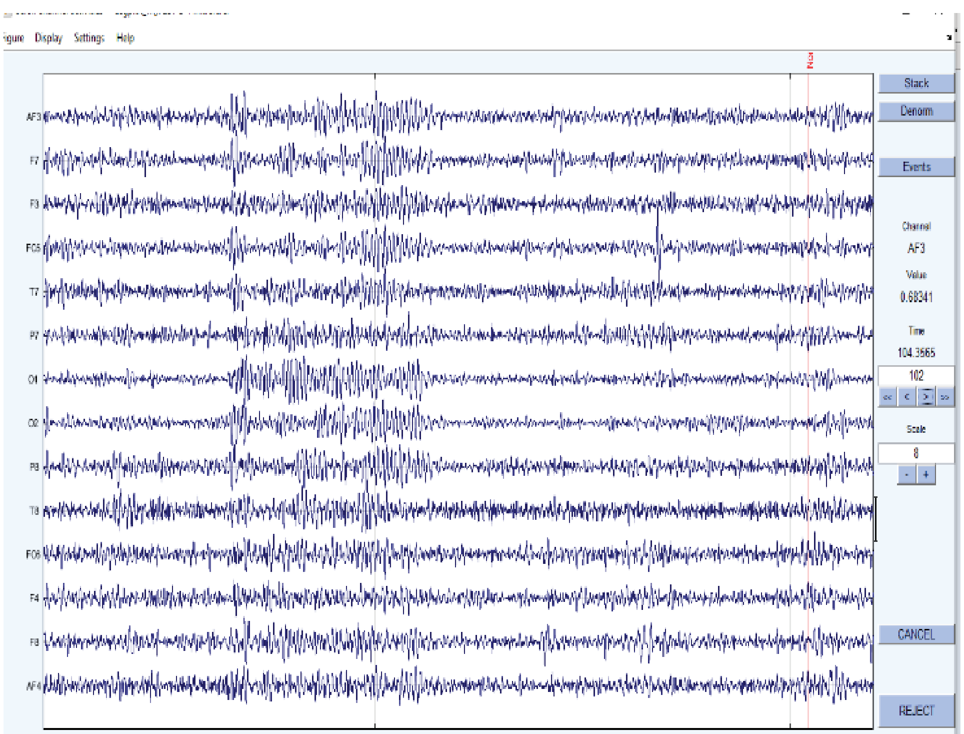


Figure 7

Filtered EEG Data during Events (all electrodes)



The purpose of this test was to test selective attention and monitor any significant changes or artifacts in the EEG signal. After this experiment was concluded, the next test began. This test observed attention over a short duration of 20 seconds. Three mediums were selected for this test. The mediums were a Z-space laptop with VR-enabled software, Google VR on an android smartphone, and a PC monitor screen. For this trial, a 3D cube was used to ensure that the same object could be observed in each instance. Each had 10 trials with 20-second durations. For the first 5 seconds, the cube was simply observed. For the next 5 seconds, the participants were asked to close their eyes.

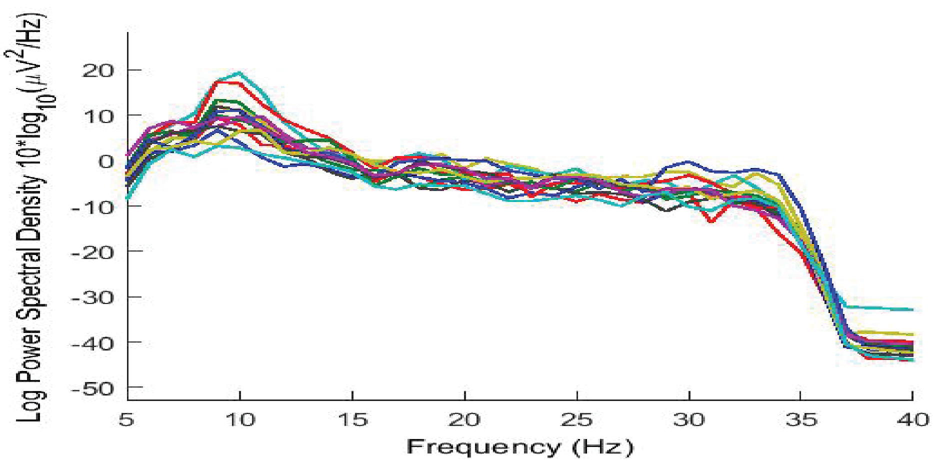
Finally, for the last 10 seconds, the participants were asked to interact with the cube by manipulating it or observing it from different angles. A marker was placed at the beginning of the trial, and another was placed after the trial, beginning the next trial. These tests were repeated for each medium and the data was then exported with the markers. After exporting the data as CSV and EDF files with markers, the data were imported into MATLAB and analyzed using the EEGLAB toolbox, as shown in Figure 7.

Preliminary Results and Analysis

After conducting the experiments, the test data captured was imported, processed, and plotted. The results verified the presence of *Beta* wave frequencies during each event. There was a higher presence of *Alpha* waves during the rest portion of each test. The plot for Figure 8 shows the relative weighted presence of frequencies during one event. This shows that there was a higher presence of frequencies between 7–12 Hz. This plot also shows the relative power at each electrode, with a higher presence of power at both the 18 Hz and 25 Hz range, as compared to the other frequencies in the *Beta* wave range. It must be noted that research has shown 18 Hz waves appear to be optimal for indicating attention and focus.

Figure 8

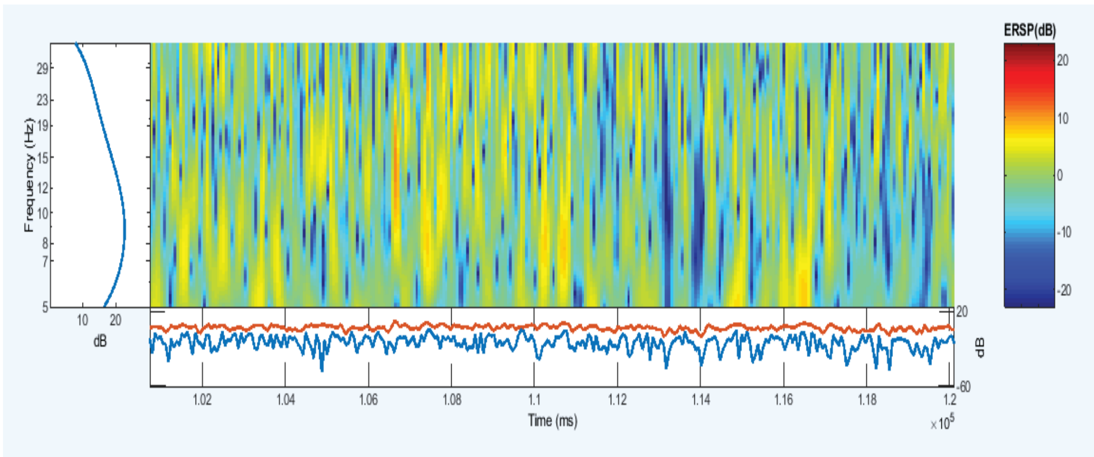
Frequency domain plot of EEG signals recorded showing the relative weighted presence of frequencies during one event



Furthermore, Figure 9 illustrates a wavelet transform of the EEG data during an event lasting 20 seconds (Note: This figure is provided as a sample of the visualization aspect of attention in experiments of this article.) The colors represent the amount of powerful presence and at what time during the event this power occurred. For instance, the yellow represents 5 microvolts of power and is present during the activity portion of the test within the *Beta* wave frequency range.

Figure 9

The time-domain plot of EEG signals was recorded. The colors represent the amount of powerful presence and at what time during the event



General Conclusion and Future Research Direction

The designed and tested EEG arrangement was able to consistently monitor neural activity with little to no artifacts to disrupt the data. A series of tests were implemented to test for attention using the designed EEG. These tests were the *Anne Treisman* test and the *Eriksen Flanker* test. To measure the differences in immersive technologies, three mediums were used, including VR on a cellular device, ZSPACE on a laptop, and 2D images on a regular PC monitor. The data was able to be visualized and analyzed using EEGLAB. The presence of *Beta* wave frequencies was observed at electrodes F3, F4, P7, and P8 during each event, asserting a fairly strong record of attention by participants. In brief, the research question was positively affirmed; the purposed design of experiments to collect and analyze brain signals induced by attention in a variety of immersive environments generated optimal attention waves within the *Beta* wave range, asserted to have a strong correlation with attention and focus.

Ultimately, a pipeline for further experimentation was made through extensive experimentation and documentation. This allows for the next phase of experimentation to begin. This research and design of experiments will be passed on to the brain-augmented technology group to continue data collection using a 3D-immersive dome and/or other immersive environments. Further changes can be made to incorporate different types of experiments and tests, as well as changing the duration of each event for longer testing periods. The results were obtained by a limited number of participants; for a future wider research scope, the continuation of this experiment will include additional participants.

Acknowledgments

This research investigation is supported by the Vertically Integrated Projects (VIP) program that is designed to facilitate long-term research involving large teams of faculty/staff members and students. VIP is an established program with sites at universities all around the world. Furthermore, the initial theoretical and graphical design of the visualization component of this research was conducted at the Immersive Visualization Environments Research Cluster/Laboratory that was founded by an equipment grant from the U.S. Department of Defense (DoD)/U.S. Army Research Office (ARO) with the collaboration of Immersive Display Systems, Incorporate (IDS). The content of this work does not reflect the position or policy of the DoD, ARO, or IDS and no official endorsement should be inferred. The authors thank Javan Hutchinson, Blake Shook, Caleb Winfrey, Aaron Stinebaugh, and Clay Brown for their initial research and for assisting in the experimental phases of this research. Ultimately, the authors express gratitude to all the reviewers for their constructive and technical suggestions.

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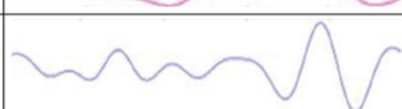
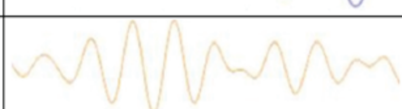
Appendix I

The following table depicts different brain waveforms (*Delta*, *Theta*, *Alpha*, and Beta) with their frequency, wave chart and color, and description/interpretation.

Waveform	Frequency	Wave Chart with Color	Description/Interpretation
Delta	0.5–4 Hz		Unconscious level wave Correlated with the deep stage of sleeping
Theta	4-7 Hz		Subconscious level wave Emotional experience, Sustained attention, Learning
Alpha	8-13 Hz		State of relaxation Focused state (excited brain), Recharging
Beta	14-30 Hz		Conscious mind Constant alert, Agitated, Problem-solving, Engaging

Note: For simplicity of design and composition, Gamma waveform is not included in this table. Gamma waveform is a pattern of neural oscillation in humans with a frequency between 30 and 140 Hz that associated with higher level of focus and inspiration activities.