

BIO-SIGNALS FOR THE OBJECTIVE MEASUREMENT OF PRESENCE IN VIRTUAL REALITY

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Abstract

USING BIO-SIGNALS FOR OBJECTIVE MEASUREMENT OF PRESENCE IN VIRTUAL REALITY

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Presence is a mental state when a user in a Virtual Environment reacts to events in it as if it is real. Currently, Presence is measured using methods such as Questionnaires and Behavioural methods. These methods offer limited insights and are not real-time. We propose an experiment to identify Bio-signal correlates of Presence (Slater's Definition) and its components such as Place Illusion and Plausibility illusion. Based Slater's Theory of Presence, a 2x2 factorial within-subjects experiment was designed. Then, VR Scenarios controlling the two factors: Immersion and Coherence were designed using Unity with in-VR questionnaires and teleportation based locomotion to control for simulator sickness. A Pilot study was conducted following which an experiment was conducted with 20 subjects. Afterwards, the questionnaire results were tested to see if there is statistically significant results across scenarios for the corresponding mental states. Afterwards EEG and ECG were pre-processed and mined to extract useful features which can measure the level of presence.

Dedication

To our families, friends, supervisors, and all others that supported us in this work.

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Acronyms and Abbreviations

HCI - Human Computer Interaction
VR - Virtual Reality
EEG - Electroencephalography
fMRI - Functional Magnetic Resonance Imaging
PI - Place Illusion
PSI - Plausibility Illusion
VE - Virtual Environment
HMD - Head Mounted Display
LSL - Lab Streaming Layer
ECG - Electrocardiogram
PPG - Photoplethysmogram
AR - Augmented Reality
BCI - Brain Computer Interface
ERP - Event Related Potential
ICA - Independent Components Analysis
PCA - Principal Component Analysis

1 Introduction

Virtual Reality (VR) is the use of computer technology to create a simulated environment. This simulated environment is known as 'Virtual Environment'. Virtual Environments (VEs) are complex human computer interfaces which are used in many applications such as entertainment, psychological treatment, military training, medical training and psychological research. Each application has different forms of software and hardware for the VEs depending on the task requirements and objectives.

Presence (or Telepresence) is a mental state when the user unconsciously reacts to the virtual simulated world just as if it is the real physical world. [1]. Today, Human Computer Interaction researchers have iteratively modified and grown our understanding of presence based on experiments. They have come with various interpretations. Scientists use this level of presence of a user to measure the effectiveness of their simulated environment. An effective simulated environment has many benefits as it will enhance the VR experience.

1.1 Problem

Traditionally, HCI Researchers use post-experience Questionnaires to measure Presence. However questionnaires are flawed in that they are (1) intrusive (2) not continuous (3) generally not contemporaneous (4) subjective (5) reliant on users' interpretations of difficult concepts (119) [1].

There are also behavioural methods to measure Presence. According to Joy van Baren and Wijnand Ijsselstein, Behavioural measures designed believing that the more a participant feels present in a virtual environment, the more similar his/her responses to stimuli will be to those s/he would exhibit in a similar real environment[3]. Therefore, it has been proposed that naturalistic behaviours such as startle responses, postural sway, and conditioned social responses can be used as indicators of presence. [3]. However these behavioral methods have weaknesses, they require some feature or task to be added to the virtual environment. Often these tasks may have nothing in common with the application or virtual reality, but only used to measure presence[4]. According to Skaberz, these are objective, contemporaneous and non intrusive but not continuous[1]. Behavioural measures are have limited generalizability and they are prone to bias originating from the experimenter[3].

1.2 Objectives and Scope

According to Meehan, presence means that a user is “responding physiologically to the mediated environment in a manner consistent with human response to similar real situations.” [5]. This means it is possible to physiologically measure presence using known bio-signals. In the literature, there have been several attempts to measure Presence using Physiological Signals.

Out Primary Objective is to design a VR environment to identify bio-signal features which can be used to measure the level of Presence and its components.

However, a through understanding of Presence and current bio-signal research is required.

1.3 Related Work

1.3.1 Eye Tracking based Methods

Laarni, Ravaja, Saari presented the use of eye tracking measures for measuring spatial presence. They identified three methods for researching about spatial presence. Laarni et al. proposed that eye tracking should be combined with other continuous measures such as phasic heart rate deceleration (as a measure of automatic attention) and respiratory sinus arrhythmia (as a measure of controlled attention). [6]

- The degree to which the user’s attention is distracted away from the mediated experience
- The aspects of the mediated information looked at by the user and the order in which different areas of media stimuli were processed
- Attention strategy (focused attention or distributed attention).

Pupilometry based methods were also suggested. However there is no research as to whether these methods have been successful.

1.3.2 Galvanic skin response and ECG data

- Dillon attempted to measure immersion using galvanic skin response and EKG data while measuring presence with ITC-SOPI questionnaire.[7]
- Meehan used the same measures with skin temperature with VEs that contained stressful stimuli. He found that heart rate variability had a higher correlation with the sense of presence[5].

1.3.3 Breaks in Presence

- Slater and colleagues have used breaks in presence and in tandem measured physiological metrics such as galvanic skin conductance and heart rate to measure user's responses to breaks in presence. A break in presence (BIP) is when the user stops responding to VE sensory input and instead responds to real world sensory input. This paper presents an approach to measure the degree of presence using the transitions from virtual to real [4]. Using a set of simplifying assumptions, they designed a stochastic process which models these transitions or BIPS.

Treating BIPs as stimuli and changes in physiological metrics as response, they attempted to find a powerful connection. It must be careful so that the equipment doesn't encumber the user. They used both experimenter caused breaks and incidental breaks[8].

Schlögl, Slater, Pfurtscheller suggest to use adaptive autoregressive (AAR) parameters to continuously classify the EEG spectrum. They feel the EEG based approach can compliment the "breaks in presence" technique.[9]. Their paper further describes how to modify EEG experiments for presence research.

1.3.4 EEG and fMRI

- Baumgartner et al. was the first person to evaluate brain activity in spatial presence experienced in virtual reality [10]. They got the subjects seated in front of a computer screen and made them watch roller coaster scenarios. In a low presence condition, subjects were shown a scenario of a roller-coaster on a horizontal roundabout track. In a high presence condition, they were shown with different ups, loops and downs. Then they were asked to rate their feeling on a presence scale. They found out that increased spatial presence led to an high event-related desynchronization of the alpha band activity in the parietal brain areas known to be involved in spatial navigation.

They subsequently did an fMRI study on the same scenario [11]. They found that the hemodynamic responses in the dorsolateral prefrontal cortex negatively correlated with the subjective feeling of presence.

- Bouchard et al. used fMRI and identified the parahippocampus as the brain region most associated with the feeling of presence.[12] It must be noted however, both authors used different study methodologies. These are however limited as they are only shown to be useful in experiments which affect the physiological systems in a certain way or impose severe restrictions. They are also not generalizable across scenarios[1].

- Clemente attempted to use an Emotiv EPOC EEG to measure brain activation of the feeling of presence when a person is navigating a virtual environment [13]. They used the sLORETA tool to compare the conditions between free navigation and automatic navigation. They discovered that theta and alpha band activity in the right insula (which relates to the stimulus attention and selfawareness process) and alpha band activity in the prefrontal gyrus corresponds to increased presence. [13].
- Kober used two different systems: one a highly immersive Single-wall-VR-system and a less immersive desktop-system. The former was used to elicit high levels of presence and the latter lower levels of presence. [14] They discovered that in the former system there was an increase in the alpha band for the parietal TRPD. The latter case was accompanied by strong functional connectivity between the frontal and parietal areas of the brain. [14]

Kober modified Baumgartner's approach with a more interactive VE. They concluded the parietal brain areas might play an important role in the experience of presence.

Given that these areas are associated with the generation of a body-center/egocentric representation of space [15],

Kober et al [14, 16] gave a new definition to the sense of presence as egocentric spatial experience and it has been assumed that this egocentric part might be vital for the spatial presence.

- Furthermore, additional research has been carried out [17] to investigate and verify the involvement of prefrontal areas in the modulation of the sense of presence in adult users. The discrimination between adults and children has been made because prefrontal areas are not recruited during a VR experience in children since they haven't fully developed yet.
- Pugnetti et al were the first to analyse human reactions in Virtual reality. [18]. They concluded that VR users can dedicate only a portion of their processing abilities to process stimuli. They analyzed 30 minutes of EEG signals during a VR experience and 15 minutes each for pre and post VR experience. Major findings were:
 - Since subjects participated in the study with their eyes open, the amount of alpha activity over occipital and parietal regions was considered as an index of brain activation.
 - While engaging in the VR task substantially reduced the amplitude of N1-P2 components; no effect was seen on the latency of the responses. They inter-

preted their findings as further supporting the hypothesis that ERP amplitude can be used as an index of saturation of residual cognitive resources left to process concurrent but irrelevant ambient stimuli.

- Baka et al. using EEG to study brain activity between VR simulated classrooms and real classrooms. They attempted to also see if the graphics and nature of such environment can influence user experience, and also measured the time taken to perceive and adapt to a new state. They used the I-group Presence questionnaire in tandem with the EEG recordings in 10 brain regions, and found significant difference in the all areas, especially in the frontal and occipital regions[19].
- Clemente et al's study was conducted with a sub-optimal configuration: the researchers used data from low-density (14- channel) consumer-oriented EEG equipment to perform signal source-localization analysis and with a small participant sample [13, 20, 21].

Summing up, the up to date bibliography has revealed that VR has an impact on brain activity, not necessarily according to the executed task. Parietal brain areas, involved in egocentric spatial processing and prefrontal cortex, responsible for the highest order of cognitive functions are the main brain parts proved to be associated with VR so far. Most alterations occur in the alpha brain state, which has also been correlated with the aspect of concentration. Flow also seems to be reflected in brain activity and game-like environments, without the need of excessive features, provoke more positive responses.

1.3.5 Auditory ERP

- In a different study, Kober and Neuper used the auditory-event-related potentials(AERP) of the EEG, which are not related to the VR, to evaluate the degree of presence in a virtual environment[16]. A person was made to navigate through a virtual city and they rated their sensation of hearing while hearing frequent standard tones and infrequent deviant tones. (These were irrelevant for the VR task). Then the AERP was compared between the participants with a high level of presence and low level of presence. increased presence led to 'decreased late negative slow wave amplitudes' particularly in the frontal regions. It has be shown that these are correlated with attentional resource allocation and central stimulus processing.
- Pugnetti, Mendozzi, Barberi, Rose, and Attree have used EEG and auditory evoked potentials to study cognitive tasks carried out in a VE. An inverse relationship was found between EEG alpha amplitude and performance measures (time, errors).[22]

- There have been many other studies which used the Kober Oddball Paradigm such that by Naatanen [23] and Burns[24]. However it must be noted the recent work by Terkildsen and Makransky did not replicate their findings even though they used similiar paradigms [25]
- Recently a study was done by Terkildsen and Makransky [25] to see if presence can be objectively evaluated by game irrelevant ERPS. They found that the N1 amplitudes and lower MMN difference-waveform amplitudes significantly decrease as a result of higher presence.
- In Burns study they defined Immersion as either "Sensory Immersion" and "Challenge Immersion". What they found was that the amplitude of late component ERPs to oddball stimuli were significantly reduced when demand increased from easy to hard/impossible levels. However this study must be noted that they used

According to Skarberz, these are objective measures which are also contemporaneous and continuous. However they can be inconvenient and intrusive and not easily generalizable [1]. He says sometimes the equipment can encumber the user or might require the experience to affect the physiological signals in certain ways.

When using physiological measures, it is sometimes difficult to determine what is being measured. Other effects include measurement noise, interference noise from head mounted displays and orienting effects (reactions to new stimuli) can sometimes overwhelm effects of experimental manipulations. Some physiological measures changes can be too slow to be detected.

1.4 Method of Investigation

Presence as a theory has evolved tremendously in the past years. There have been various modifications and interpretations in the literature. Our first goal is to study the literature and identify a suitable interpretation of Presence as a frame work for the study.

Once a suitable framework or theory of presence is identified and justified. Our goal is to design an experiment based on that framework such that 'Presence' can be measured. It involves manipulating the components of presence identified by the said theory and identifying statistically significant neural and physiological correlates.

1.5 Principal Results of Investigation

After a rigorous literature review and discussions Slater's theory of presence was chosen as the primary theory for the experiment.[26].

We have the following justifications for selecting Slater's theory

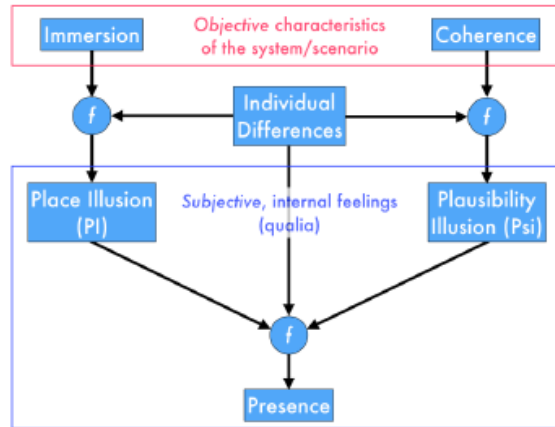


Figure 1.1: Overview of Slater's Theory of Presence [1]

- Skabecz managed to show that many other theories are variations of Slater's theory focusing on its different factors.[1]
- Slater Theory is the only theory which has seen tremendous evolution in the recent times. Slater has iteratively modified his theory based on experiments [16,28, 16, 19, 23, 25]
- Slater's theory is one of the most cited when it comes to VE effectiveness research with 941 citations.

1.5.1 Slater's Theory of Presence

Slater says "Presence Is the feeling that what is happening in the VE is 'real'. If a VR invokes a higher level of 'Presence', the person would react to VR scenarios just as she/he would react in Real life".[26].

There are two objective and controllable factors of the VR system known as Immersion and Coherence.

The Immersion factor of the VR system gives rise to an mental illusion known as Place illusion, which is the illusion of being in a place even though you are physically not' [26].

The coherence factor of the VR system gives rise to a mental illusion known as 'Plausibility illusion', which is the perceived realism. [26].

The presence of these two illusions gives rise to the state of 'Presence' ,which is what we want to measure. [26].

Now we look into detail about these two objective factors.

1.5.2 Slater's Theory of Presence : Immersion

Slater describes 'valid actions' as a set of actions that a participant can take that can result in changes in perception or changes to the environment. The immersion of a VR system is the set of all valid actions supported by that VR System [26]

Factors affecting the quality of the immersion[26]:

- Graphics frame rate (time taken to graphically render the visible portion of the virtual environment currently viewed)
- The overall extent of tracking (how much of the body movement is tracked)
- Tracking latency (how long it takes before a head movement results in the correct change in the displayed image)
- The quality of the images (how great the brightness, spatial, colour and contrast resolutions are)
- The field of view (How much the displays encompass a person's view)
- The visual quality of the rendered scene (how much objects appear geometrically to appear like what they are supposed to depict, and how realistic the illumination is)
- The range of sensory modalities accommodated (and within each sensory modality the fidelity of its displays)

Researchers have also found that,

- Stereoscopy, Tracking-level, and field of view contribute more to immersion/spatial presence than other factors[27]

1.5.3 Slater's Theory of Presence : Coherence

Plausibility Illusion is feeling that what is happening is what is really happening. According to Skarbez, the plausibility of a virtual environment is closely tied to its consistency and the extent it meets user's expectations. [28]

Users' prior knowledge entails

- what they know about the real world
- what knowledge they have of the (potentially fictional) world generated by the virtual environment.

Required conditions for Plausibility illusion:

- Events occur in relation to you personally, you are often a subject of another character.
- The world responds to you. (e.g. you offer to shake your hand, the character shakes your hand.)
- Credibility: events happen according to user's trained expectations.

Where PI emerges when a user successfully probes the immersive characteristics of a system, Psi emerges when a user successfully probes the behavioral characteristics of a scenario. PSI and PI are logically orthogonal, but not certain if statistically independent.[28]

Coherence describes the degree to which the virtual scenario behaves in a reasonable and predictable way [28].

The coherence characteristics of a system include, but are not limited to:

- The extent to which the appearance and behavior of a user's virtual body matches his real body
- The extent to which virtual humans are present in the scenario and act appropriately for the scenario.
- The extent to which objects in the scenario can be interacted with
- The extent to which a scenario accurately depicts what it purports to depict.
- The degree to which those interactions are correct or predictable

Skarbez explains that presence can be experienced by individuals in low immersive environments such as books. This is due to PSI. Coherence is better in traditional media because of [28]

- Linear plot
- Singular point of view
- Books offer justifications for the actions

This effect explains games such as 'Super-Mario-Bros', which is less immersive.[28]

- Fewer buttons
- Low number of valid sensorimotor actions

But because of clear and consistent rules of behavior in the game world. As one plays more, the more matching of the stimulus to response and expectation to realization, leads to one being more present in the world it represents. [28]

1.6 Proposed Deliverable

Considering the literature review, the following deliverable were decided.

- Proposing an experimental protocol to measure Presence, Place Illusion, Plausibility Illusion based on Slater's Theory of Presence using Biosignals such as ECG and EEG
- Identifying Pre-processed EEG and ECG Features for each mental state in Virtual reality.
- Writing a research paper.
- Giving Physiological Interpretation of the Results.

2 Methodology

2.1 Experiment Design

We wanted to control the immersion and coherence factors such that we get different levels of Place illusion, Plausibility illusion and Presence. Since we have two factors, we made a 2X2 factorial within-subject design. We designed four VR scenarios controlling each factor. We then sequentially expose a subject to each scenario while simultaneously taking bio-signal recordings.

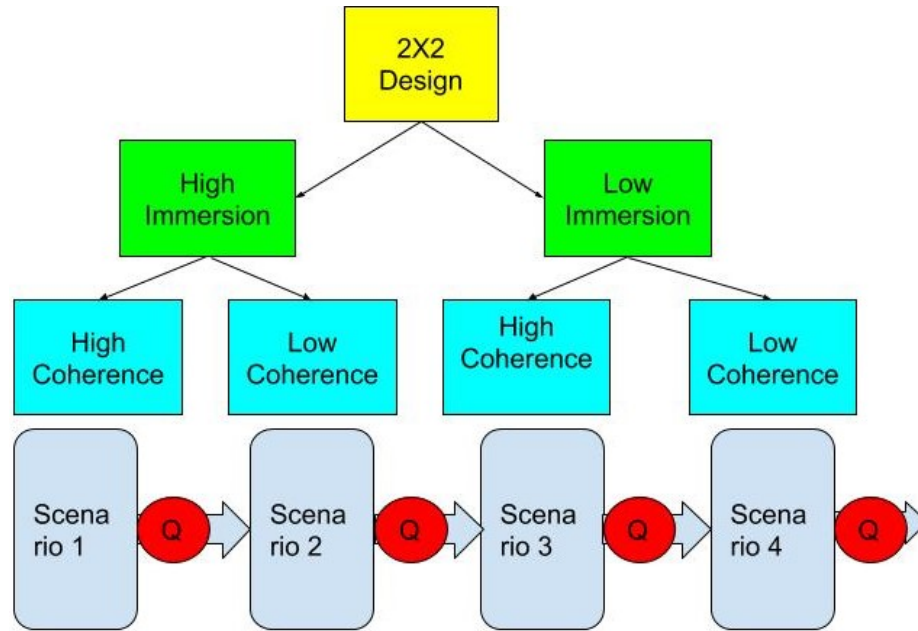


Figure 2.1: Experiment Design

Individual differences also affect the responses, thus to reduce the affect of individual differences we used the following choices.

- Within Subjects Design
- Randomization of the order scenarios shown

After we manipulate the factors, we have to verify if the correct illusion is present or absent in the subject. For that, we give Questionnaires designed by human computer interaction experts after the subject sees each scenario.

- To verify if the subject is present , we use the SUS Questionnaire [29]

- To verify if Place illusion is present, we used the Audio and Haptic Sub-score of the presence questionnaire. [30]. This have been shown to correlate with high Place illusion by Skaberz.[1]
- To verify if Plausibility illusion is present we used the Realism Sub-score of the presence questionnaire.[31] This have been shown to correlate with high Plausibility illusion by Skaberz. [1]

After confirming it, we will analyze the recordings taken by the sensors to identify statistical significant features that can discriminate between the different illusions.

2.1.1 Experimental Hypothesis

- We expect the virtual reality environments designed with varying levels of immersion and coherence to have statistically significant and different levels of Presence, Place Illusion, Plausibility Illusion when measured using questionnaires.
- We expect varying and statistically significantly different EEG activity in varying levels of Presence, Place Illusion and Plausibility Illusion.
- We expect varying and statistically significantly different ECG activity in varying levels of Presence, Place Illusion and Plausibility Illusion.

2.1.2 Sample Size calculation

Most Human Computer Interaction studies use sample sizes of the powers of twos. Thus we opted to go with 32 subjects. However we did a full statistical analysis to come with a good number for the sample size considering statistical parameters such as effect size,etc.

Using G Power statistical software, the team found the number of participants required using an effect size of 0.5(based on evidence from the “Does a Sense of Presence Affect the EEG Activity of Participants, when Watching Affective Content During a VR Experience?”) We found that we need a minimum sample size of 34.

2.1.3 Ethics Approval

For our experiment we got Ethics approval from the University Ethics Committee. Reference number: ERN/2020/002.

2.2 Scenario Design

2.2.1 Varying the immersion factor across the scenarios

Based on the Human Computer Interaction literature, The Immersion factor depended on five common sub-factors in general. We created control scenarios where all the sub-factors are suppressed and experimental scenario where it is not suppressed.

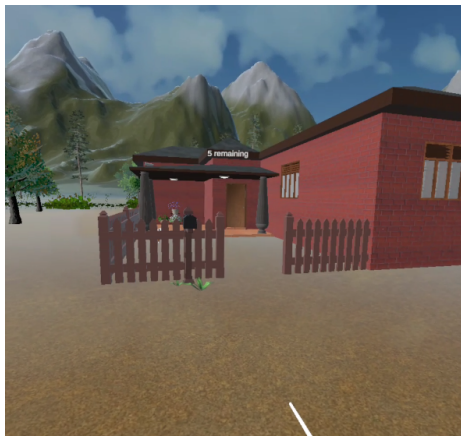


(a) Field of View: High Immersion Scenarios



(b) Field of View: Low Immersion Scenarios

Figure 2.2: Immersion sub-factor control: Field of View



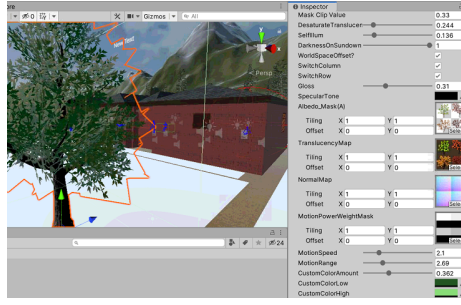
(a) Display Resolution: High Immersion Scenarios



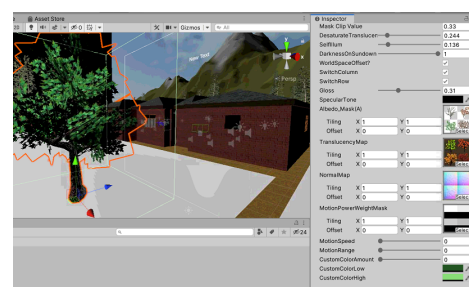
(b) Display Resolution: Low Immersion Scenarios

Figure 2.3: Immersion sub-factor control: Display Resolution

- Field of View



(a) Environmental Dynamism: High Immersion Scenarios



(b) Environmental Dynamism: Low Immersion Scenarios

Figure 2.4: Immersion sub-factor control: Environmental Dynamism



(a) Set of Valid Actions: High Immersion



(b) Set of Valid Actions: Low Immersion

Figure 2.5: Immersion sub-factor control: Set of Valid Actions

- Display Resolution
- Stereo Sounds
- Environmental Dynamism: Making the environment more dynamic to enhances the technical features of the VR headset.
- Increasing/Decreasing the set of Valid Actions. For this we limited the teleportation range.

2.2.2 Varying the Coherence factor across the scenarios

Coherence is another factor which affects our study. Coherence affects perceived realism. There are numerous sub-factors as described in the human computer interaction literature. Based on the study and research by Skarbez .et. al. We broke it down to the following sub-factors and controlled them. [1]

- Correlational coherence: Correlational coherence depends on how the environment interacts to the player. High-coherence scenarios contain human avatars, animals

and an alexa to respond to the player's movements while these responses are muted in low-coherence scenarios.

- Narrative coherence: Narrative coherence depends on how consistent the VR scenario with the user's expectations. To differentiate narrative coherence in high-coherence and low-coherence scenarios, inappropriate objects are placed inside virtual scenarios.
- Physical coherence depends on how far our scenarios perceive laws of physics. In high-coherence scenarios, usual environment arrangements are deployed while messed up environment arrangements like floating objects, moving objects are used to break laws of physics in low-coherence scenarios.



(a) Correlational Coherence: High Coherence Scenarios



(b) Correlational Coherence: Low Coherence Scenarios

Figure 2.6: Coherence sub-factor control: Correlational Coherence

2.2.3 Questionnaires within Virtual Reality

Presence is typically repeatedly assessed through questionnaires completed after leaving a VR scene. Requiring participants to leave and re-enter the VR costs time and can cause disorientation. However it was also noted the subjects did not like wearing the EEG cap. This must also be considered in the study.

Valentin and Pascal found that completing presence questionnaires (such as PQ[31], SUS[29] directly in VR aside from reducing a study's duration, making it easier for the subject to access presence, reducing the effect of distracting and biasing clues and reducing disorientation, increased the consistency of the variance. However it did not change the measured presence.[32]



(a) Narrative Coherence: High Coherence Scenarios



(b) Narrative : Low Coherence Scenarios

Figure 2.7: Coherence sub-factor control: Narrative Coherence



(a) Physical Coherence: High Coherence Scenarios



(b) Physical Coherence: Low Coherence Scenarios

Figure 2.8: Coherence sub-factor control: Physical Coherence

We designed the questions in VR. Technology wise we used the UI System of Unity along with XR interaction toolkit for the design. Since there were only 14 questions all the questions are hard-coded into the code instead of loading them from a separate file. Since there is a 1-7 likert scale for the answers, seven interactable buttons were used for answering. Participants have to tap on the “Next” button in order to move forward to the next question. But this is allowed only when he submitted the answer for the current question, otherwise he has to stay in the current question until he submit the answer. A progress bar was added onto the question canvas in order to show participants how many

questions are answered.

After a participant completes all the 14 questions, they proceed to the next scenario while all the answers he gives are saved into a text file inside the internal storage of Oculus Go naming the relevant scenario. After a participant completes all the four scenarios, then there are four questionnaire result text files and they can be accessed and used for our analysis.

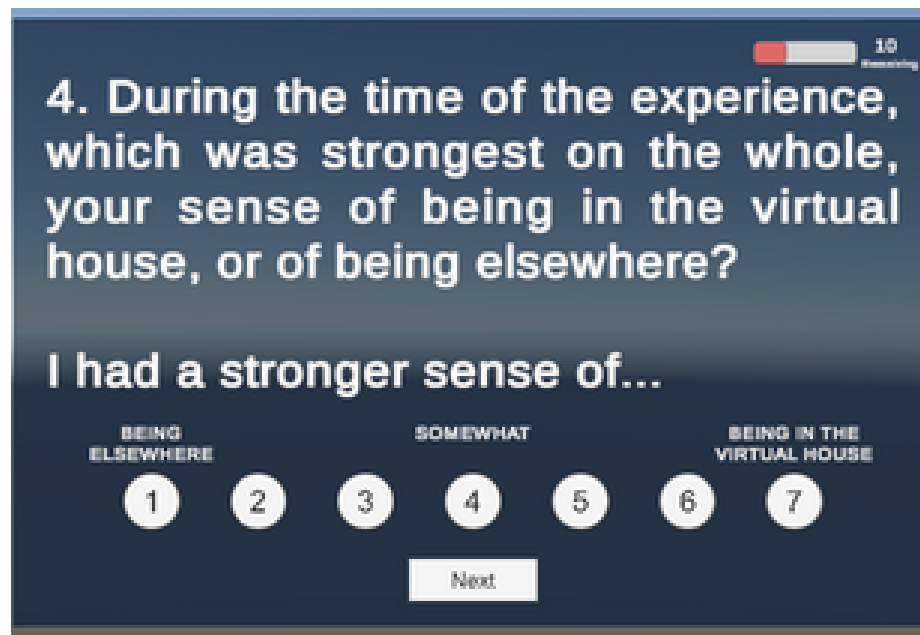


Figure 2.9: In-VR Questionnaire

2.2.4 Teleportation

In the design phase, a literature survey was employed to identify methods to minimize any form of motion sickness in the users. Because C. Boletsis and J. E. Cedergren mentions the motion sickness inversely related with the presence [19]. This motion sickness occurs when the subject receives conflicting sensory inputs. To minimize motion sickness, VR scenarios are designed with teleportation based locomotion which needs a hand held controller. Because the previous VR headset didn't contain a controller, an Oculus Go with handheld wand was contributed by Dr.Roshan Peiris, our external collaborator.

2.2.5 Technologies used in VR Design

- Blender was used to create the house object.
- MakeHuman is used to build human avatars.

Table 2.1: Technologies used

Technology	Ref
Blender	Create the House object
MakeHuman	Build human avatars
Animation Rigging	Create human interactions
XR interaction toolkit	Create interactions in Virtual Reality
Audio Sources	Create stereo/monophonic sounds

- Animation rigging is used to create human interactions.
- XR interaction toolkit is used to create interactions in VR
- Audio sources are used to create stereo/monophonic sounds

2.3 Data Acquisition and Subject preparation

EEG signals were acquired using the internationally accepted 10-20 electrode montage with 32 electrodes by g.Tec HI.amp system with g.nautilus head cap and g.HEADbox connector provided by the bionics lab. And ECG and PPG signals were recorded by a biopac system provided by the biomedical laboratory at the department of Electronics and Telecommunication. These ECG and PPG signals were acquired to measure heart rate variability which is shown to be effective correlates of stress.

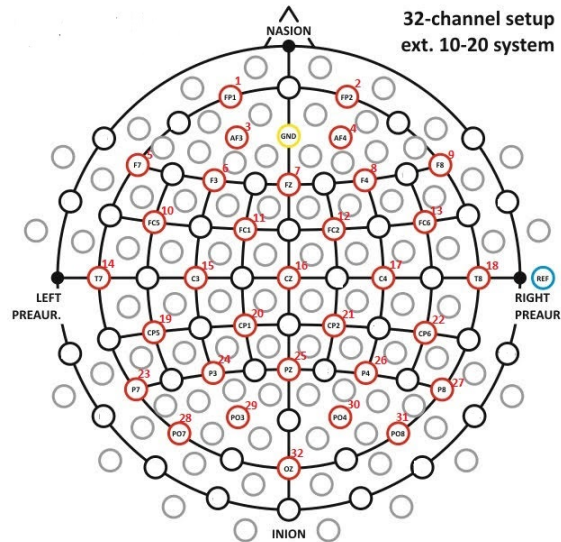


Figure 2.10: EEG acquisition montage

The subject was given an information sheet and collected their written consent. Additionally, we demonstrated and explained how to navigate in VR by using the controller until the subject gets familiar with the teleportation based navigation. A g.nautilus head cap

was placed on the head of the subject and adjusted the cap in order to ensure all electrodes are placed in correct positions. Electrodes were connected to g.Hiamp via a g.HEADbox connector. Then a water soluble electrode gel was applied to each electrode checking impedance checklist until it confirms less than 5k■ impedance for all electrodes. ECG electrodes were attached with a Lead II ECG configuration (right arm (-) to left leg (+)) and PPG electrode was also attached with the index finger of the subject. Then, Oculus VR headset was put into the subject safely and adjusted until the subject confirms a clear and a comfortable view.

Channel Selection

The User must select a fixed no. of channels. The un-selected channels cannot be recovered later. ICA decomposes the signal into same no. of sources as net channels. However to generate a strong robust ICA decomposition and prevent any form of over-learning, it is important to have some constraints (Särelä et al., 2003) Onton and Makeig came up with this formula to estimate the minimum time required for decomposition. (e.g., Onton and Makeig, 2006).

$$Time(seconds) = \frac{30 (NoOfChannels)^2}{SamplingRate}$$

We record the EEG for all scenarios at once and preprocess it once before decomposing, thus it is not required to worry about this.

2.4 Pilot Study

We have done a pilot study on 6 subject 3 with the EEG and 3 without the EEG.

To analyze the Questionnaire results, we used a non-parametric Friedman's test followed by post-hoc Wilcoxin's Tests.

We were able to show there was some effect in the study as evidenced by the results from the Friedman's test. (p = 0.015 ,alpha= 0.05)

However Friedman's test showed no effect in the Naturalness Sub-score. (p=0.198 , alpha = 0.05) . It was also further evidenced by the post-hoc Kruskal Wallis tests done between High Coherence and Low Coherence scenarios. For High Coherence and Low Coherence scenarios conditioned on low Immersion, the result was p =0.232. For High Coherence and Low Coherence scenarios conditioned on high Immersion, the result was p =0.054.

Overall, we can conclude the experimental manipulations done using Coherence had no effect.



Figure 2.11: Pilot Study

Upon reviewing the footage of participants navigating the Scenario, we identified many reasons why the manipulation might not have been successful.

- Participants rarely interacted or saw the VR characters. This is because the placement was such that the participants just ignored them. In the next attempt, the plan is to modify the locations of the VR characters.
- VR Characters had robotic voices which is not realistic.
- Audio sounds were not loud enough.

Additional modifications we had to do based on the results/observations from the pilot study.

- Subjects had trouble understanding some questions. Thus it is important to rephrase it (without it losing meaning) so they can understand it. Possibly, their lack of understanding might cause uninterpretable results.
- Subjects moving constantly tend to remove the electrodes.
- Add more VR Characters
- Place the teddy bears close to the VR Characters

- Power drains quickly from the HMD when live casting the result to a mobile phone. Thus, to prolong the battery life, it is essential to not live cast.

2.5 EEG Signal Pre-processing

- Removing Drift, Trend : High Pass filter
- Removing Common Mode noise : Channel Rejection, Interpolation, Average Referencing
- Removing Line Noise from power-lines : CleanLine
- Removing Non-stationary burst noise : ASR
- Removing Stationary noise and physiological artifacts : ICA + ICALabel

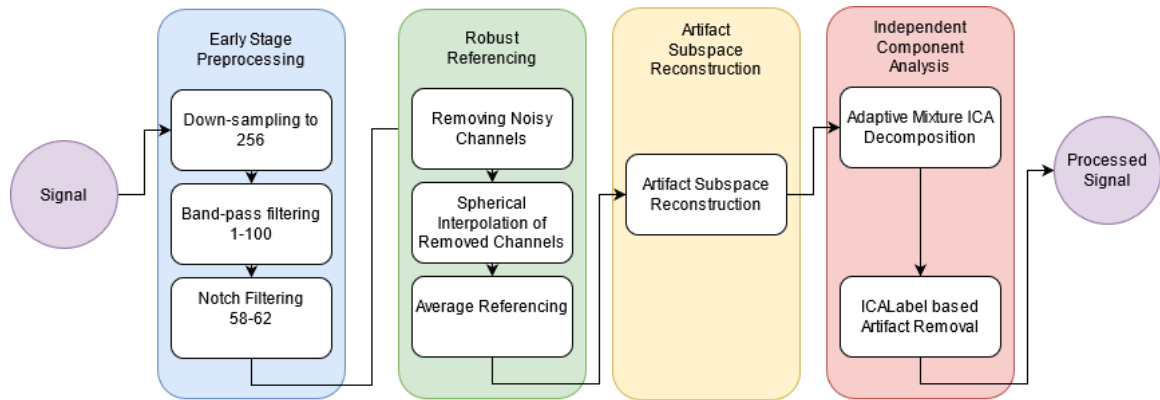


Figure 2.12: Overview of EEG Signal Pre-processing

2.5.1 EEG Signal Pre-processing

Early Stage Pre-processing

The Signal was down-sampled to 256Hz, filtered using the Band-pass filter of 1-100Hz and Notch filtered at 48-52Hz during acquisition by the g.NEEDaccess Software.

- The 1Hz high pass filter removes any signal drift caused by electrode movement, sweat, etc and improves ICA decomposition.[33]
- The Notch filter removes the line noise and any HMD generated noise.

Signal was preserved in the double precision during processing by the EEGLAB software to prevent any finite-precision effects.

Low pass filtering is bad for the connectivity and ERP analysis, thus it was kept at a higher threshold.

Robust Referencing

The signals were acquired using a CZ electrode as reference. However to remove any common mode noise and avoid any bias, it is essential to average reference the system. To avoid contaminating the other channels via corrupt channels, it is essential to remove corrupt channels and interpolate them during the referencing stage.

- Firstly, the Faulty channels were removed. For this Christian Kothe's "clean-rawdata" plugin in EEGLAB is used. Flatline channels were removed by setting the Maximum tolerated flatline duration as 20s. Noisy channels were identified by channel correlation, and any channel without a minimum channel correlation of 0.6 was removed.
- The removed channels were interpolated using Spherical Interpolation
- By taking the global average, we get a better topological representation of the brain activity. We assume there is no mono-polar sources/sinks in the brain.
- A Zero filled channel (Cz) is added before average referencing to avoid rank deficiency. This way the reference channel is recovered.

2.5.2 *Artifact Subspace Reconstruction for Burst Correction*

This is used to remove burst noise and augment it with corrected data, As per Chang [34], a cutoff parameter for K(SD param) between 20 and 30 is optimal.(Higher the more conservative and lesser is stringent) We will go with 25 because

- To avoid excessive augmentation of the data
- To preserve useful signal information during pre-processing steps

ASR complements ICA very well. ASR is good at removing occasional large-amplitude noise/artifacts (Non-stationary noise). ICA is good at decomposing constant fixed-source noise/artifacts/signals (Stationary Noise). [35]

2.5.3 *ICA for decomposition with ICALabel for selection*

ICA

Independent Component Analysis algorithm like Principal Components Analysis. However it decomposes the signal into statistically independent components. Because EEG, EMG, EOG, ECG are independent processes, this algorithm is a method to remove these artifacts from our signal.

We used the AMICA variant since it works well with signals with large no. of channels and low amount of time. [36]

ICALabel

Now after ICA decomposition, we have to identify components which are artifacts and remove them. For this we used the ICLabel, a deep neural network which can classify a component as either an EEG signal, or any other artifact. The remaining components are added together to get the artifact-free signal. ICAlabel is superior to MARA in many aspects.[37]

- 5 categories to classify instead of 2
- Larger training data-set with various data from different paradigms and subjects.
- Better cross-entropy and higher accuracy

Components were identified as either eye, muscle, channel or heart rate with probabilities greater than 0.8,0.9,0.9 and 0.9 respectively were removed.

2.6 EEG Feature Engineering

After processing the signals, EEG features were designed and extracted, according to the literature. These features have a physiological and psychological interpretations. This process was done using MATLAB 2018 using the EEGLAB toolbox.

EEG features were analyzed by decomposing the signal into functionally distinct bands using FIR Band-pass filters of 270 windows (With Kaiser Windows). Subsequently each of the following features were extracted for each of the band and the complete signal.

Band	Frequency Range (Hz)
All	1-100
Delta	0.5-4
Theta	4-8
Alpha	8-12
Beta	12-30
Gamma	30-100

2.6.1 Statistical Features

Sample Entropy is a measure of the regularity/unpredictability of the time series data depending on the presence of patterns. [38, 39] Usual entropy measures quantifies the randomness of generating process of time series instead of the time series or involve the calculation of several limits or is influenced by system noise, which are problems the sample entropy solves. Low sample entropy value values reflect systems which are very repetitive and predictive while high values indicate the opposite. [38, 39]

Let $N = \{x_1, x_2, \dots, x_N\}$ be a time series of length N with a constant time interval τ . Let a template vector of length m be defined as $X_m(i) = \{x_i, x_{i+1} \dots x_{i+m-1}\}$. Consider a distance function Chebyshev distance $d[X_m(i), X_m(j)]$ where $(i \neq j)$

$$SampEn = -\log\left(\frac{A}{B}\right)$$

Where,

- A = number of template vector pairs having $d[X_{m+1}(i), X_{m+1}(j)] < r$
- B = number of template vector pairs having $d[X_m(i), X_m(j)] < r$

Mean

$$Mean = E[x] = \sum_{m=1}^N x_m$$

Standard Deviation

$$StandardDeviation = Std[x] = \sqrt{\sum_{m=1}^N (x_m - E[x_m])^2}$$

2.6.2 Band-power based Features

This calculates the Average band-powers of the signals.[2] For the process an estimate of the power spectral density was calculated using the Welch Spectrum. Then, the frequency bins which intersect the relevant frequency range was identified, and the area was extracted using composite Simpson's rule. This is called the absolute band-power.

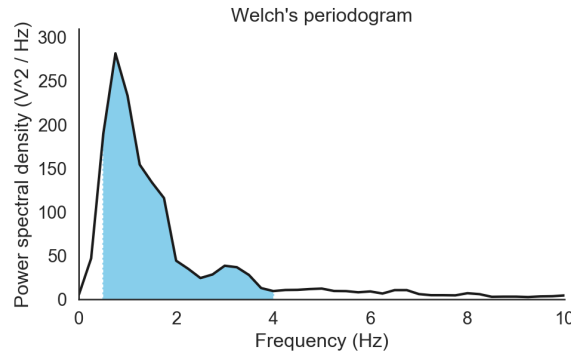


Figure 2.13: Example of band-power calculation (Figure taken from [2])

The relative band power was found expressing the absolute band-power as a percentage of the total power. [2]

Power Asymmetry This measures the band power symmetry between the two hemispheres of the brain.

$$BandAsymmetry = \log\left(\frac{LeftHemisphericalBandPower}{RightHemisphericalBandPower}\right)$$

2.6.3 Functional Connectivity based Features

Physiologically, Oscillatory synchronization is shown as the key mechanism by which neural populations communicate information.[40] This FYP mainly focused on functional connectivity between EEG electrodes, it mainly identifies active brain regions that have correlated frequency, phase or amplitude activity. Two types of bi-variate measures such as Envelope Amplitude Correlation and Spectral Coherence are used to measure the level of un-directed-connectivity between two electrodes.

However, before doing functional connectivity it is important to address the problem of volume conduction. This is a confound that can lead to spurious connectivity results that lead to false interpretations. When doing connectivity analysis, it is expected that the value reflects the connectivity between physically distinct brain regions. However some cases, the electrodes can measure activity from overlapping brain regions, it can lead to a spurious high correlation because the activity is the same. Additionally, the EEG field can spread laterally in the scalp leading to more spurious results similar to the above. [41]

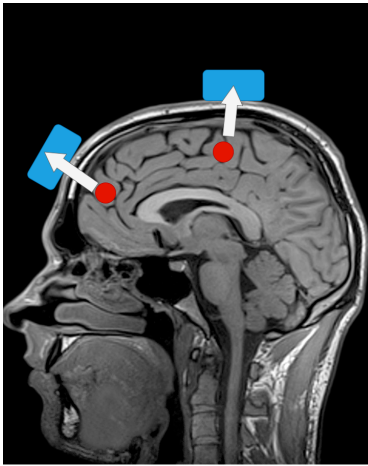


Figure 2.14: Ideal Case

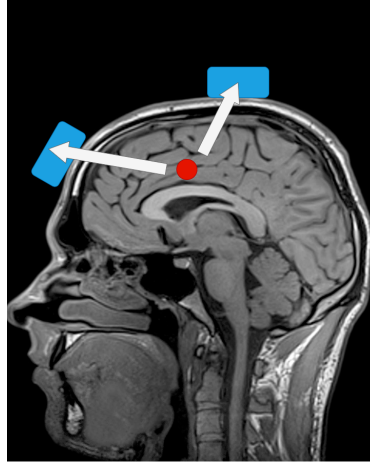


Figure 2.15: A single source leading to a spurious result

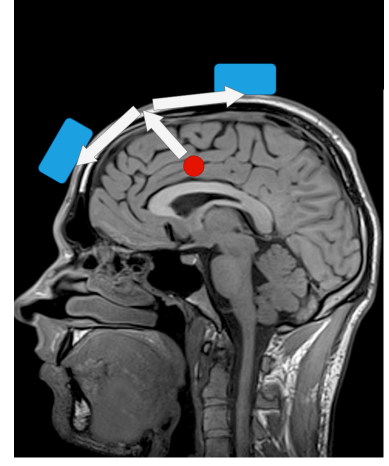


Figure 2.16: Electric fields spreading tangentially across the scalp

Figure 2.17: Volume Conduction Cases

To remove it, spatial filtering using the Surface Laplacian was used. [42]

Coherence is a type of phase-based connectivity measure.[43]It is used to quantify the

phase synchronization, between two signals. It is a function of power spectral densities and the cross-power spectral density of two signals. The Coherence for each of the bands were taken by the average value of the respective coherence values for each frequencies. Unlike other methods to measure phase synchronization such as phase lag index, this method is more robust to noise.

$$C_{xy}(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)}$$

Envelope Amplitude Correlation is a type of power-based connectivity measure. It measures the correlation between time-frequency power between two electrodes. First the signal was band-pass filtered and Hilbert transform was applied to create the analytic signal. Then the magnitude of the analytic signal was extracted. This sequence of steps extracts the envelope of the signal. Then the spear-man correlation was calculated between the Hilbert-transformed band-passed signals of two electrodes. The spear-man correlation is used because it is more resilient to outliers and works with non-normally distributed data.

2.6.4 Source Localization based Features

After extracting the relevant Brain Independent Components via both ICLabel, this steps attempts to identify the current source of activity. Finding the locations of the sources (current dipoles) of the independent components is based the scalp projections. The source estimation is done by the Dipole Fitting function on EEGLAB with the Field-Trip extension. Since MRI recordings were not taken, this was done using the Boundary Element Model of the Montreal Neurological Institute Standard Brain. Afterwards, dipoles whose residual variance which exceeded 15% and were located outside of the brain were removed. A total of 457 IC clusters remained afterwards.

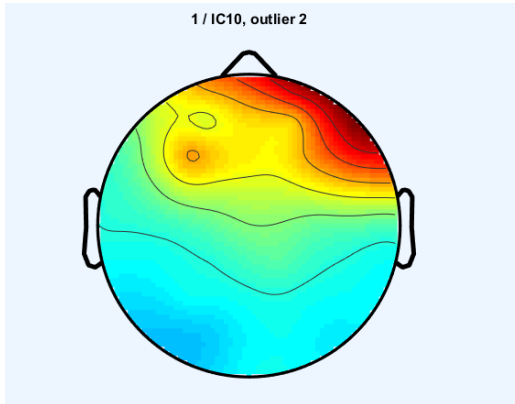


Figure 2.18: Scalp Map of an Independent Component, based on which dipole is fitted

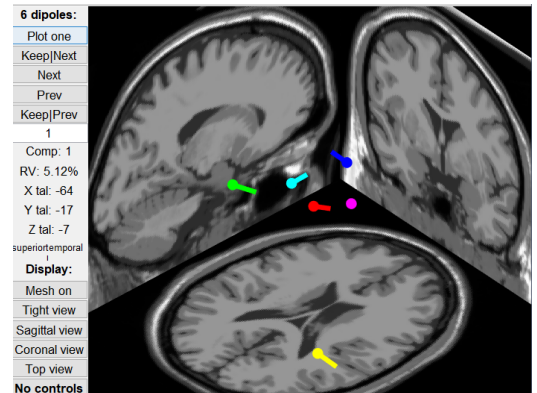


Figure 2.19: Locations of Brain dipoles which are fitted on the Brain independent components

Figure 2.20: Dipole Fitting on Independent Components

The remaining components were clustered into 10 clusters (with out-lier rejection) using K-means based on the dipole locations and dipole orientations. A total of 16 outliers were removed. The remaining clusters were then analyzed.

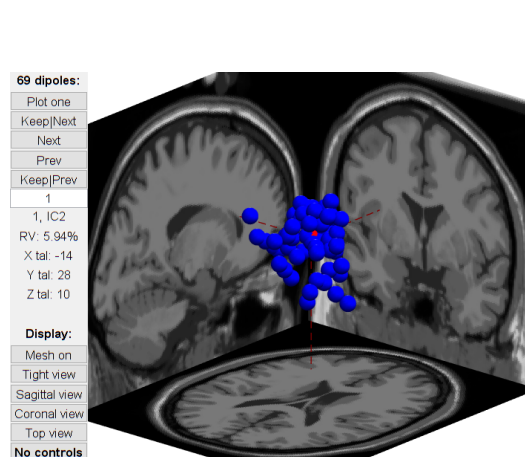


Figure 2.21: One cluster of independent components which have clustered together

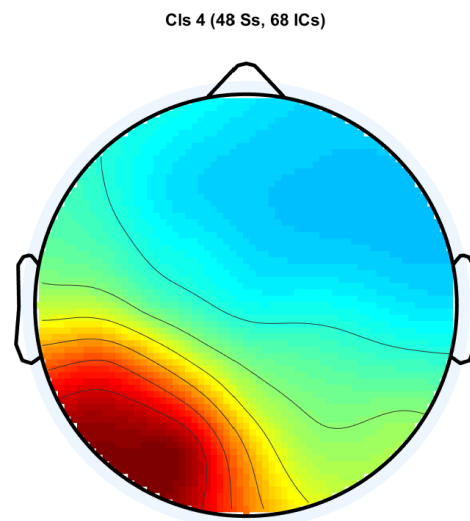


Figure 2.22: The scalp projection of the corresponding cluster

Figure 2.23: Example of a Cluster of Independent Components

Afterwards, for each subject and scenario, if cluster's corresponding Independent component is available in the decomposition, it's absolute and relative band-powers were extracted. Since the components are independent, no connectivity features were extracted. Note that now, instead of channel features, you have cluster features. Each cluster is the weighted sum of all of the electrodes which correspond to an anatomical source. The primary issue here is the large amount of missing data. However, when doing analysis with IBM SPSS, it automatically does missing value imputation.

2.7 ECG Preprocessing and Feature Engineering

2.7.1 ECG Signal Recording

Initially an ECG signal acquisition device was built using AD8232 single lead heart rate sensor with Arduino 2560 development board. It was configured with a lab streaming layer through a serial port app. The serial communication was used to transfer sensory data to the lab streaming layer. Captured data was recorded by a lab recorder app. But for the very first two subjects the recorded data were not proper ECG signals. Therefore, a Biopac MP36 system was used alternatively to conduct recording from the third subject onwards as experiments were conducted continuously. Lead II electrode placement was used to attach

electrodes to the subject and PPG signal was also recorded in parallel. Biopac Student Lab 4.1 was used to record ECG and PPG data acquired from the Biopac MP36 amplifier. ECG and PPG were recorded separately from the beginning of the scenario to the end of the scenario for each scenario for each subject.

2.7.2 ECG Data Set

The ECG data set includes a set of ECG of 17 subjects. First two subject's ECG data were not proper and as the subject rotated throughout the experiment, for one subject electrode contacts disappeared in the middle of the second scenario. Therefore, 3 ECG data sets out of 20 subjects, had to be removed from the ECG data set. Each lesson file corresponding to each scenario of each subject was converted into matlab (.mat) file for feature extraction algorithms.

2.7.3 Pre-Processing ECG signals

The ECG signals contained mainly muscle artefacts, external interferences such as power line noise and movements artifacts. Specially, movement artifacts had a significant contribution to ECG signals by varying the baseline of ECG signals. The pre-processing stage introduced filters to remove these artifact components. First a low-pass butter-worth 10th order filter with cutoff frequency of 18 Hz was introduced to ECG signals in order to eliminate muscle artifacts and external interferences such as a power line noise. But even after low pass filtering, the baseline variations were remaining. Then a high-pass butter-worth 10th order filter with a cutoff frequency of 4 Hz was introduced to ECG signals in order to remove base line variations in ECG signals.

2.7.4 Machine Learning based Feature Selection

There are many features extracted from the EEG signals of the 20 participants. Obviously, such a large number of features cannot be introduced to the classifier due to the large number of participants which had to be recruited to obtain enough training data. Since it is required to use at least ten times more training data per class than the features, even in the case of binary classification, it would be necessary to include a large number of participants for the study which is practically difficult because it takes such a long time and resources. Comparing the huge dimension of the whole set of features extracted from raw EEG signal, often exceeding 1000, the great reduction of the original feature space is needed. One of the methods for feature selection, applied frequently in the BCI domain, are genetic algorithms. Their main advantage is the fact that during the exploration of the space of possible solutions, they do not evaluate solutions one by one, but evaluate a set of

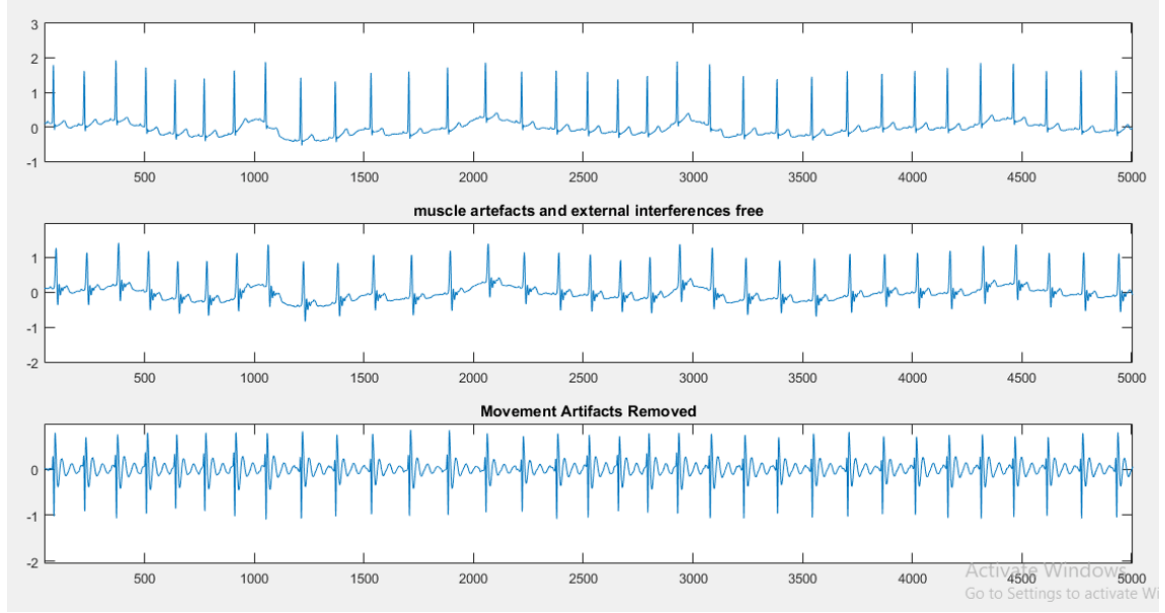


Figure 2.24: ECG noise artifacts

solutions in parallel. Moreover, they are not very prone to get stuck at local minima and they do not need to make assumptions about the interactions between features.

Genetic algorithm (GA) is one of the heuristic methods for solving optimization problems. Nowadays, this method is used in many different research fields, but it originates from genetic sciences. To run the optimization process with a GA, first, the problem environment has to be defined, that is: a method of coding problem solutions to the form of GA individuals, a fitness function used for evaluating individuals in each generation, genetic operations used for mixing and modifying individuals, a method for selecting individuals and other additional GA parameters. The individuals of a GA are problem solutions and are composed of chromosomes and genes. The most popular approach adopted when a GA is to be used in the feature selection process is a classic version of a GA, with one-point crossover and one-gene 582 I. Rejer mutation. The individual is composed of only one chromosome and its number of genes is equal to the number of features existing in the problem at hand. Each gene can take one of two binary values, zero or one. Zero indicates that the feature of the number equal to the gene index is not present in the solution coded in the individual, one - means that the feature is present in the current solution.

The data-set is first normalized using a Standard-Scaler and then a support vector classifier is used to classify the data-set into four classes which represents the four scenarios. The evaluation method used is leave one out cross validation where one participant is left out and the model is trained on the remaining 19 subjects' data and then tested on the remaining.

In the Coherence data set there is a total of 2976 features for the twenty participants, the best features were discovered using the genetic selection algorithm with different values for the hyper-parameters number of populations, number of generations and the number of generations to change, the model was trained on raw EEG data as well as with normalized data referred as scaled data and it was observed that the performance is good on scaled data. The summary of the obtained results is described in the table below.

Table 2.2: Technologies used

Time Taken for Selection Algorithm (min)	Filtered Number of Features (out of 2976)	Population Size	Generation Size	n_Generation no change	Accuracy of Scaled Features	Accuracy of Raw Features
1	729	50	10	10	25.5%	26.25%
5	24	1000	100	10	40%	65%
45	27	5000	1000	10	55%	65%

3 Results

Firstly the questionnaires for each subject were analyzed to see if there is any discernible differences across scenarios. Following which Statistical methods were used to mine for useful features.

3.1 Questionnaires

To validate the experimental protocol, the questionnaire results from 20 subjects and their 4 scenarios were used to calculate the statistical significance.

To analyze the Questionnaire results, we used a Friedman's test followed by post-hoc Wilcoxin's signed rank Tests with Holm's correction for multiple comparisons.

3.1.1 Presence effect: SUS Questionnaire

Friedman's test indicated the there is a statistically significant effect ($\chi^2(3)=20.074$, $p < 0.05$) between the levels of Presence in the experiment caused by experimental manipulations.

Subsequent post-hoc tests with holm correction revealed there were significant differences between the scenarios

- Low Coherence High Immersion vs High Coherence High Immersion ($0.001 < p = 0.01$ [Holm corrected])
- Low Coherence Low Immersion vs High Coherence High Immersion ($0.0001 < p = 0.0083$ [Holm corrected])

Thus, in order to identify important EEG/ECG features for distinguishing presence, we should consider only these features between the 2 scenarios as above.

3.1.2 PI effect: Audio/Haptic sub-scale of Witmer and Singer's Questionnaire

Friedman's test indicated the there is a statistically significant effect ($\chi^2(3)=33.338$, $p < 0.05$) between the levels of Place Illusion in the experiment caused by experimental manipulations.

Subsequent post-hoc tests with holm correction revealed there were significant differences between the scenarios.

- High Coherence Low Immersion vs High Coherence High Immersion ($0.001 < p = 0.025$ [Holm corrected])

- Low Coherence Low Immersion vs High Coherence High Immersion ($0 < p = 0.0125$ [Holm corrected])
- Low Coherence High Immersion vs Low Coherence Low Immersion ($0.0001 < p = 0.016$ [Holm corrected])

Thus, in order to identify important EEG/ECG features for distinguishing place illusion, we should consider only these features between the 3 scenarios as above.

3.1.3 *PSI effect: Naturalness sub-scale Witmer and Singer's Questionnaire*

Friedman's test indicated there is a statistically significant effect ($\chi^2(3)=20.450, p < 0.05$) between the levels of Plausibility illusion in the experiment caused by experimental manipulations.

Subsequent post-hoc tests with holm correction revealed there were significant differences between the scenarios

- Low Coherence High Immersion vs High Coherence High Immersion ($0.006 < p = 0.016$ [Holm corrected])
- Low Coherence Low Immersion vs High Coherence High Immersion ($0.001 < p = 0.0125$ [Holm corrected])
- High Coherence Low Immersion vs Low Coherence Low Immersion ($0.019 < p = 0.025$ [Holm corrected])

Thus, in order to identify important EEG/ECG features for distinguishing plausibility illusion, we should consider only these features between the 3 scenarios as above.

3.2 EEG Features

After calculating all the scores, each of the feature was tested using Friedman's test with a p threshold of 0.01. This is non-parametric version of Repeated Measures ANOVA. This allows you to mine the relevant signal features which has useful signal information. Then afterwards, post-hoc tests were done using Wilcoxin's signed rank test (Non parametric equivalent of paired t-test). Multiple comparisons were corrected using Bonferroni correction, which was applied to the post-hoc tests.

Experimental Manipulations	Low Immersion High Coherence vs High Immersion High Coherence	High Immersion High Coherence vs High Immersion Low Coherence	High Immersion High Coherence vs Low Immersion High Coherence	High Immersion High Coherence vs Low Immersion Low Coherence	Low Immersion High Coherence vs Low Immersion Low Coherence
Detected States (at 0.01 significance)	Place Illusion	Presence Plausibility Illusion	Place Illusion	Presence Plausibility Illusion	Plausibility Illusion
Envelope Amplitude Correlation	-	AF4_F4_GAMMA F8_PO7_THETA FC2_C3_ALL FC2_C3_DELTA C3_C4_ALL CP2_PO7_DELTA	FC1_Pz_THETA	AF4_PO7_THETA PO8_Fp1_DELTA	Fz_P3_BETA Fz_PO3_THETA Cz_Pz_ALL Cz_PO4_ALL PO3_PO4_ALPHA PO3_PO4_BETA PO3_PO4_GAMMA
Spectral Coherence	-	AF4_F4_ALL AF4_F4_GAMMA F8_PO7_THETA FC2_C3_THETA	F8_C3_DELTA	Fz_F8_BETA	PO3_PO4_BETA
Absolute Band-powers	P4_THETA	-	-	-	Fp2_ALL Fp2_THETA Fp2_ALPHA Fp2_BETA CP1_THETA Pz_ALPHA P4_THETA
Relative Band powers	-	-	-	-	T8_GAMMA
Standard Deviation	-		F8_ALL F8_DELTA P3_DELTA PO3_ALL PO3_DELTA	-	CP5_DELTA P7_ALL

Table 3.1: Results from Previous Studies

Study	Measured Aspect of Presence	Questionnaire	Important Results	Our Results
Baumgartner et al. [10]	Spatial Presence (Place Illusion) in Adults and Children.	Self Location of MEC - Spatial Presence Questionnaire	High Event Related De-Synchronization in the Alpha Band in Parietal Regions (involved in Spatial Navigation). Higher activity at Parietal sites than frontal sites	In the event of Low Immersion, there is significant (0.05 $\leq$ p) increase in the absolute alpha band-power of the Pz(mid), P4(right), and left-center-parietal regions at high coherence
Bouchard et al. [11]	fMRI study on Spatial Presence	Questionnaire Designed by themselves	Right and left dorsolateral prefrontal cortex were correlated negatively with the presence rating from questionnaire. The right dorsolateral prefrontal cortex down-regulates the activation in the dorsal visual processing system. This is mainly involved in regulating the presence experience.	The FP2 Electrode, corresponding to the right dorsolateral prefrontal cortex [44] showed significant variations ($p < 0.05$) across all the bands for the low immersion scenarios. The power is higher in high coherence scenario.
Bouchard et al. [12]	fMRI study on Subjective Realism (Perceived) and its effects on Presence (PSI)	Single Item Self Report	Showed activity in the parahippocampal cortex for differing states of presence. It is primarily involved with processing of contextual associations. It is also involved in deriving meaning for scenes and places.	Parahippocampal cortex is too deep to be analyzed by EEG
Clemente et al. [13]	Level of Immersion during Free Navigation vs Fixed Navigation	SUS Questionnaire	Right Insula showed increased activity for the free navigation (higher presence case) in both alpha and theta bands. There is a trend to increased activity in the prefrontal gyrus for the alpha band.	Right insula is too deep to be analyzed by EEG. The FP2 Electrode in the prefrontal regions [44] showed significant alpha activity variations ($p < 0.05$) across all the bands for the low coherence scenarios.
Kober et al. [14]	Level of Immersion for a Spatial Navigation Task	SUS Questionnaire and PQ	In Parietal Regions, Alpha Task Related Power Decrease was higher in high immersive case. (Effect was stronger at parietal sites more than central or frontal sites.)	In the event of Low Immersion, there is significant (0.05 $\leq$ p) increase in the absolute alpha band-power of the Pz(mid), P4(right), and left-center-parietal regions at high coherence

3.2.1 Coherence based features

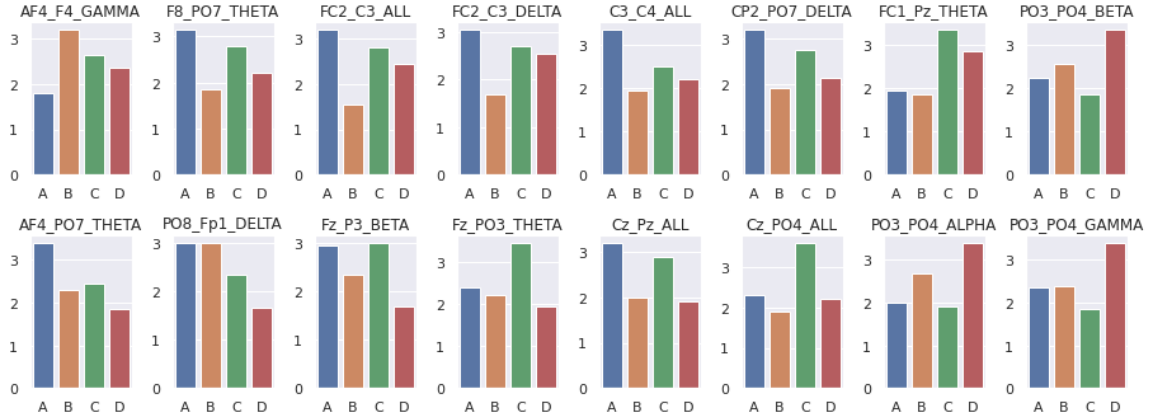


Figure 3.2: Descriptive Statistics of each EAC Features after rank transformation. Each feature with its Average Rank vs Condition with A = High Immersion High Coherence, B = High Immersion Low Coherence, C = Low Immersion High Coherence, D = Low Immersion Low Coherence

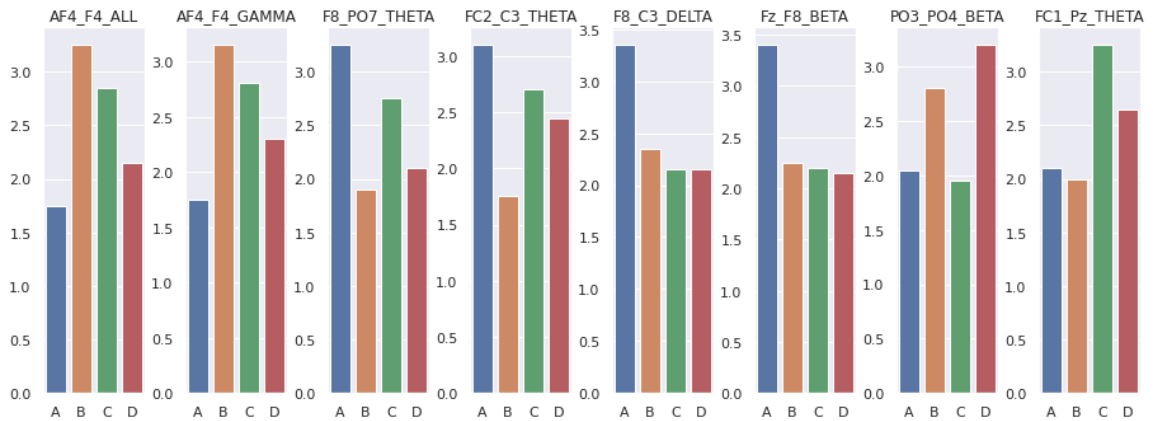


Figure 3.3: Descriptive Statistics of each Spectral Coherence Features after rank transformation. Each feature with its Average Rank vs Condition with A = High Immersion High Coherence, B = High Immersion Low Coherence, C = Low Immersion High Coherence, D = Low Immersion Low Coherence

Left Parieto-Occipetal and right frontal (F8-PO7) show functional connectivity in the theta band for both EAC and Spectral Coherence. The connectivity is higher in high coherence scenarios compared to low coherence scenario. This is statistically significant between the optimal scenario and low-coherence high immersion scenario. The right frontal (F8) regions is shown to be involved in a variety of processing, especially in the social awareness and episodic memory. [45].

Transcallousal EAC (C3-C4, FC2-C3) can be observed in the central regions. This activity is for the whole signal. This is statistically significant between the optimal scenario

and low-coherence high immersion scenario. Transcallousal EAC (FC2-C3) Spectral Coherence in the theta band also show similar behaviour. The central electrodes are directly over the sensory-motor complex, combined activity is indicative of sensory and motor integration and processing.[45].

The right Central-parietal and parieto-occipetal delta bands also show connectivity in the EAC. This is statistically significant between the optimal scenario and low-coherence high immersion scenario.

Mid-frontal to left parietal beta (Fz-P3) activity show increased EAC in high coherence scenarios compared to low coherence scenarios. There is a statistically significant effect between high coherence low immersion scenario and low coherence low immersion scenario. Getting signals from the prefrontal cortex, this indicates motor, focus and action observation. Beta activity is indicative of thinking, focus, sustained attention, alertness and excitement. Parietal lobes is said to be solving problems conceptualized by the frontal lobes. Commonly, the left parietal lobes is said to be focused on grammar processing, mathematical processing and similar activities.[45].

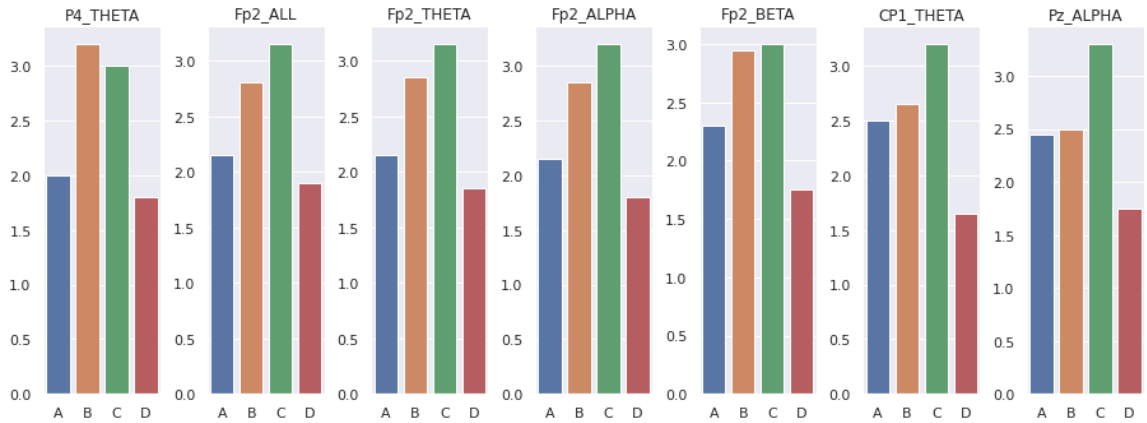


Figure 3.4: Descriptive Statistics of each Absolute Band-power Features after rank transformation. Each feature with its Average Rank vs Condition with A = High Immersion High Coherence, B = High Immersion Low Coherence, C = Low Immersion High Coherence, D = Low Immersion Low Coherence

3.2.2 Band-power based features

Observing the Right Parietal Lobe, Theta activity is stronger in mismatched scenarios than matched scenarios. A statistically significant result is seen between the completely suppressed scenario and the two mismatched scenarios. The Right Parietal lobe is associated with Spatial Awareness and Map orientation.[45] Theta waves are often associated with dream-like feelings associated with mental inefficiency.

The Mid parietal regions and left central-parietal regions also show elevated activity in the alpha band and theta band respectively for the low-immersion/high coherence scenario compared to the suppressed scenario. The other two scenarios have middling effects. Mid parietal regions are involved in somato-sensory integration with visual perceptions and working memory [46] Alpha waves are associated with relaxation when the person is in an awake state.

Similar activity is seen in the right pre-frontal (Fp2) regions of the brain, in general there is higher theta, alpha,beta activity in the mismatched scenarios compared to matched scenarios. This effect is statistical significant between the completely suppressed scenario and the Low-immersion/High-coherence scenario. The right frontal part of the brain is associated with episodic memory and social awareness. [45]

Similarly when considering the above activity is seen in relative band-powers of the right temporal regions. Specifically between the Low Immersion Low Coherence and Low Immersion High Coherence scenarios. There is larger spectral increase in the gamma regions compared to the other regions. The right temporal lobe is associated with music/anxiety/facial recognition/sense of direction[45]

No statistically significant asymmetry features were identified.

3.2.3 Statistical features

No statistically significant effects would found in the signal mean and sample entropy. However some electrodes displayed differences in variability (measured in standard deviation) between the conditions.

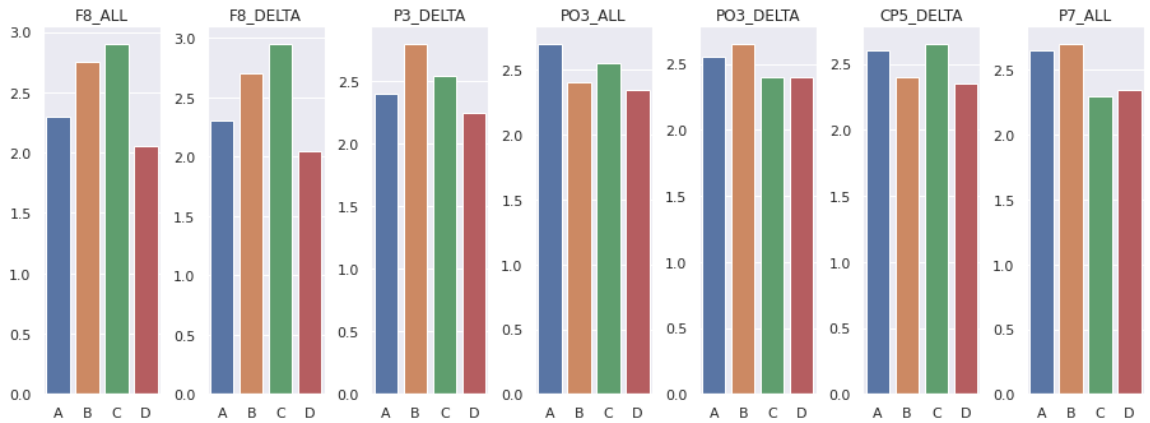


Figure 3.5: Descriptive Statistics of each Standard Deviation Features after rank transformation. Each feature with its Average Rank vs Condition with A = High Immersion High Coherence, B = High Immersion Low Coherence, C = Low Immersion High Coherence, D = Low Immersion Low Coherence

In terms of variability in the signals, the right frontal lobe showed increased variability

in the gamma bands for the mismatched scenarios compared to the matched scenarios. This difference is significant between the optimal scenario and the low immersion-high coherence scenario.

The left parietal-occipetal region delta activity showed increased variability in high immersion scenarios compared to low immersion scenarios. The effect is statistically significant between the optimal scenario and the low immersion-high coherence scenario and also between the mismatching scenarios. However, in the same region, the overall activity showed increased variability in the High coherence scenarios compared to the low coherence scenarios. The effect is statistically significant between the mismatched scenarios.

The left lateral central parietal region (close to the temporal lobe) shows higher variability in the high coherence low immersion scenario compared to the low coherence high immersion scenario.

3.3 ECG Features

Pre-processed ECG signals were used to calculate heart rate variability (hrv) measurements to analyse the effect of presence into ECG signals. HRV measurements were extracted under two main domains which are time domain and frequency domain for each scenario for each subject. At first, "findpeaks" function in matlab is used to identify peaks in the ECG signal and then a threshold is used to locate R waves out of identified peaks. After identifying R wave locations in the waveform, Mean Heart rate and Mean RR interval can be extracted. The SDNN and RMSSD features are extracted using the Mean RR interval. Frequency domain features are obtained by calculating band powers of corresponding bands in the power spectral density periodogram which is built by welch's power spectral density estimator (pwelch function) in MATLAB.

Table 3.2: ECG Features and Their Descriptive Statistics

Measurement	Definition	Scenario A	Scenario B	Scenario C	Scenario D
Mean Heart Rate (BPM)	Beats per minutes	8.00E+01	8.14E+01	8.03E+01	81.35323412
Mean RR interval (sec)	Mean value of R to R intervals	0.10020492	0.103411807	0.1049867	0.10526763
SDNN (sec)	Standard deviation of all RR intervals	0.05600979	0.056771	0.05720316	0.05795587
RMSSD (sec)	Root mean square of successive differences between normal heartbeats	0.115123818	0.118110936	0.111970905	0.1202966
VLF (sec ²)	Power of the very-low-frequency band(0.00-0.04 Hz)	1.03E-06	1.08E-06	1.12E-06	1.06E-06
LF (sec ²)	Power of the low-frequency band(0.04-0.15 Hz)	0.004638884	0.005077879	0.005225055	0.004954541
HF (sec ²)	Power of the high-frequency band(0.15-0.40 Hz)	0.018133002	0.019714757	0.019629179	0.018959751
VHF (sec ²)	Power of the very-high-frequency band(0.40-3.00 Hz)	0.015764993	0.017142337	0.017008061	0.016479503
LF/HF	LF to HF ratio	30.65215892	30.51646041	31.54370412	31.62278406

4 Conclusion

Our project's primary objective is to identify statistically significant and robust bio-signal correlates of Presence/Place Illusion(Spatial Presence)/Plausibility illusion in Virtual Reality.

Two of the hypothesis of the experiment were proven. The virtual reality environments designed with varying levels of immersion and coherence had statistically significant and different levels of Presence, Place Illusion, Plausibility Illusion when measured using questionnaires. This validates the strength of the experimental design and many design choices taken.

By analyzing the questionnaire responses after each scenario, it was possible to confirm that the experimental manipulations of immersion and coherence were successful in inducing low and high levels of presence, place illusion and plausibility illusion.

For presence, the variations in the bio-signal features for the following cases

- Low Coherence High Immersion vs High Coherence High Immersion
- Low Coherence Low Immersion vs High Coherence High Immersion

are considered.

For place illusion, the variations in the bio-signal features for the following cases

- High Coherence Low Immersion vs High Coherence High Immersion
- Low Coherence Low Immersion vs High Coherence High Immersion
- Low Coherence High Immersion vs Low Coherence Low Immersion

are considered.

For plausibility illusion, the variations in the bio-signal features for the following cases

- Low Coherence High Immersion vs High Coherence High Immersion
- Low Coherence Low Immersion vs High Coherence High Immersion
- High Coherence Low Immersion vs Low Coherence Low Immersion

are considered.

Upon analyzing the EEG data, Statistically significant and different EEG activity were found in varying levels of Presence, Place Illusion and Plausibility Illusion.

Now hypothesis which wasn't proved was that varying and statistically significantly different ECG activity in varying levels of Presence, Place Illusion and Plausibility Illusion was not found. We reason that, our scenarios didn't have any strong emotional triggers or wasn't stress provoking. This isn't a weakness as not all VR scenarios are like that. It indicates the weakness of heart-rate based measures which can only work in specific scenarios.

This FYP was severely hindered by the pandemic, causing multiple hindrances

- No access to subjects to acquire bio-signals
- Difficulty in developing the VR scenarios as the files are extremely large to share over internet. Github LFS and Team viewer was used.
- Limited access to the equipment.
- Some items getting detained at customs due to pandemic restrictions
- Funding cuts.

4.1 Future Work

- Use Dry Contact EEG instead of Wet Gel Electrodes as it will give more robust and clean measurements since the subject is constantly moving his head.
- Use full body tracking with VR as this will allow the subject to fully immerse in the scenario and will give more options to engage in the scenario.
- Use Haptics to enhance Immersion as this will give an additional dimension to analyze the effects of Immersion.
- Obtain data from more subjects as it will allow you to extract features using machine learning methods. Currently the data-set is too high-dimensional for the ML methods to work.

References

- [1] R. Skarbez, F. P. Brooks, Jr., and M. C. Whitton, "A survey of presence and related concepts," *ACM Comput. Surv.*, vol. 50, no. 6, Nov. 2017. [Online]. Available: <https://doi.org/10.1145/3134301>
- [2] R. Vallat, "Raphael vallat," May 2018. [Online]. Available: <https://raphaelvallat.com/bandpower.html>
- [3] "Omnipres project ist-2001-39237 deliverable 5 measuring presence : A guide to current measurement approaches," 2004.
- [4] M. Slater and A. Steed, "A virtual presence counter," *Presence*, vol. 9, pp. 413–434, 10 2000.
- [5] M. Meehan, S. Razzaque, B. Insko, M. Whitton, and F. Brooks, Jr, "Review of four studies on the use of physiological reaction as a measure of presence in stressful virtual environments," *Applied psychophysiology and biofeedback*, vol. 30, pp. 239–58, 09 2005.
- [6] J. Laarni, N. Ravaja, and T. Saari, "Using eye tracking and psychophysiological methods to study spatial presence," in *Annual International Workshop on Presence, USA, 2003*, 2003.
- [7] C. Dillon, E. Keogh, J. Freeman, and J. Davidoff, "Presence: Is your heart in it," *4th Int. Wkshp. on Presence*, 01 2001.
- [8] M. Slater, A. Brogni, and A. Steed, "Physiological responses to breaks in presence: A pilot study," 10 2003.
- [9] A. Schlögl, M. Slater, and G. Pfurtscheller, "Presence research and eeg," 01 2002.
- [10] T. Baumgartner, L. Valko, M. Esslen, and L. Jäncke, "Neural correlate of spatial presence in an arousing and noninteractive virtual reality: An eeg and psychophysiology study," *Cyberpsychology behavior : the impact of the Internet, multimedia and virtual reality on behavior and society*, vol. 9, pp. 30–45, 03 2006.
- [11] T. Baumgartner, D. Speck, D. Wettstein, O. Masnari, G. Beeli, and L. Jäncke, "Feeling present in arousing virtual reality worlds: prefrontal brain regions differentially orchestrate presence experience in adults and children," *Frontiers in Human Neuroscience*, vol. 2, p. 8, 2008. [Online]. Available: <https://www.frontiersin.org/article/10.3389/neuro.09.008.2008>
- [12] S. Bouchard, S. Dumoulin, J. Talbot, A.-A. Ledoux, J. Phillips, J. Monthuy-Blanc, G. Labonté-Chartrand, G. Robillard, M. Cantamesse, and P. Renaud, "Manipulating subjective realism and its impact on presence: Preliminary results on feasibility and neuroanatomical correlates," *Interacting with Computers*, vol. 24, p. 227–236, 07 2012.

- [13] M. Clemente, A. Rodríguez, B. Rey, and M. Alcañiz Raya, “Measuring presence during the navigation in a virtual environment using eeg,” *Studies in health technology and informatics*, vol. 191, pp. 136–40, 06 2013.
- [14] S. Kober, J. Kurzmam, and C. Neuper, “Cortical correlate of spatial presence in 2d and 3d interactive virtual reality: An eeg study,” *International journal of psychophysiology : official journal of the International Organization of Psychophysiology*, vol. 83, pp. 365–74, 12 2011.
- [15] E. A. Maguire, “Knowing where and getting there: A human navigation network,” *Science*, vol. 280, no. 5365, pp. 921–924, May 1998. [Online]. Available: <https://doi.org/10.1126/science.280.5365.921>
- [16] S. Kober and C. Neuper, “Using auditory event-related eeg potentials to assess presence in virtual reality,” *International Journal of Human-Computer Studies*, vol. 70, p. 577–587, 09 2012.
- [17] T. Baumgartner, D. Speck, D. Wettstein, O. Masnari, G. Beeli, and L. Jäncke, “Feeling present in arousing virtual reality worlds: Prefrontal brain regions differentially orchestrate presence experience in adults and children,” *Frontiers in human neuroscience*, vol. 2, p. 8, 02 2008.
- [18] L. Pugnetti, L. Mendozzi, E. Barberi, F. Rose, and E. Attree, “Nervous system correlates of virtual reality experience,” *Proceedings of 1st European Conference on Disability, Virtual Reality and Associated Technologies, Maidenhead, UK.*, vol. 1996, 01 1996.
- [19] E. Baka, K.-E. Stavroulia, N. Thalmann, and A. Lanitis, “An eeg-based evaluation for comparing the sense of presence between virtual and physical environments,” 06 2018, pp. 107–116.
- [20] S. Grassini and K. Laumann, “Questionnaire measures and physiological correlates of presence: A systematic review,” *Frontiers in Psychology*, vol. 11, p. 349, 2020. [Online]. Available: <https://www.frontiersin.org/article/10.3389/fpsyg.2020.00349>
- [21] J. Tarrant, J. Viczko, and H. Cope, “Virtual reality for anxiety reduction demonstrated by quantitative eeg: A pilot study,” *Frontiers in Psychology*, vol. 9, p. 1280, 2018. [Online]. Available: <https://www.frontiersin.org/article/10.3389/fpsyg.2018.01280>
- [22] L. Pugnetti, L. Mendozzi, E. Barberi, F. Rose, and E. Attree, “Nervous system correlates of virtual reality experience,” *Proceedings of 1st European Conference on Disability, Virtual Reality and Associated Technologies, Maidenhead, UK.*, vol. 1996, 01 1996.
- [23] R. Näätänen, T. Kujala, and G. Light, *The Mismatch Negativity*. Oxford University Press, Mar. 2019. [Online]. Available: <https://doi.org/10.1093/oso/9780198705079.001.0001>

- [24] C. G. Burns and S. H. Fairclough, "Use of auditory event-related potentials to measure immersion during a computer game," *International Journal of Human-Computer Studies*, vol. 73, pp. 107 – 114, 2015. [Online]. Available: <http://www.sciencedirect.com/science/article/pii/S1071581914001219>
- [25] T. Terkildsen and G. Makransky, "Measuring presence in video games: An investigation of the potential use of physiological measures as indicators of presence," *International Journal of Human-Computer Studies*, vol. 126, pp. 64 – 80, 2019. [Online]. Available: <http://www.sciencedirect.com/science/article/pii/S1071581918303112>
- [26] M. Slater, "Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments," *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, vol. 364, pp. 3549–57, 12 2009.
- [27] J. Cummings and J. Bailenson, "How immersive is enough? a meta-analysis of the effect of immersive technology on user presence," *Media Psychology*, vol. 19, pp. 1–38, 05 2015.
- [28] R. Skarbez, "Plausibility illusion in virtual environments." [Online]. Available: <https://cdr.lib.unc.edu/concern/dissertations/v118rf14z?locale=en>
- [29] M. Slater and M. Usoh, "Representations systems, perceptual position, and presence in immersive virtual environments," *Presence*, vol. 2, pp. 221–233, 01 1993.
- [30] B. G. Witmer, C. J. Jerome, and M. J. Singer, "The factor structure of the presence questionnaire," *Presence: Teleoper. Virtual Environ.*, vol. 14, no. 3, p. 298–312, Jun. 2005. [Online]. Available: <https://doi.org/10.1162/105474605323384654>
- [31] B. G. Witmer and M. J. Singer, "Measuring presence in virtual environments: A presence questionnaire," *Presence: Teleoper. Virtual Environ.*, vol. 7, no. 3, p. 225–240, Jun. 1998. [Online]. Available: <https://doi.org/10.1162/105474698565686>
- [32] V. Schwind, P. Knierim, N. Haas, and N. Henze, "Using presence questionnaires in virtual reality," 05 2019.
- [33] I. Winkler, S. Debener, K.-R. Muller, and M. Tangermann, "On the influence of high-pass filtering on ICA-based artifact reduction in EEG-ERP," in *2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, Aug. 2015. [Online]. Available: <https://doi.org/10.1109/embc.2015.7319296>
- [34] C. Y. Chang, S. H. Hsu, L. Pion-Tonachini, and T. P. Jung, "Evaluation of artifact subspace reconstruction for automatic artifact components removal in multi-channel eeg recordings," *IEEE Transactions on Biomedical Engineering*, vol. 67, no. 4, pp. 1114–1121, 2020.
- [35] "Home: Artifact subspace reconstruction :github page," 2016. [Online]. Available: [https://scn.ucsd.edu/wiki/Artifact_Subspace_Reconstruction_\(ASR\)](https://scn.ucsd.edu/wiki/Artifact_Subspace_Reconstruction_(ASR))

- [36] J. A. Palmer, K. Kreutz-delgado, and S. Makeig, “Amica: An adaptive mixture of independent component analyzers with shared components.”
- [37] L. Pion-Tonachini, K. Kreutz-Delgado, and S. Makeig, “ICLabel: An automated electroencephalographic independent component classifier, dataset, and website,” *NeuroImage*, vol. 198, pp. 181–197, Sep. 2019. [Online]. Available: <https://doi.org/10.1016/j.neuroimage.2019.05.026>
- [38] J. S. Richman and J. R. Moorman, “Physiological time-series analysis using approximate entropy and sample entropy,” *American Journal of Physiology-Heart and Circulatory Physiology*, vol. 278, no. 6, pp. H2039–H2049, Jun. 2000. [Online]. Available: <https://doi.org/10.1152/ajpheart.2000.278.6.h2039>
- [39] A. Delgado-Bonal and A. Marshak, “Approximate entropy and sample entropy: A comprehensive tutorial,” *Entropy*, vol. 21, no. 6, p. 541, May 2019. [Online]. Available: <https://doi.org/10.3390/e21060541>
- [40] E. Salinas and T. J. Sejnowski, “Correlated neuronal activity and the flow of neural information,” *Nature Reviews Neuroscience*, vol. 2, no. 8, pp. 539–550, Aug. 2001. [Online]. Available: <https://doi.org/10.1038/35086012>
- [41] P. L. Nunez and R. Srinivasan, *Electric Fields of the Brain: The Neurophysics of EEG*. New York, NY: Oxford University Press, 2006.
- [42] F. Perrin, J. Pernier, O. Bertrand, and J. Echallier, “Spherical splines for scalp potential and current density mapping,” *Electroencephalography and Clinical Neurophysiology*, vol. 72, no. 2, pp. 184–187, Feb. 1989. [Online]. Available: [https://doi.org/10.1016/0013-4694\(89\)90180-6](https://doi.org/10.1016/0013-4694(89)90180-6)
- [43] M. A. Guevara and M. Corsi-Cabrera, “EEG coherence or EEG correlation?” *International Journal of Psychophysiology*, vol. 23, no. 3, pp. 145–153, Oct. 1996. [Online]. Available: [https://doi.org/10.1016/s0167-8760\(96\)00038-4](https://doi.org/10.1016/s0167-8760(96)00038-4)
- [44] X. Yang, M. Gao, J. Shi, H. Ye, and S. Chen, “Modulating the activity of the DLPFC and OFC has distinct effects on risk and ambiguity decision-making: A tDCS study,” *Frontiers in Psychology*, vol. 8, Aug. 2017. [Online]. Available: <https://doi.org/10.3389/fpsyg.2017.01417>
- [45] H. Marzbani, H. Marateb, and M. Mansourian, “Methodological note: Neuro-feedback: A comprehensive review on system design, methodology and clinical applications,” *Basic and Clinical Neuroscience Journal*, vol. 7, no. 2, 2016. [Online]. Available: <https://doi.org/10.15412/j.bcn.03070208>
- [46] “Parietal lobes,” 2016. [Online]. Available: <https://www.neuroskills.com/brain-injury/parietal-lobes/>

Appendix I : Questionnaires

Slater-Usuh-Steed Questionnaire

1. I had a feeling of “being there” in the house
(1) Not at all. (7) Very much.
2. There were times during the experience when the virtual house was the reality for me
That is, the Virtual Reality became the Reality for me.
(1) At no time. (7) Almost all the time.
3. When you think back about your VR experience, do you think of the virtual house,
more as images that you saw, or more as somewhere that you visited?
The house seems to me to be more like
(1) Images that I saw. (7) Somewhere that I visited.
4. During the time of the experience, which was strongest on the whole, your sense of
being in the virtual house , or of being elsewhere?
I had a stronger sense of
(1) Being elsewhere. (7) Being in the virtual house.
5. How similar in detail is your memory of your virtual house, compared to your mem-
ory of a real house?
Consider things like the extent to which you have a visual memory of the virtual
house, whether that memory is in color, the extent to which the memory seems vivid
or realistic, its size, location in your imagination, the extent to which it is panoramic
in your imagination, and other such structural elements.
I think of the virtual house as a place in a way similar to other houses that I have been
today
(1) Not at all. (7) Very much so.
6. During the time of the experience, did you often think to yourself that you were
actually in the virtual house?
During the experience I often thought that I was really standing in the house
(1) Not very often. (7) Very much so.

Haptic Subscore of PQ

1. How well could you move or manipulate objects in the virtual house? NOT AT ALL
SOMEWHAT COMPLETELY
2. How well could you actively survey or search the virtual house using touch? NOT
AT ALL SOMEWHAT COMPLETELY

Naturalness Subscore of PQ

1. How natural did your interactions with the virtual house seem? EXTREMELY ARTIFICIAL BORDERLINE COMPLETELY NATURAL
2. How natural was the mechanism which controlled movement through the virtual house? EXTREMELY ARTIFICIAL BORDERLINE COMPLETELY NATURAL
3. How much did your experiences in the virtual house seem consistent with your real-world experiences in a real house? NOT CONSISTENT MODERATELY CONSISTENT VERY CONSISTENT

Audio Subscore of PQ

1. How much did the auditory aspects of the virtual house involve you? NOT AT ALL SOMEWHAT COMPLETELY
2. How well could you identify sounds? NOT AT ALL SOMEWHAT COMPLETELY
3. How well could you localize sounds? NOT AT ALL SOMEWHAT COMPLETELY

Appendix II : Biosignals

- **Electroencephalography (EEG)** Electroencephalography signals are generated in the brain due to electrical activity of the brain. There are billions of neurons in the brain and they are connected to others. These neurons communicate with each other using small electrical currents. So, when several neurons in an area of the brain are activated, electrical pulses are produced by these small electrical currents. These pulses result as EEG signals.
- **Event Related Potentials** Event Related Potential (ERP) is a voltage fluctuation of EEG response associated in time with specific sensory, cognitive, memory or motor event such as present a word or listen to a tone with a specific frequency. In other words, they are time locked EEG changes with respect to a specific event.
- **Steady State Visually Evoked Potential (SSVEP)** Steady state visually electric potential (SSVEP) is an ERP which naturally responses for visual oscillations at specific frequencies. When a repetitive visual stimuli (RVS) excites the retina of the eye, the brain induces electrical signals at the same frequency (or harmonics) of the visual stimulus. These are called SSVEPs. SSVEP is commonly used in Brain Computer Interface (BCI) systems as it holds a shorter training and provides a higher information throughput.
- **Auditory event related potential (AERP)** Auditory event related potential (AERP) is an event related potential generated due to synchronous cortical brain activity based on an auditory stimulus. AERPs are derived extracting segments of EEG signals for an auditory stimulus With respect to the time. These auditory ERP elicits vital information of auditory processing in different stages either with or without attentional engagement for an auditory event.
- **Electrocardiogram (ECG)** Electrocardiogram represents the electrical activity of the heart. The heart functions based upon polarizations and depolarization processes which based upon electrical pulses generated by sinoatrial node in the heart. ECG signals provides information about the heart rate and contraction rhythm of the heart.
- **Skin Conductance** Skin conductance or Electrodermal activity (EDA) is another measurement of psychological or physiological arousal. The skin owns a resistance which depends on functionality of sweat glands. The sympathetic nervous system stimulates these sweat glands in order control regulate body temperature, emotional stress anxiety etc. When the sympathetic branch of the autonomic nervous system is aroused based on emotion state, sweat glands will be more activated and increase the conductance through the skin This is also an important bio signal which can be used to evaluate psychological responses for visual, auditory or haptic stimuli.

Appendix III :Information Sheet and Consent Forms

Consent Form

Research Project: Measurement of Presence in Virtual Reality using Biosignals

Principal Investigator: Dr. A.C. De Silva

Investigators: T.T.N Bahavan, K.I Akalanka, N.Suman, S.A.D.O Wickramasooriya

External Collaborator: Dr. Roshan Peiris, Rochester Institute of Technology, USA

I,....., have read and understood the '**Information Sheet and Consent Form**'. All questions I asked were answered to my satisfaction.

I have been given a copy of the '**Information Sheet and Consent Form**'.

I agree to participate in this activity, realizing that I may withdraw at any time.

I agree that research data collected for this study may be published or provided to other researchers on the condition that anonymity is preserved and that I cannot be identified.

Participant Number			
Name of Participant			
Contact Number			
Signature		Date	

Name of the Investigator			
Signature		Date	

Information Sheet

Research Project: Measurement of Presence in Virtual Reality using Biosignals

Principal Investigator: Dr. A. C. De Silva

Investigators: T.T.N Bahavan, K.I Akalanka, N.Suman, S.A.D.O Wickramasooriya

External Collaborator: Dr. Roshan Peiris, Rochester Institute of Technology, USA

Explanation of the Project

The main objective of this study is to identify biosignal correlates when participants are exposed to virtual reality (VR) scenarios of varying levels of 'Presence'.

If you choose to participate in the data collection for this project, you will be subjected to measuring brain activity (using electroencephalography also known as EEG), heart activity using ECG, and skin perspiration levels using EDA while wearing the VR headset Oculus Go manufactured by Facebook Technologies. Signals collected from you will be used to investigate a relationship between the level of presence in VR and EEG signals. During that experiment, electrodes will be placed on your head while you are wearing a VR headset with a handheld controller to navigate and interact with the virtual environment. You will be shown four different scenarios of 2 minutes each to interact with and at the end of each scenario, you will be asked to fill out a series of questions within the virtual environment itself. The total duration of the study will be approximately 40 minutes.

During the procedure, we will wear an EEG cap with electrodes on your head. To establish proper electrode contact with your skin, we will use a liquid gel. Please note that there will be some minor discomfort while wearing the EEG cap or the VR headset. Additionally, you will have to wash off the gel after the experiment. The scenarios are designed to minimize any form of dizziness or motion sickness, however there is a small likelihood that you might experience some discomfort from these factors.

You are under no obligation to participate in this data collection procedure. Even if you decide to participate, you are free to withdraw at any time during the study. We understand and respect your decision. Please note, that if you withdraw during the recording, it may take up to 5 minutes to remove electrodes before you can leave the recording room.

You have the right to ask questions about this research study and to have those questions answered by us before, during or after the research. If you have any further questions about the study, at any time feel free to contact any of the investigators of this research study.

There will not be a direct benefit to you by participating in this study, but you will gain experience in working with acquiring biosignals and be able to experience different VR scenarios. You will not be given any monetary compensation for participating in this study.

Privacy Protection

Your privacy will be protected the way in which we record the information. Accordingly, the participants will be identified only by a participant number.

Information collected here is for research activities and possible publication in research theses, conferences and in scientific journals. In all instances, no individual will be identified and only the results reflecting specific data collection conditions and settings will be used.

General information regarding this research program and the conditions and settings in which brain activity is recorded today could be used to promote or report the University's research efforts through normal media or government reporting channels, but no private data will be used in such activities.

Any questions regarding this project can be directed to the supervisors

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