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UNIVERSITI TEKNOLOGI PETRONAS

EVALUATION OF VISUALLY INDUCED MOTION SICKNESS CAUSED BY VIEWING OF 3D STEREOSCOPY USING ELECTROENCEPHALOGRAPHY TECHNIQUE

By

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DECLARATION OF THESIS

Title of thesis	Evaluation of Visually Induced Motion Sickness Caused by Viewing of 3D Stereoscopy Using Electroencephalography Technique.

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hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UTP or other institutions.

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DEDICATION

I dedicate this dissertation to my parents and to my wife.

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ABSTRACT

The 3D movies are attracting the viewers as they see objects flying out of the screen. However, many viewers report of problems that they face after watching 3D movies. Visual fatigue, eye strain, headaches, dizziness, blurred vision or in other words, Visually Induced Motion Sickness (VIMS) are reported by viewers of 3D movies. In this thesis, we aim to compare a 3D passive technology with a conventional 2D technology to find whether 3D is causing trouble in the viewers or not.

For this purpose we designed an experiment in which participants were randomly assigned to watch 2D or a 3D movie. The movie was specially designed to induce VIMS. The movie was shown for 10 minutes to every participant. The movie presents a scene resembling a camera moving on the road while it is rotated continuously along the pitch and roll axes on alternate minutes. The electroencephalogram (EEG) and electrocardiogram (ECG) data was recorded throughout the session. At the end of the session participants rated their feelings using the Simulator Sickness Questionnaire (SSQ).

First we analyzed the SSQ data and compared the ratings of 2D and 3D participants using a two tailed t-test. From the SSQ results, it was found that participants watching 3D movies reported significantly higher symptoms of VIMS (p-value < 0.05). From the analysis of the ECG data, we have found no significant results. EEG data was analyzed in time-frequency domain and topographic plots are created from the data. A significant difference has been found in the frontal theta power which increased with time in 2D condition while decreased with time in 3D condition. We found decreased beta power in the temporal region of the brain of the participants in the 3D group. There was no significant change found in the temporal region of the brain in the participants of the 2D group. Finally, features were reduced to few highly significant features that can classify the symptoms of VIMS.

ABSTRAK

Filem-filem yang berasaskan 3D menjadi tarikan kepada penonton kerana mereka dapat melihat objek seakan terbang keluar dari skrin. Walau bagaimanapun, ramai penonton mengadu menghadapi masalah selepas menonton filem 3D. Diantaranya seperti keletihan visual, ketegangan mata, sakit kepala dan penglihatan kabur atau dalam erti kata lain, Mabuk Pergerakan Disebabkan Visual (VIMS). Dalam tesis ini, kami berhasrat untuk membandingkan teknologi pasif 3D dengan teknologi konvensional 2D untuk mencari sama ada teknologi 3D yang menyebabkan masalah kepada penonton atau tidak.

Untuk tujuan ini, kami telah mereka satu ekperimen di mana peserta dipilih secara rawak untuk menonton filem 2D dan 3D. Filem ini telah direka khas untuk merangsang kesan VIMS. Filem ini telah ditayangkan selama 10 minit kepada setiap peserta. Filem ini memaparkan pergerakan kamera di jalan raya sambil ia berputar secara berterusan pada sudut tertentu silih berganti. Data dari *electroencephalogram* (EEG) dan *electrocardiogram* (ECG) dicerap sepanjang eksperimen dijalankan. Pada akhir sesi, peserta dikehendaki menilai perasaan mereka menggunakan Simulator Soal Selidik Penyakit (SSQ).

Dari data yang diperolehi, pertama sekali, kami menganalisa data SSQ kemudian membandingkan ia dengan peserta 2D dan 3D melalui ujian *two tailed t-test.* Daripada keputusan SSQ yang diperolehi, ia mendapati bahawa peserta yang menonton filem 3D dilaporkan mempunyai simptom VIMS (nilai-p <0.05) yang ketara lebih tinggi berbanding peserta filem 2D. Dari analisis data ECG pula, kami tidak menemui sebarang perbezaan yang besar terhadap keputusan yang diperolehi. Manakala data EEG dianalisis berdasarkan domain masa kekerapan dan plot topografi dibuat berdasarkan data yang dicerap. Perbezaan yang ketara dapat dilihat pada *frontal theta power* di mana ia meningkat dengan masa dalam keaadan 2D manakala menurun dengan masa dalam keadaan 3D. Penurunan *beta power* juga didapati di *temporal region* otak bagi peserta 3D. Manakala tiada perubahan yang ketara pada tempat yang sama bagi peserta 2D. Akhir sekali, ciri-ciri telah dikurangkan kepada beberapa ciri-ciri yang sangat penting untuk mengklasifikasikan gejala VIMS.

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LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
VIMS	Visually Induced Motion Sickness
SSQ	Simulator Sickness Questionnaire
ECG	Electrocardiography
EEG	Electroencephalography
FOV	Field Of View
HMD	Head Mounted Devices
PW	Power Wall
SYN	Synoptic View
RS	Reduction Screen
FMS	Fast Motion sickness Scale
DLP	Digital Light Processing
LCD	Liquid Crystal Display
ITU	International Telecommunication Union
SSS	Some Sensation Section
OKN	OptoKinetic Nystagmus
OKAN	OptoKinetic After Nystagmus
EOG	Electrooculography
VR	Virtual Reality
MSQ	Motion Sickness Questionnaire
SSCQE	Single Stimulus Continuous Quality Evaluation
Hz	Hertz
BP	Blood Pressure
MS	Motion Sickness
IC	Independent Component
FEF	Frontal Eye Field
bpm	beats per minute
RCT	Randomized Controlled Trial

CISIR	Centre for Intelligent Signal and Imaging Research
PS	Power and Sample size software
MSSQ	Motion Sickness Susceptibility Questionnaire
EGI	Electrical Geodesic Inc.
HRV	Heart Rate Variability
LF	Low Frequency
HF	High Frequency
FFT	Fast Fourier Transform
EPSP	Excitatory Post Synaptic Potential
IPSP	Inhibitory Post Synaptic Potential
PSD	Power Spectral Density
NFFT	Number of FFT points
N	Nausea
D	Disorientation
O	Occulomotor
TS	Total Score
SVM	Support Vector Machine

LIST OF SYMBOLS

°	Degree
m	Meter
cm	Centimeter
α	Alpha band;
	Significance level
β	Beta band
Δ	Delta band
θ	Theta band
P	Power
D	Diaopter
f	Arbitrary function;
	Frequency
π	Pi
t	Time
Φ	Phase
$S(e^{j\omega})$	Spectrum estimate
$C^2(f)$	Coherence function
Cxy	Cross Spectrum

CHAPTER 1

INTRODUCTION

Stereoscopy is the illusion of creating depth in two dimensional images. The technique of stereoscopy is based on binocular vision i.e. viewing two images at the same time to give the perception of depth. Human perception of three dimension is based on a number of cues such as binocular parallax, motion parallax, accommodation and convergence.

The advancements in the display technology have taken it to a new dimension. Display technology is now moving from 2D viewing to 3D viewing. Adding another dimension to display devices increases the entertainment value to viewers, since images seem more realistic and life-like and appear to "pop out" from the TV screen. The entertainment and film industries continue to explore new and exciting ways of filmmaking and producing animations in 3D. The audiences too are showing more interest in films and animations that incorporate the latest viewing experiences. Hence they are more likely to enjoy films that offer an immersive feeling where the audience feels like they are part of the scenes.

The popularity of 3D technology is found in the entire world but this technology is not limited to entertainment only, instead it is moving into different fields such as medical science, sports and primary education, the growth of 3D technology assures us that in the future, viewing devices will be having additional feature of 3D in them. It can be assumed that large screen TV's, computer screens, smart phones and tablet PC's will all offer 3D content soon. Every new cinema is showing 3D movies and almost every 2 to 4 months there is a new 3D movie in the market and people are eager to watch it.

By the end of 2009 Sony announced that they will be bringing 3D viewing into the home viewing environment and experts claimed that "we will watch all our media

in 3D within a decade". Sony's chairman Howard Stringer said that 3D will be the next $10 billion business [1]. Other companies have also joined the 3D bandwagon, with the president of Samsung Electronics' Visual display division, Mr. Yoon Boo-Keun, announcing "Samsung aims to sell 2 million 3D LED TVs in 2010" [2]. At present, there are a number of 3DTV choices available in the market, and most of them use either active or passive glasses.

1.1 Types of Stereoscopy

Different methods are used to produce stereoscopic effects. They can be classified into aided viewing or free viewing. Aided viewing is further divided into active and passive viewing. Passive viewing includes using anaglyph glasses and polarized glasses while active viewing includes LCD-shutter glasses. Auto stereoscopic display, which does not require any filtering lenses, is associated with free viewing. Each type of stereoscopy is briefly explained below and the details can be found in [3].

- Anaglyph: They are also called color-multiplexed displays. In anaglyphs the two right and left images are filtered by color, like red and green, red and cyan and green and magenta. The viewers have to wear the same filter lenses as of the color in the image, which will produce the effect of 3D depth in the image.
- Polarized Glasses: In polarized glasses each lens is perpendicularly polarized. Therefore the eyes see the image based on horizontal and vertical polarized light. The effect of 3D in polarized glasses is better than anaglyphs.
- LCD – Shutter Glasses: Shutter glasses are electronically powered and only one lens of the glasses is active at a time. They are synchronized with the refresh rate of the screen. The display device displays only one image and this gets synchronized with the lens. Therefore the eyes are intended to see only particular frames which create the depth effect.
- Auto Stereoscopic Displays: Auto stereoscopic displays are a more advanced form of stereoscopy. In auto stereoscopy, multiple views of an object are created from multiple cameras. Frames are presented on the screen with left and right views parallel to each other. The views are set in a way that left and

right eyes can see their respective frames only. Parallax barrier and lenticular lens are two different modes of producing auto stereoscopic images.

1.2 Pros and Cons of Stereoscopy

From the aspects of entertainment and enjoyment viewers find stereoscopic displays as the best viewing device, as they give a feeling of immersion. Viewers enjoy being a part of the movies they are watching as the things appear to fly by them and motion looks more realistic. However, this technology also has some negative side effects. Viewers have reported that after watching 3D stereoscopic films they feel strain in their eyes and suffer from headaches. In an article a viewer of 3D movie who ended up in an accident reports that 3D might be the cause of altered vision, confusion and dizziness [4]. It is also reported from an ophthalmologist that people with minor imbalance in eyes can have a headache while watching 3D movies [5]. These symptoms are derived from motion sickness and the type of motion sickness which is caused by viewing is known as Visually Induced Motion Sickness (VIMS).

1.3 Motivation and Problem statement

3D stereoscopic technology is growing day by day with advancements in hardware as well as in content. However, viewers have reported symptoms of VIMS when during 3D viewing Therefore it is necessary to evaluate the symptoms of VIMS that are produced by 3D stereoscopy.

For the evaluation of VIMS in viewers, it is important to know that how VIMS can be easily induced and evaluated. Evaluation of VIMS requires different methods that can be subjective (questionnaire or interviews) and objective (physiological data). A combination of different data will provide a better and reliable result. In this study Simulator Sickness Questionnaire (SSQ) in combination with physiological data such as data from Electrocardiography (ECG) and Electroencephalography (EEG), are used for the comparative analysis of 3D display with 2D display.

1.3.1 Research Objectives

- To find the brain regions that are activated when visually induced motion sickness is present.
- To evaluate and compare the brain wave changes and level of motion sickness in individuals, induced by 2D and 3D movies.
- To propose an objective indicator/measurement of VIMS using EEG signals.

1.4 Scope of Work

A number of evaluation methods of VIMS are studied and different parameters of physiological data that have been analyzed to find visual discomfort in 3D stereoscopy are reviewed. EEG has been proposed as the suitable measure compared to all the other measures which can give maximum data in terms of signals from brain. Thus, changes in the signals of brain regions will highlight the areas associated with VIMS as well as their severity. ECG data can also be analyzed in a similar manner but has limitations in terms of high dependency on other factors such as overall fatigue and drowsiness. This work will focus on comparing 2D technology with 3D technology particularly in finding differences in symptoms of VIMS.

1.5 Thesis Outline

The rest of the thesis is organized as follows:

Chapter 2 introduces the basics of VIMS and discusses the methods that induce VIMS. Section 2.3 focuses on the assessment of VIMS by subjective and objective methods and section 2.4 provides the neuroanatomy and physiology of brain areas that are related to VIMS.

Chapter 3 explains the protocol of experiment design. Experiment protocol includes study design, sample size calculation, selection criteria, data acquisition and hardware

configurations. This chapter provides a better understanding of the experiment design which will help to reproduce the proposed results.

Chapter 4 discusses the details of data processing. Sections 4.1, 4.2 and 4.3 provide the procedures of analysis of SSQ, ECG and EEG data, respectively. Section 4.4 gives the procedure of feature selection using hypothesis testing.

Chapter 5 is dedicated to the results obtained from SSQ, ECG and EEG analyses along with a detailed discussion of the results. Finally, chapter 6 provides concluding remarks on this work and highlights some extension of this work that can be done in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Visually Induced Motion Sickness

Many symptoms have been reported to have arisen from watching stereoscopy visuals such as visual fatigue, visual discomfort, eye strain, blurred vision, headache, dizziness, confusion, and disorientation. However, it has been found that not all people report the same symptoms. Henceforth, a person suffering from such symptoms is said to have VIMS, which is categorized as a type of Cinerama/Imax sickness in which visual signals are present but signals from the vestibular system are absent [6].

The human visual system perceives depth with four mechanisms, namely; binocular parallax, motion parallax, accommodation, and convergence [7]. 3D stereoscopic devices use at least one of these mechanisms, in which the more commonly used method being disparity between images, to produce depth. Disparity can be of two types; positive (uncrossed) disparity, with objects appearing at the back of the screen and negative (crossed) disparity; with objects appearing in front of the screen. Research has shown that vergence (converging and diverging movement of the eyes) is more active when watching 3D movies than when watching movies in 2D [8]. Vergence is caused by the disparity found in the scene and hence the eye shall go through accommodation. Accommodation is the process in which the lens adjusts itself to focus the light beams on the fovea. If the eyes produce vergence, accommodation will automatically take place. Previous studies report that the major cause of visual fatigue is due to conflict in vergence and accommodation response.

Both vergence and accommodation have their limits, beyond which, problems can occur.

In normal condition, the point where the focus is set coincides for accommodation and vergence. This is not so in the case of 3D stereoscopy. For example, if the point of fixation are apart from each other, i.e. images are having uncrossed disparity, they switch from uncrossed to crossed disparity. This will cause the eyes to converge to a new focus point. This activation of vergence response also activates accommodation response, causing the lens to change its focus. Vergence shifts the focus of eyes on to a new plane. Focus should be set again onto the screen plane as the objects are displayed over it. This process creates a conflict in the visual system which is commonly known as vergence-accommodation conflict, and is one of the major causes of discomfort in 3D [9]. There are a number of factors that affect visual comfort and discomfort, but, they are out of scope for this discussion details can be found in these sources [7, 9, 10].

The viewers who cannot tolerate these visual discomforts will experience VIMS. It is reported that symptoms of VIMS and visual stress are found during and after watching a 3D movie [11]. Another survey reports that children must be cautioned when watching 3D TV, as they will not be able to realize any physical problem even if it exists [3]. In [12], it is reported that 5% of viewers in 3D cinemas experience symptoms of nausea or disorientation. Overall, people can develop symptoms of VIMS while viewing 3D movies.

2.2 Methods of Inducing MS

Reason and Brand [13] define motion sickness as a conflict in the visual and vestibular systems. Thus motion sickness can be induced by producing such a conflict in the visual and vestibular sense of a human. Considering conflicts involving visual and vestibular cues, there are three possibilities that can occur. In the first case, both visual and vestibular cues are present but provide conflicting information to the brain. In the other two types either one, the visual or vestibular cues, is absent. In the first case visual signals are present and vestibular signals are absent. This type of motion

sickness is mostly caused by viewing motion in a stationary environment. The symptoms are not very severe, but they can cause motion sickness. Some examples of environments in which this type of motion sickness occurs are simulators, IMAX movies, and first person shooting games. In the second case, vestibular signals are present and visual signals are absent. This involves a stationary visual gaze and a moving environment. For example, reading during a moving journey can cause this type of motion sickness. All these types of motion sickness cause a visual vestibular mismatch.

Researchers have investigated all the three possibilities of inducing motion sickness. There is enough evidence to show that visual, vestibular, or both inputs, simultaneously can cause motion sickness. Hence, viewers should be cautioned about the content which they see on TV and Computer. The makers of the content should make them in such a way that there should not be any conflict between the visual and vestibular system of the humans. Directors of movies try to give the best viewing experience possible so the audience has the feeling of involvement in the movies but this sometimes causes conflict in our brain.

2.2.1 Visual Stimulation

Visual stimulation to induce motion sickness requires a specialized environment. In this case a visual display device is used to provide stimulation to the viewer. The stimulus shown on the screen should be specifically designed to induce motion sickness and the viewer must be in a stationary position. It has been reported that moving images at certain frequency ranges cause VIMS and they should be avoided in normal viewing environments such as games and movies.

Min et al. [14] tried to induce motion sickness in his experiment through visual inputs. He came up with a graphic simulator that projected the images of the road on an 80-inch screen using back-projection. Another study done by Kshavarz et al. [15] shows that motion sickness mostly occurs when the Field Of View (FOV) is large. Motion sickness increases due to the interference of laboratory environment i.e., the surrounding objects like walls, ceiling and other objects that can be seen during the

experiment other than the experimental screen. This can be a major cause of motion sickness in the subjects. In the research conducted, three experiments were performed using the following:

- Large screens & Head mounted device (HMD) with same FOV
- Large screens with reduced FOV and synoptic view using synopter; a device that projects identical images in both eyes.
- Large screens and mask view (the group wore a mask that limits the FOV)

Table 2.1: Summary of Experiments

	Group	FOV	Visual Angle	Observation
Experiment 1	HMD	48	48° × 36°	Low score of Motion Sickness
	Large Screen (PW)	180	48° × 36°	High score of Motion Sickness
Experiment 2	SYN (No Stereo conflict)	32	32° × 17°	SYN and RS group showed lower rating of VIMS than PW and HMD
	RS (Stereo conflict)	32	32° × 17°	
Experiment 3	Mask	48	48° × 36°	Mask group in comparison to PW and HMD showed lower rating of VIMS

HMD = Head Mounted Device, PW = Power Wall, SYN = Synoptic view, RS = Reduction Screen, VIMS = Visually Induced Motion Sickness

The paper used fast motion sickness scale (FMS) which has a high correlation with the Simulator Sickness Questionnaire (SSQ), which will be discussed in Section 2.3. In the first experiment the rating of VIMS on FMS was higher when using the Large Screen instead of the HMD. In the second experiment, the rating of VIMS was

higher for Large Screen instead of synoptic view. In the third experiment, the group viewing the Large Screen recorded more symptoms of VIMS as compared to the Mask viewing group.

The paper concluded that the display angle is directly proportional to the visual input, that is, if the display angle is decreased, it will also decrease the visual input. Less sickness scores were recorded when the FOV or display angle is reduced. Additionally, it was concluded that the laboratory environment can contribute to motion sickness while in a driving or flight simulator. The visual angle is calculated with respect to the screen size and screen distance. One should not confuse FOV of large screens with visual angle. FOV for watching a stimulus on large screens is usually more than 180° and that is the cause of visually induced motion sickness.

From this point onwards, this section will focus on experiment designs with different screen sizes and screen distances because it will give us the information about the FOV and display angle. The summary of the experiments where each group uses different devices and their results can be seen in Table 2.1.

Ujike et al. [16] induced motion sickness through visually simulated moving images in three experiments. They back-projected the images on a large screen with a visual angle of 82° x 67° from a viewing distance of 1m, using a 70-inch screen. Both rotational (yawing, pitching, and rolling) and translational-type motion were present in the image. Results show that roll motion produces more motion sickness symptoms.

Sugita et al. [17] performed an experiment for the evaluation of VIMS in which visual stimuli was shown on a 203 x 149 cm^2 screen which is approximately an 80-inch screen. Images were projected from a Digital Light Processing (DLP) projector, and the stimulus shown was a movie recorded from a handheld camera with a lot of camera movement so that VIMS could be induced. The viewing distance was 1.2m. Then they compared the cross correlation of the atrial pulse wave transmission time with heart rate against the cross correlation of the blood pressure with heart rate. They concluded that atrial pulse wave transmission time, which has a low signal to noise

ratio, has a higher correlation with the heart rate and can extract physiological changes more sensitively than the correlation of blood pressure to heart rate.

Fujita [18] compared self-motion perception and motion sickness in terms of subjective responses of the participants. Participants performed different tasks such as free watching, fixed gaze, predictive cues and sub-task. They took 18 subjects for their experiment and 3D fly-through images were presented on a 120 inch screen. It was found that the feeling of self-motion by the subject was higher in predictive cue, but they did not feel motion sickness when they were freely viewing the flying objects on the screen. However, in the other three tasks, the feeling of self-motion was less reported. Motion sickness rating was also found to be higher in the fixed gaze task. This may be attributed to a conflict between the subject's visual input and their surroundings. Each subject was asked to focus on a single point while objects were flying all over the screen. These objects tend to disturb the gaze with conflicting visual cues; this might be a cause of higher sickness rating.

Abe et al. [19, 20] performed a similar experiment to that used in [17]. The only difference was in the type of projector used (LCD instead of DLP projector). In these experiments the screen size was large and viewing distance was small. Both experimental techniques do not follow the recommendations of ITU, which states that viewing distance should be 3 times the height of screen [21].

A similar study was done by Kiryu et al. [22], where VIMS was evaluated using ECG, blood pressure and heart rate. The screen size used here was 70 inch and viewing distance was 1.7m. To induce motion sickness, they created a movie that had strong and weak VIMS inducing sections in the images and those sections were supposed to have sensational effects on the observer. The authors named the regions of images in which VIMS was reported as Some Sensation Sections (SSS).

Ujike et al. [23] did a survey in which junior high school students watched a video on a 170 inch screen. Out of 294 students, 50 students felt sick and 34 were treated in hospital. The movie was captured using a hand-held camera in which camera motion such as pan, tilt and zoom were over-used. After this incident, researchers modeled an

algorithm that could automatically estimate VIMS from the motion vectors of the image by calculating the velocity component of the images [24].

Sakamoto et al. [25] used two screens of sizes 42 inches and 65 inches and compared them with different viewing distances varying from 110cm, 165cm, 220cm, and 330cm. The purpose of the experiment was not to induce motion sickness but to test visual fatigue using normally watched image content. Subjective recording was done using questionnaires and interviews whereas the objective measurements were taken from recording the eye blink rate and heart rate variability. From the objective results and subjective comments, they concluded that 165 to 220 cm is the optimum distance for watching movies with a feeling of involvement in it.

A summary of experiments discussed in this section are presented in Table 2.2.

Table 2.2: Summary of Screen Size and Distance

Author	Screen Size	Screen Distance	Visual Angle
Min	80 inch	Not mentioned	30°
Kashavarz	100 inch	3m	48°
Ujike	70 inch	1 m	82°
Sugita	80 inch	1.2 m	80.5°
Fujita	120 inch	Very close to viewer	
Abe	50 inch	1.27 m	53°
kiryu	70 inch	1.7 m	56°
Ujike	170 inch	Minimum 7 m	34°
Sakamoto	42 inch 65 inch	1.1m, 1.65m, 2.2m, 3.3m	51°,35°,27°,18° 74°,53°,41°,28°

m = meter

Visually induced motion sickness depends on two main factors; one is related to screen size and viewing distance and the other is related to the velocity component of the images. Nowadays, large screen TVs are easily available and affordable. Large screen TVs help the audience to focus on a particular area of interest. Therefore fixing the gaze on an object with movement in the surrounding produces slight symptoms of motion sickness.

2.2.2 Vestibular Stimulation

Sickness symptom that can be felt during any kind of motion without sensing motion from visual pathways, is said to be induced by vestibular stimulation. Mostly people suffer from this type of sickness i.e. carsickness, airsickness and seasickness. A number of research work has been done to study motion sickness induced by vestibular stimulation where the brain signals are recorded for analysis [26-28]. The results of these researches will be discussed in detail in Section 2.3.2.2.

2.2.3 Visual and Vestibular Stimulation

2.2.3.1 *Optokinetic Stimulation*

The word optokinetic is a combination of two terms: opto relates to the eyes and kinetic relates to movement. Thus, optokinetic stimulation is the stimulation which is caused by the movement of eyes. Optokinetic drum is a device that is placed over the subject's head and then rotated. Vertical lines are arranged inside the drum and when the drum is rotated, the eyes set their focus on the line and move according to its rotation. This rotation, results in movements of eyes in the direction of lines and jumps to following line in opposite direction i.e. to and fro movement of eyes also known as *OptoKinetic Nystagmus* (OKN) [29].

Cuiting et al. [30] used *OptoKinetic After Nystagmus* (OKAN) to test if their subject is susceptible to motion sickness. First, OKN is invoked by using the rotating optokinetic drum as described earlier. During this procedure, when a subject is concentrating on the line patterns, the Electrooculography (EOG) generates a graph of the eye movements. The experimenter then switches the light off. This causes complete darkness in the drum. If the graph shows the same pattern that was present with lights on, then the subject is showing *OptoKinetic After Nystagmus* and is more susceptible to motion sickness. Hu et al. [31] also used optokinetic rotating drum to induce motion sickness, but measured the brain areas that are showing higher power to correlate with the sickness symptoms.

2.2.3.2 *Virtual Reality (VR) Environments*

It is very important that the motion sickness that is being induced should be similar to the one induced in reality so that the main symptoms can be determined instead of its derivatives. A VR environment refers to an environment that is virtually created to emulate and closely resemble reality and is suitable to be used in the study of motion sickness during driving, sailing and flying. The computer-generated graphics can be viewed in many different ways such as projecting images on a wall of a closed room or through a head mounted device. In VR, apart from computer graphics, the subject can actually feel the movement and by visual inputs, he can also see the motion.

A driving simulator was used in [32] to induce motion sickness. In the experiment, a car was mounted on a Stewart motion platform, with six degree of freedom of motion, while images of driving on the road were shown on the screens surrounding the car. This allows the subject to experience both kinesthetic and visual stimuli.

2.3 Assessment of MS

2.3.1 Subjective Assessment

To assess and treat motion sickness, doctors usually use questionnaires or interview their patients as there is no standard objective measure of motion sickness. To our knowledge a standard objective measure that could quantify level of motion sickness has yet to be developed. To evaluate simulator sickness which is a type of motion sickness induced from virtual reality environments, Kennedy [33] developed a questionnaire known as the " Simulator Sickness Questionnaire" (SSQ), which helps researchers to question their subjects about their feelings. There are other types of questionnaires used by some researchers such as the Motion Sickness Questionnaire (MSQ) similar to SSQ [32]. FMS which is a type of rating scale, does not ask subjects to rate specific symptoms of motion sickness but it requires the subject to rate the

severity of motion sickness felt between a scale of 0 (no sickness) to 20 (frank sickness) [34]. Another questionnaire [35] is used specifically for the identification of factors related to visual fatigue such as eye pain, visual stress, nausea, eye blur, and body stiffness. Solimini et al. also conducted the study on symptoms of VIMS and visual stress and used a self-administered questionnaire [36]. The VIMS symptoms that they investigated included visual discomfort, visual fatigue, headache, dizziness, vertigo, palpitation, nausea, and vomiting, before, during and after the experiment.

Researchers have also employed electronic ratings systems that can provide continuous rating of sickness by pressing a button or using a joystick [37]. These rating systems are helpful as they do not interrupt the subject's concentration in the middle of the experiment and can identify the exact time, scenes or types of motion that are causing sickness. Yano et al. [38] used the Single Stimulus Continuous Quality Evaluation (SSCQE) in their work on accommodation response. Using a rating system for visual comfort, where 5 = good and 1 = bad, the researchers investigated the difference in the visual fatigue and visual comfort for 2D and 3D stereoscopic images. Subjective evaluations for visual comfort are well discussed in [9] but for the evaluation of VIMS, the scale must be calibrated so that the researchers can easily determine all the symptoms of VIMS and not only the occulomotor symptoms. The calibration of a scale to a standard scale is important because some people rate their feelings more than others. For example, it is possible that two people rate 5 and 8 for same amount of pain on a scale of 10. Therefore, different scales should be calibrated to a standard one.

These subjective ratings from a research point of view are important for correlating with objective parameters. If the subject is involved in the experiment and there is an emotional factor involved in the stimulus, then physiological changes can occur. These changes can be seen in the objective recordings but the correlation with subjective feelings will verify whether the subject is experiencing sickness symptoms. For the purpose of experiments, it is important to select those subjects who actually suffer from motion sickness. The susceptibility to motion sickness varies from one individual to another, and a questionnaire was developed for the purpose of observing susceptibility levels of individuals to motion sickness [39].

Table 2.3: Summary of Subjective Rating

Questionnaire	Description	Examples	Comments
Symptoms based	Symptoms are rated by subjects according to severity	SSQ, Solimini	Can be used as pre- or post-questionnaire but may interrupt experiment
Grading Based	Single symptom is graded according to severity	Discomfort level, comfort ability	Good for rating during experiment but only one symptom can be rated
Rating in terms of symptoms	Symptoms rated according to severity	Ujike 2004, 11 point rating scale	Can be during experiment but only one symptom is recorded as subject can feel more symptoms.
Verbal Rating	A scale of symptoms to rate directly from 0 - 20	FMS	Good for use during experiment but dividing sickness on a large scale is difficult.
Real Time	Electronic rating of symptoms compiled with data for correlation	MSQ, SSCQE	Can be evaluated with physiological data but subject would be continuously thinking of symptoms.

SSQ = Simulator Sickness Questionnaire, FMS = Fast Motion Sickness Scale, MSQ = Motion Sickness Questionnaire, SSCQE = Single Stimulus Continuous Quality Evaluation.

Different questionnaires have been introduced to assess feelings of motion sickness, as presented in Table 2.3. However, different individuals understand, interpret and assess symptoms differently and there are variations in the reporting by each individual. Hence it is very important to have an objective marker that can be correlated with the subjective assessment.

Furthermore, using questionnaires result in a problem referred to as demand characteristics. Participants in an experiment will anticipate that there must be some change before and after the experiment and this will affect how they answer the questionnaire. Young et al [40] tested this using a pre and post sickness questionnaire and hypothesized that if pre-questionnaire is given in an experiment, then it will demand a change in post-questionnaire. He implemented his experiment by taking two groups and inducing motion sickness in both. One group was given both pre and post SSQ whereas the other group was provided with only post SSQ. The group which was tested with both pre and post SSQ showed higher rating of motion sickness then the other group which was tested with only post SSQ.

2.3.2 Objective Assessment

To diagnose symptoms that are present due to motion sickness, a number of objective parameters are used. The most common are heart rate, blood pressure, and pulse. If there is a change in the normal value of these objective parameters then further assessments are conducted. In neurosciences, brain areas associated to motion sickness are currently being investigated. Researchers are interested in developing an EEG-based system that can identify a subject's motion sickness level [41]. In order to achieve this goal, subjective and autonomic responses are correlated with EEG results to find those areas and brain dynamics that are activated when a subject is suffering from motion sickness.

2.3.2.1 *Autonomic Responses*

VIMS is a state, which is composed of many different symptoms but, it itself is not a disease. There are other symptoms as well that take place during VIMS such as nausea, occulomotor symptoms and disorientation. It is clear that all these symptoms create different effects on the body which cannot be diagnosed using one particular method. Heart rate and blood pressure are two main parameters which are most affected. These two parameters change rapidly according to the condition and the changes can be recorded easily.

The cheapest and easiest method of evaluating VIMS is to observe the blood pressure (BP) and heart rate. However, these parameters can change with any kind of stress caused by any physical or mental activity. Hence, these parameters have a factor of dissimulation (deception) in them.

Sugita et al. discussed the correlation between BP and ECG in [17]. When the BP and heart rate are correlated, then the Mayer wave component appears at around 0.1 Hz in the ECG signal. The paper also suggested a new and better objective parameter which is based on *atrial pulse wave transmission time*. The *atrial pulse wave transmission time* is the time delay between the peak of the atrial pulse wave recorded from the fingertip and the peak of the atrial pulse on the ECG signal. Sugita used this procedure and compared the cross correlation of heart rate and BP with the cross correlation of pulse transmission time and heart rate. However, the drawback of this method is its low accuracy due to the low amplitude of the atrial pulse measured at the fingertip. Another drawback is that signal cannot be acquired correctly if the sensor is attached too tightly to the finger. Along with this problem, the emotional condition of the subject may also affect the signal recorded.

Abe et al. [19, 20, 42] performed the same experiment but used photo plythesmography independently to evaluate VIMS. Independent Component Analysis was then used to estimate VIMS by decomposing a single pulse wave signal into seven features to estimate the level of VIMS. These parameters can be used for the evaluation of VIMS but for the reference, feedback from the subject is required in

which his feelings are rated at the time of sickness. In both of the above cases the authors have not done any continuous reporting of the subjects' feelings.

Continuous reporting from the subject can help researchers determine which scene of the movie is actually causing VIMS. In an experiment performed in [22], the scenes that cause VIMS were called as some sensation section. The experiment was to evaluate VIMS simultaneously when there is a change in the autonomic nervous activity and the time when the subject reported it. The recorded objective parameters were ECG, respiration, and blood pressure. Sickness was evaluated with different combinations of the low and high frequency components of those parameters. The sensation section reported by subject and recorded objective responses were correlated to find the scenes that exhibit the property of inducing motion sickness. Even though they claim to find the sickness inducing sections but they did not report any particular type of images that causes VIMS.

Autonomic responses are good for short term evaluation in cases where the causes of changes in the system are known. Sometimes variability in the human autonomic responses is caused by other responses. These variations are not directly related to symptoms but they are a part of changes that are taking place due to some other regulations. That's why autonomic responses may be misleading A summary of autonomic responses and there disadvantages are presented in Table 2.4.

TABLE 2.4: SUMMARY OF AUTONOMIC RESPONSES

Objective Measure	Sensor	Disadvantage
Heart Rate	ECG	Heart rate changes with physiological conditions, such as fear, excitement
Blood Pressure	BP sensor	BP sensor is bulky and cannot be instantaneous
Pulse Transmission Time	Pulse oximeter probe	If sensor is pressed tightly changes can occur
Respiration	Respiration Rate sensor	It can be irritating for subject as the belt is placed around the chest to measure respiration rate
Photo Plythesmography	Pulse oximeter probe	Atrial Pulse wave is low and Inaccurate

ECG = Electrocardiography, BP = Blood Pressure

2.3.2.2 *Brain Activity Response*

Apart from autonomic response, brain activity is now becoming an increasingly popular measurement tool to evaluate VIMS. Information can be acquired by recording the brain activity as all the work that is done by humans is caused by the activity in the brain. Any illness disorder or disease that is felt by human body, directly or indirectly affects the human brain. It is a fact that predefined actions are saved subconsciously by our body. Therefore when that subconscious task comes into consciousness, the brain areas related to that task becomes activated. This activity can be easily captured by EEG recording. EEG is cost effective and easily available technology which is used for the measurement of brain disorders.

Research is still in progress to develop a suitable feature of EEG that could be used to categorize motion sickness. It is difficult to say what actually happens when motion sickness occurs. Either there is a higher activity in areas that are dealing with motion sickness or perhaps those areas may get slow due to motion sickness. Activity recorded in an EEG can be understood with respect to EEG bands. Mostly delta and

theta bands are said to be associated in motion sickness related areas. Table 2.5 summarizes the EEG bands associated with motion sickness experiments.

Table 2.5: Brain Function and Area Associated with EEG Bands

Author (year)	**Task**	**Experiment**	**Frequency**	**Areas**	**Comments**
Wu [27] (1992)	Vestibular Stimulation	Subjects placed and moved in parallel swing device.	θ band power increases	Frontal and Central areas	θ band increase can be due to the movement of subjects as all the three studies are related to vestibular stimulation and having an increase in θ power in all of them, this can be correlated with recent studies of Chen, et. al., [43]. The recent study shows an increase in Δ band in motor areas due to motion of participant.
Chelen [26] (1993)	Cross coupled Angular stimulation	motion-induced motion-sickness study	θ band power increases by 2.2 over baseline	Temporo-frontal region	
			Δ band power increases by 13.7 over baseline	Temporo-frontal region	
Wood [28] (1994)	Vestibular Stimulation	Motion sickness induced by rotating drum	θ band increases	Frontal areas	
Hu [31] (1999)	Viewing	An optokinetic rotating drum	Δ band net percentage increases than in base line	C3 – C4 electrode cites	—
Min [14] (2004)	Driving	Virtual Reality-based car-driving	θ power declined as motion sickness increased	In Fz and Cz electrode	Questionnaire was asked every 5 min which can be the reason of increasing symptoms, as subjects would have rated higher after each time they fill questionnaire.
			Δ power increases	In Fz and Cz electrode	

Strychacz [44] (2005)	Viewing	Flow field ball tracking driving video	1 – 10 Hz higher power	Frontal IC component – Eye artefact.	20 and 40 Hz peaks were suppressed in MS condition.
			Spectral power increases in all frequencies (baseline compared to MS epoch)	Due to ionic changes in IC 3 (may be temporo frontal) not specified in paper	
			20 and 40 Hz peaks in baseline region	Central posterior (occipital) IC	
Kim [45] (2005)	Object finding	Virtual Reality Experiment	β power increases	Frontal and temporal areas	The total severity of cyber sickness had a significant positive correlation EEG delta wave and a negative correlation with EEG beta wave.
			Δ power increases	Frontal and temporal areas	
Chen [43] (2010)	To sit as a passenger of a car driving simulator	Motion sickness inducing virtual reality environment	θ band increases	In Motor areas	The used both visual and vestibular inputs therefore there is an increase in power in θ band in motor areas due to high movement on the swinging road.
			α power increases with the subjective MS level,	In the parietal lobe.	
			Δ power increases	occipital, occipital midline and right motor areas	

MS = motion sickness, α = Alpha band, β = Beta band, Δ = delta band, θ = Theta band, IC = Independent Component, Hz = hertz

In 1993, Chelen et al. [26] performed an experiment in which motion sickness was induced through rotating a chair and a 14 channels EEG was used through invasive electrodes based on 10-20 system. Verbal reporting from subjects was also performed on the basis of 1-10 scale after every 30 seconds. Results showed that as compared to baseline, mean power spectral energy increased by a factor of 13.7 in frank sickness. Similarly, a difference was noted in the theta band with a factor of about 2.2 and no difference was noted in the alpha band. This comparison was done between baseline recording and imminent emesis (max nauseous condition) of subjects. Most changes were recorded in the temporo-frontal region. It is clear from their results that the maximum power was higher in delta level when motion sickness (MS) level was at a peak. Thus, when MS level reached its peak, slow wave activity started in temporo-frontal region with high amplitude

In evaluating simulator sickness, Min et al. [14] also found similar results that there was an increase in the delta band when MS level was reported to be higher by the subject. There was no physical movement of the subject in this experiment as the stimuli were presented on a screen. Theta activity in correlation to sickness level decreased with time but showed maximum correlation with sickness level. So they chose theta parameter to indicate simulator sickness.

In both of the above experiments one used pre-coriolis stimulation that is based on vestibular stimulation and the other used visual cues to stimulate the brain, respectively. To have complete motion sickness it is better to have both of the stimulations at the same time. Ideally if a subject is stimulated with both, physical movement and visual stimuli then the actual symptoms of car sickness can be addressed.

In [32, 37, 43] the researchers conducted a similar kind of experiment to find the effects on EEG produced by motion sickness. The experiment design is previously discussed in the VR environment section. During the period of the experiment, they performed EEG recording with a 32 channel EEG device based on the international 10 – 20 system. The experiment consists of 10 minutes of baseline recording on a straight road, 40 minutes driving on a curved road for inducing motion sickness and

15 minutes recording during a rest period. At the same time there was continuous recording of the subjects' feelings from a joystick.

This experiment produces a number of stimulations to the brain. We can see that overall movement of body will be there so there must be a brain response due to this motion. Visual stimuli is also presented, hence, there must be a change in the visual activity of the brain. Finally, there is continuous reporting from a joystick about the sickness level. The authors selected those brain areas in which the power spectrum of the EEG was highly correlated with the subjective reporting of the results. Due to the movement of the subject they found that theta power was higher in motor areas. Secondly, there was a high activity of alpha waves in the parietal region of the brain and the level of power increased as the subjects' rating of sickness level increased. Finally, there was a higher delta wave power in the occipital region which they interpreted as a stress component due to the curved road section.

Based on these results, motion sickness can be classified or estimated through the EEG power spectrum [41, 46]. The main approach is to extract the best EEG features caused by motion sickness and estimate them through machine learning algorithms [47]. The enhancement of these methods is still under research [48].

The brain areas involved in motion sickness can be found by the symptoms of motion sickness that are present at that time. It has been discussed that the main symptoms of motion sickness are nausea, disorientation, and occulomotor symptoms. For nausea, brain areas activated should be related to the digestive system or the brain areas that are activated when there is muscle movement of stomach. This is due to the urge to vomit or unpleasant feeling present at the time of nausea. This is the extreme condition of motion sickness. Disorientation is defined as the feeling of self-motion (vertigo) or unbalancing of one self. Therefore, the brain areas such as those that receive signals from semi-circular canals must be activated at time of disorientation. The occulomotor symptom is further divided into eye strain, focusing difficulty and headache. Hence, the activated brain areas must be those involved in visual processing and eye movement.

From the point of measuring symptoms and changes in the body, the best option is the response of the brain. The highest authority in the human body which regulates all the systems is brain. Therefore, changes in any of the body part can be seen through the measurements of brain signals. Imaging and mapping the brain regions have become more advanced. The activation or deactivation of those regions can be modeled through a number of imaging devices. It is very useful to develop a relation between brain regions and motion sickness symptoms. This can only be done by imaging brain at the same time when the subject is suffering from symptoms of motion sickness.

2.3.2.3 *Visual Parameters*

Autonomic nervous activity and EEG can be useful for the evaluation of VIMS but the most affected part in VIMS is occulomotor-related [49], which can be analyzed by visual parameters. Until now, visual parameters are not used for complete evaluation of VIMS but they are used to evaluate symptoms like eye strain, visual fatigue and visual discomfort. These are the major factors that are analyzed for the evaluation of stereoscopic TV's. Accommodation-convergence conflict is said to be the major cause of visual fatigue in stereoscopic TV [9, 50]. Accommodation is defined as focusing of eye on an object this is shown in Figure 2.2 as the eye focuses on near object the far objects are blurred and vice versa. In an experiment [38], accommodation response was recorded before and after the stimulus which was a movie shown in 2D and 3D. Results showed that accommodation response changes after watching 2D movie but after watching 3D movie there was significant change in accommodation. Accommodation response is defined as the focusing of eye lens to see an image clearly. When the lens changes its focus, it makes the image to fall on the fovea where the sensors are present to read the image.

For motion sickness caused by visual functions, it is important to identify the active brain areas during visual activity. In the case of visual fatigue caused by stereoscopic depth, it is reported that the frontal eye field area can be used as an objective indicator of VIMS [51]. Eye movements increase because of the depth in the

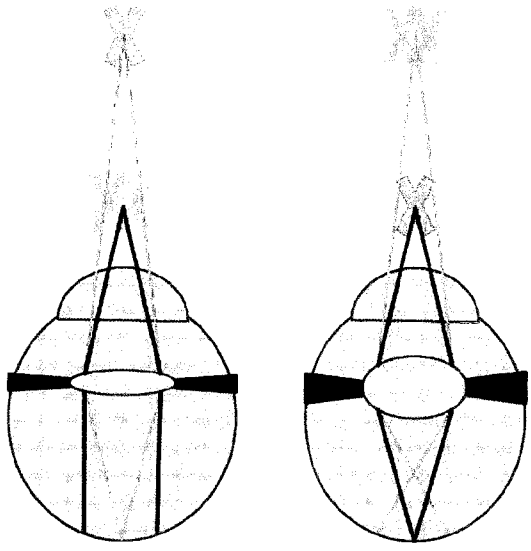


Figure 2.1: Accommodation of eye, if far object is focused then near object is blurred and if near object is focused then far object is blurred

stereoscopic images. This causes the frontal eye field area, that is mostly used in eye movement, to be activated.

A recent study for finding the vergence response over 3D TV shows that vergence was more active in 3D-viewing than 2D-viewing [8]. This is probably due to the difference in screen disparities when producing objects which appear in front of the screen and objects which appear at the back of the screen, in 3D TV. If some object appears in front of the screen than it is said to have positive (crossed) disparity and if an object appears at the back of the screen than it has negative (uncrossed) disparity [9].The phenomenon of vergence response for real world objects can be seen in Figure 2.2 and accommodation-vergence response of stereoscopic 3D TV is explained in Figure 2.3.

For watching 3D stereoscopic images, screen disparity is a must, but there is a limit to which humans can perceive the depth in the images. This limit is referred to as 1° of disparity and beyond 1° of disparity, asthenopia can occur [10]. In a study by Eui chul et al. [52], the authors compared eye strain in 2D- and 3D-viewing by studying the frequency of eye blinking and found that there were more eye blinking in 3D-viewing. They also found that watching from a shorter distance (60 cm) causes

more eye strain than watching from a longer distance (90 cm), a summary of visual parameters related to evaluation of stereoscopic 3D movies, that are used in the experiments are given in Table 2.6

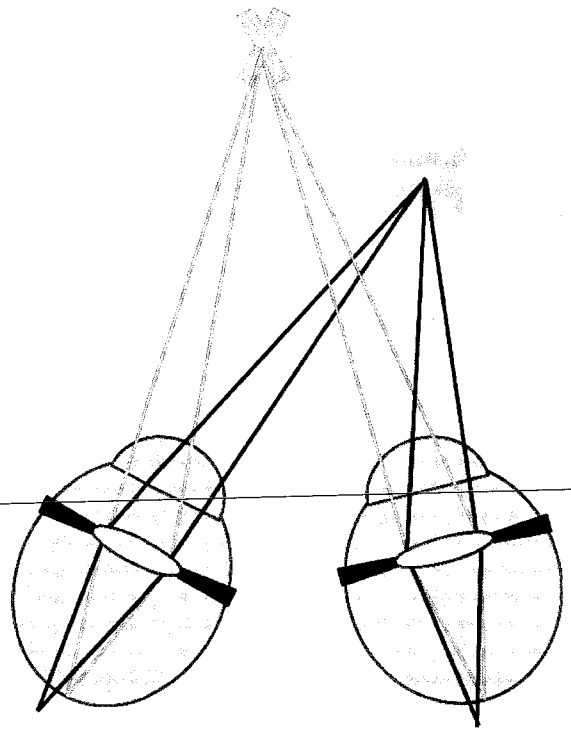


Figure 2.2: Vergence response of eyes in real world. If focusing one object then other surrounding objects are out of focus.

Table 2.6: Summary of Visual Parameters Used in the Evaluation of Stereoscopic 3D Movies.

Reference	**Eye Parameter**	**Task**	**Result**
Yano et. al., [38]	Accommodation Response	2D & S3D movie stimuli	For S3D some viewers felt visual discomfort
Daughtry et. al., [8]	Vergence Response	S3D	Vergence is more active when images have disparity
Eui Chul et. al., [52]	Eye Blinks Frequency	2D [60-90]	Eye blinks were more in 60 cm condition compared to 90 cm.
		S3D [60-90]	In S3D eye blinks were more than 2D for both 60 and 90 cm condition.

2D = Two dimension Image, S3D = Three dimension stereoscopic Image

Visual parameters are good for finding the initial factor that starts the symptoms of VIMS. And they are helpful in analyzing such devices that cause VIMS. As in case of 3D movies it is better to understand whether VIMS is caused by visual motion, large screens, or the 3D content itself. The growing advancements in eye tracking will become a powerful tool that will help researchers to find that when and where the eyes focus. It will also help them to know that how much movement in pictures is feasible for a person to handle the stress that is generated from the motion in pictures.

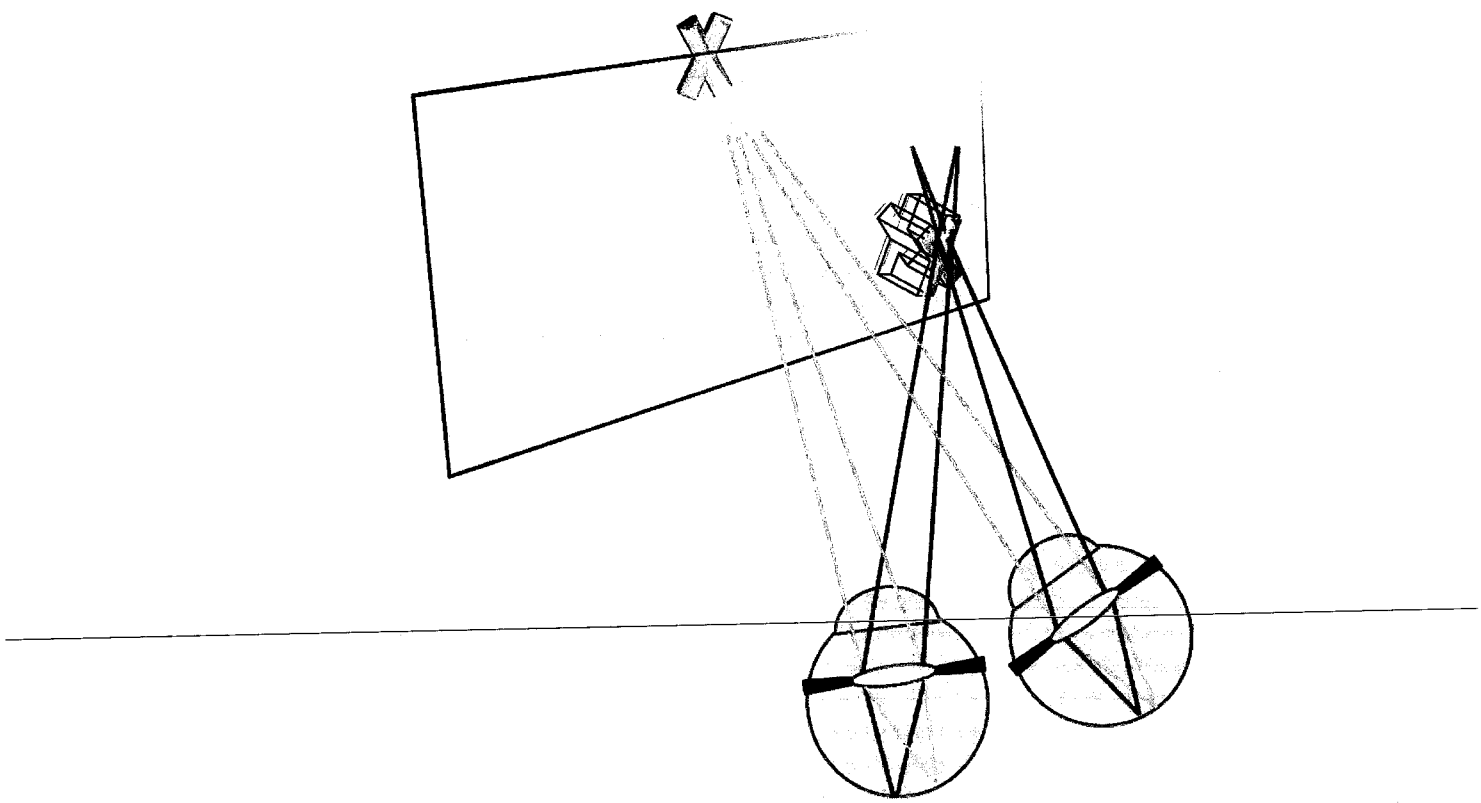


Figure 2.3: Accommodation – vergence response in stereoscopic 3D TV. Green 'X' is placed behind the screen and the eyes focus on the screen but the object appears at the back. This is called negative or uncrossed disparity. In the case of positive or crossed disparity, the object appears in front of the screen and the eyes are focused on the screen through cross viewing. When depth changes, there is a conflict in accommodation and vergence responses of the visual system.

2.4 Neuroanatomy and Physiology

Previously, there was a discussion about the regions of the brain that are activated when VIMS is induced. These regions are experimental findings and are dependent upon experimental conditions. Before continuing with these findings, it is necessary to know the brain regions that are reported to balance the human body. One may try to find the regions that should be communicating if a person is trying to balance themselves. This section will provide a brief anatomy of nervous system. It will give

an insight of the regions that are reported to control the posture and balancing of the human body. This section is mostly based on literature from [53].

The cortical part of the brain is divided into two hemispheres, right and left, which control the left and right parts of the body, respectively. From the physiological point of view, the cortex is divided into four lobes; frontal, temporal, parietal and occipital. Each lobe has different major functions. The cortex consists of a number of ridges and grooves that are known as gyri and sulci, respectively. These gyri and sulci are usually the boundaries for different lobes or parts of the cortex.

VIMS is categorized into three symptoms that are nausea, disorientation and occulomotor symptoms. Disorientation is related to balancing and body posture while occulomotor symptoms are related to eye fatigue and eye strain. Therefore, the study will focus on cortical regions that are related to visual system and vestibular system. It is also reported that nausea is the least reported symptom among the three symptoms of VIMS [49].

2.4.1 Vestibular Regions of Cerebral Cortex

The vestibular system of the brain is divided into two different regions and each of them will be discussed separately.

2.4.1.1 *Primary Vestibular Cortex*

The primary vestibular cortex is located along the upper lip of intraparietal sulcus and is continuous with the posterior part of the post central gyrus. Therefore, to distinguish primary vestibular cortex from primary somatosensory cortex it is designated as area 2v. Figure 2.4 displays the anatomical location of the primary vestibular cortex.

The area 2v functions in vestibular consciousness and helps us to understand the movement of body with respect to its surroundings. It gives us an idea that how to balance our self or maintain our posture. In short it is a sensory modality that senses

motion and integrates the different vestibular and visual stimuli to balance our body. It is reported that injuries to this region often cause dizziness or feeling of rotation or floating. Also, stimulation of this area causes vertigo. It has been concluded that balancing and other posture-maintaining properties of the brain are dependent on the vestibular inputs and vestibule-visual-somatosensory integration.

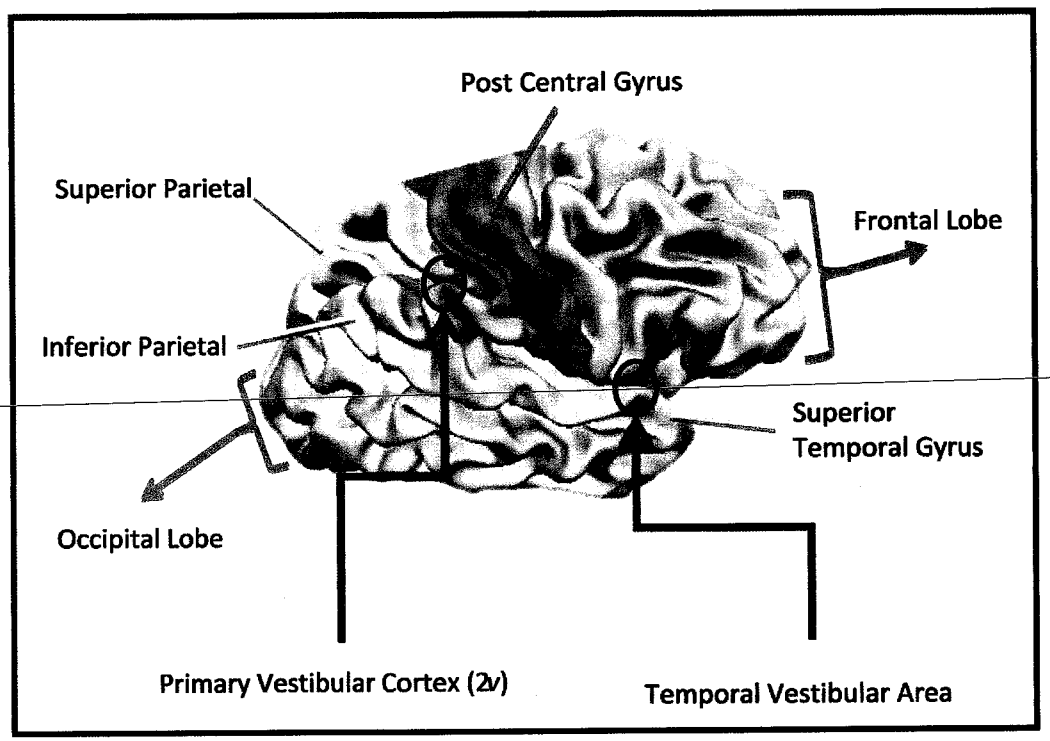


Figure 2.4: Labeled diagram of the brain regions

2.4.1.2 *Temporal Vestibular Cortex*

The temporal vestibular cortex is located on the superior temporal gyrus, anterior to the auditory area, as shown in Figure 2.4. The relationship between the temporal vestibular cortex and the primary vestibular cortex is not reported in depth. It has been observed that patients with tumor in this region often report feeling of vertigo or sensation of whirling and rotating in a quiet environment. It is reported that this region integrates information regarding vestibular input and other sensory inputs and is likely to function as vestibular association area.

2.4.2 Visual Regions of Cerebral Cortex

The occipital lobe is well reported as the primary visual cortex of human brains. This region is further divided into sub regions that have different visual functions. The study in this thesis is interested in the cortical regions that are responsible for ocular movements. In VIMS, visual sensation is more common and motion sickness is dependent upon conflict of visual and vestibular sensation, therefore regions of ocular movements are important.

2.4.2.1 *Frontal Eye Field Area (FEF)*

The Frontal Eye Field area (FEF) is located in the frontal lobe (Figure 2.4). Voluntary movements of eyes are caused by this region. If this region is externally stimulated, it causes movement of the eyes in upward direction, convergence, divergence of the eyes and pupillary changes.

2.4.2.2 *Preoccipital Area*

This area is located in both the parietal and occipital lobes and is involved in automatic movement of the eyes. This region is reported to be activated in optokinetic nystagmus. Any involuntary movement of the eyes with automatic gaze fixation would be controlled by this region. Thus, FEF and preoccipital area should communicate with each other when a person shifts from performing an automatic movement to a voluntary movement.

2.4.3 Basics of Heart Physiology

In this section, our aim is to understand the electrical activity of the heart for the recording of ECG. The heart is a blood pumping machine. It can increase and decrease the blood supply based on the physiological changes occurring in the body. The heart pumps blood at a rate of 70 - 80 beats per minute (bpm), commonly known as heart rate. The physiological changes encountered by humans due to fear,

excitement, exercise, etc. also affect the heart rate. The pumping action of the heart depends on the electrical activity of the muscles of the heart. This electrical activity of the heart can be recorded; and the recording is known as electrocardiogram [53].

A normal electrocardiogram produces a pattern of P wave, a QRS complex and a T wave (see Figure 2.5). A QRS complex can be used to determine the heart rate. For example, if the time between two adjacent QRS complex is 0.83 second, this gives a heart rate of 60/0.83 or 72 bpm. The heart rate is controlled by the autonomic nervous system, which is divided into sympathetic and parasympathetic nervous systems. The sympathetic nervous system increases the amount of blood flow while the parasympathetic nervous system decreases it. The features extracted from ECG will be discussed in Chapter 4.

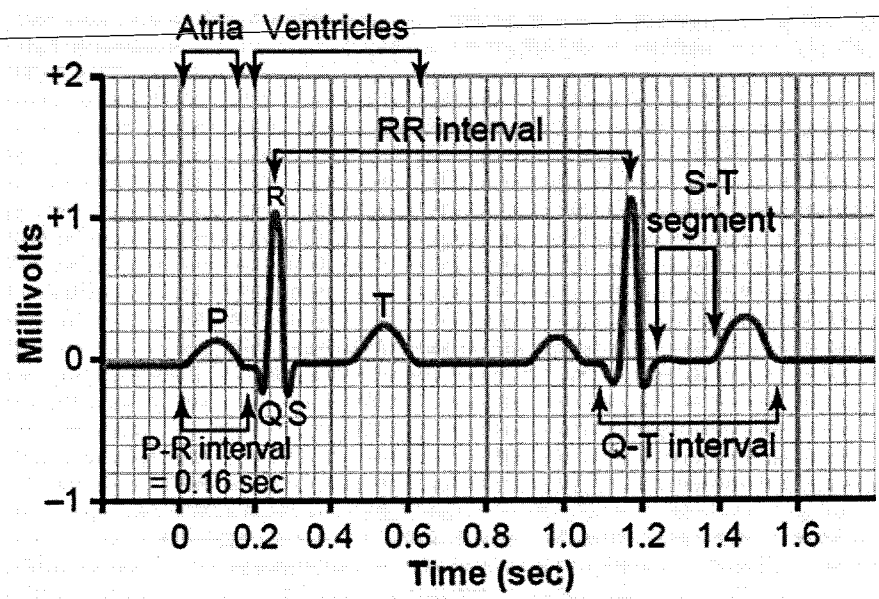


Figure 2.5: ECG wave pattern

2.5 Relationship of Visual and Vestibular Regions

It will be a great finding if any relationship or association exists between the visual and vestibular regions. According to the sensory conflict theory, the vestibular inputs and visual inputs integrate, and mismatch of this integration causes motion sickness.

If the inputs are originating from the described regions then the electrical activity of these regions must correlate. Therefore, it would be a good option to look at the electrodes that cover these regions.

CHAPTER 3

EXPERIMENTAL PROTOCOL

3.1 Research Design

Research design is the procedure that will be employed to conduct any study. From the objectives, it is evident that there should be two groups involved in the experiment. Therefore, an independent study with a parallel architecture was selected. A parallel study will ensure that subject selections do not overlap, that is if one subject is selected for the first case he/she cannot participate in the second case. The reason behind this selection is that the same stimulus (either the 2D or 3D version) shall be presented in both cases which can induce an effect of boredom for the participants who watch them a second time. There is also an effect of habituation that might occur which will reduce the VIMS effect of the movie. Hence, it was suggested that the study should be parallel-designed.

Secondly, participants selected from the population should be allocated blindly to the two conditions. There should not be any sort of bias in the study. Randomized Controlled Trial (RCT) will ensure this. In RCT subjects are randomly allocated to the groups. Thus, the research design was Parallel-Randomized Controlled Trials.

3.1.1 Parallel - Randomized Controlled Trial

In this experiment, participants were randomly allocated to 2D and 3D groups and were naïve to the viewing condition. Subjects allocated to one group were not allowed to participate in the other.

3.2 Sampling Frame

3.2.1 Study Population:

Students from Universiti Teknologi PETRONAS, Bandar Seri Iskander, Tronoh, Perak, Malaysia were recruited for selection in the experiment. The study was based on the following references:

- Students who are willing to participate should give their consent to take part in the experiment.
- Students who fulfill below mentioned selection criteria.

The experiment was conducted at the Department of Electrical and Electronics Engineering, block 22, level 2, Room no. 14, (Intelligent Neuro Signal and Medical Imaging Lab, Centre for Intelligent Signal and Imaging Research (CISIR), Universiti Teknologi PETRONAS) during the months of Nov to Dec 2012.

3.2.2 Sampling and Sample Size Calculation

Sample size calculation was done by PS (power and sample size) software, using uncorrected chi-squared test [54].

3.2.2.1 *Sample size calculation*

Sample Size formula

$$n = f(\alpha, P)\left(\frac{p_1(1-p_1) \times p_2(1-p_2)}{(p_1-p_2)^2}\right) \quad \textbf{(3-1)}$$

α = significance level, 0.05

P = power of the study, 80%

p_1 = probability of experiencing motion sickness in 2D case, 18.5 % fixed base simulators [55]

p_2 = probability of experiencing motion sickness in 3D case, 59.1 % [36]

n = 21 participants for one group

3.2.2.2 *Randomization Method*

Participants were allocated to either the 2D or 3D study using the stratified sampling method. Female participants were proportionally less than male participants. Therefore, to remove a gender bias from the study, stratified sampling was implemented. Through stratified sampling, the proportion of males and females in both the groups were equal and this was done using SPSS software.

3.3 Selection Criteria

3.3.1 Inclusion criteria

The following are the inclusion criteria for the participants:

- Subject with 18-40 years of age having normal refraction – Emmetropia (+1.00 D and -0.25 D) or corrected to normal vision [56]. Before the experiment, a complete eye assessment was performed by an ophthalmologist. This includes visual acuity, refraction and fundus examination. (See Appendix A for examination chart).

- Subjects whose susceptibility score is less than 30 as determined by Motion Sickness Susceptibility Questionnaire (MSSQ) [39]. (See Appendix B for the MSSQ).

3.3.2 Exclusion criteria

The following are the points that provide the exclusion criteria for the participants:

- Individuals who have seen 3D movies within the 3 months before the experiment.
- Subjects with refractive error i.e. Myopia, Hyperopia and Presbyopia.
- Subjects with eye diseases such as glaucoma, retinal and corneal disorder.
- Subject with history of eye surgery such as cataract surgery, cornea or retinal surgery.
- Subject with history of eye injury or trauma.
- Subject with any head injury or neurological disease like epilepsy, seizures and migraine.
- Subject with systemic problem such as hypertension, diabetes mellitus, asthma & heart disease.
- Subject with any ear problems or surgery.

3.4 Experiment Design Background

From the literature, it is clear that 3D movies produce symptoms of VIMS that can vary from one person to another. The symptoms that are mostly induced are visual and related to occulomotor system such as; Visual fatigue, eye strain, headache etc. VIMS is not limited to these symptoms, other symptoms like disorientation and nausea can be found. For this purpose, an experiment was designed that could induce motion sickness by watching a movie. The movie selected for the experiment was specially created to induce VIMS in participants [57]. The points considered during the experiment design are as follows:

- A large screen 3D TV to display the stimulus. Viewing on a large screen prompts viewers to have a feeling of involvement in the scene, as well as inducing higher levels of VIMS symptoms [15].

- The stimulus used was animated with specialized movements to induce VIMS. This reduces the time of the experiment as a normal movie viewing would take more time to induce symptoms of VIMS and the symptoms induced can be rated on a reasonable scale.

- EEG and ECG were recorded as the objective parameters while SSQ was taken at the end to compare the subjective ratings.

- EEG was selected as the major recording parameter because it records the brains neuronal activity with high temporal resolution.

- An EEG device with a dense array of 128 channels was selected so that brain activity with higher spatial resolution can be achieved.

- The participants were asked to give written consent before participating in the study. See Appendix C for the consent form.

- The maximum duration for experiment was two hours and participants were compensated for the time consumed.

The experiment flow diagram is presented in Figure 3.1.

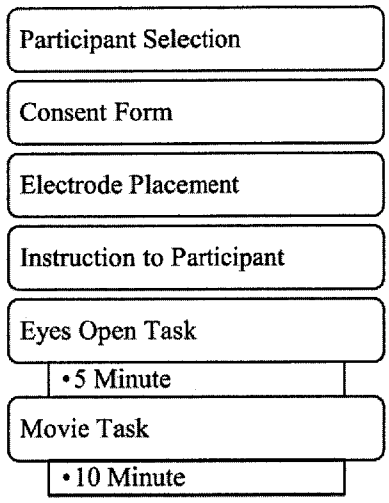


Figure 3.1: Flow diagram of the experiment.

3.5 Data Acquisition

The EEG recording was done using Electrical Geodesic Inc. (EGI) dense array EEG device. The recording net used was HydroCel Geodesic Sensor Net with 128 channels. The net uses saline electrolyte for routine recordings. Sampling rate was set at 250 samples per second. Raw data was recorded and stored on the hard disk drive for later use. A notch filter was used to remove line noise of 50 Hz. Average referencing was used during the recording. The electrode placement chart is presented in Figure 3.2.

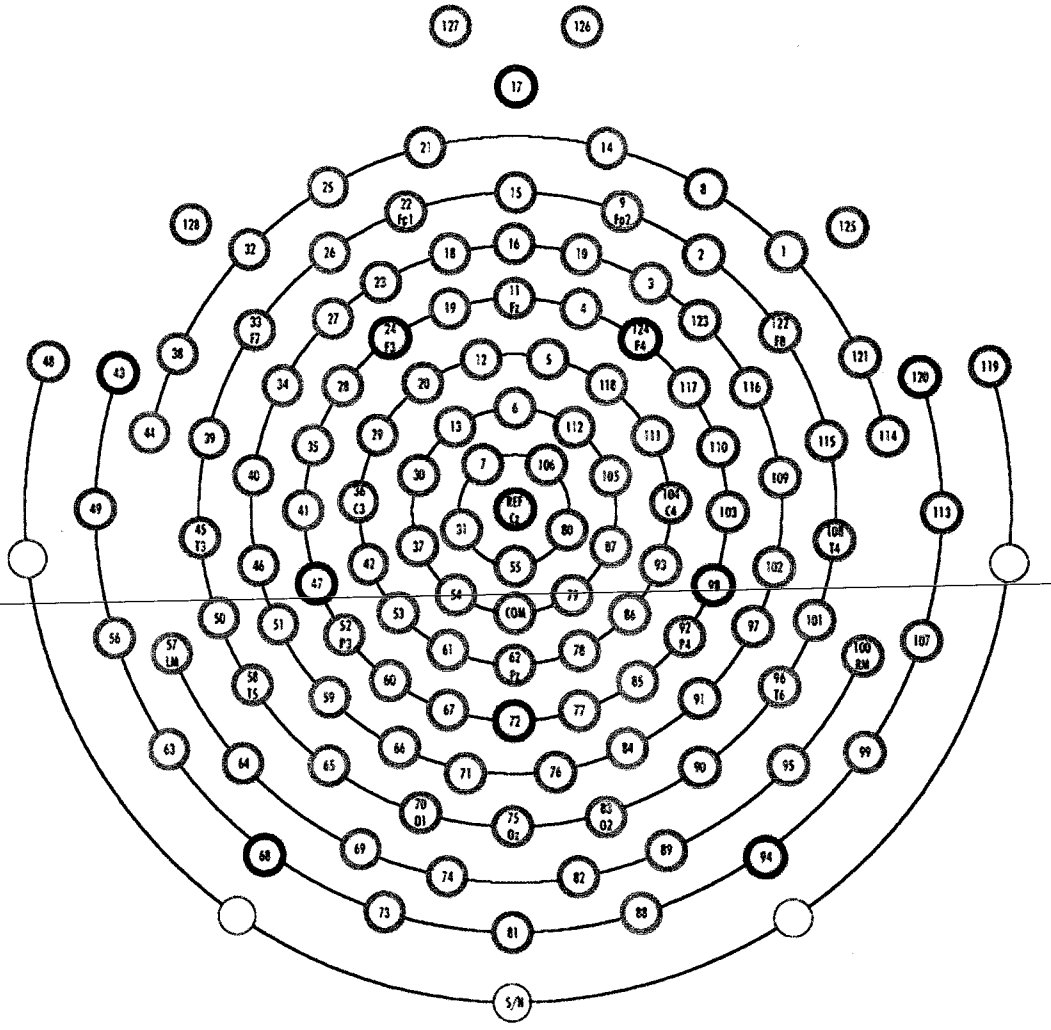


Figure 3.2: EEG electrode placement chart.

ECG recording was done via Ag – AgCl electrodes using additional input to the EEG amplifier using a Polygraphic Input Box. The electrodes were roughly placed above the clavicle and were adjusted to acquire the best ECG signal. Please refer to Figure 3.3 for electrode placement. Recording of the data was done using NetStation Software on a MAC based PC.

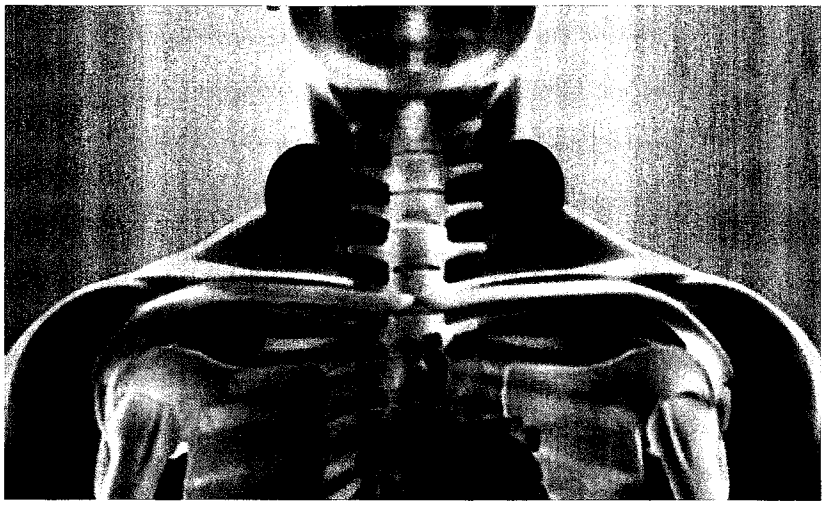


Figure 3.3: Electrode placement of ECG sensor, sensors are shown in black just above the clavicle on the neck region.

3.6 Visual Stimulus

The visual stimulus was shown on a 42-inches 3D LCD TV. The TV uses polarized glasses technology to create 3D images. The stimulus was displayed using the TOBII software. The stimulus was a view from a camera while it moves along a road, as shown in Figure 3.4. The camera was animated to have specialized movements along the pitch and roll axes. The camera was rotated alternately on the two axes with 30 degrees of amplitude and 0.167 Hz of temporal frequency. The stimulus was created in both 2D and 3D using 3D computer graphics software, Omega Space, Solidray Inc.

Figure 3.4: A view of the stimulus as seen by the participants.

It has been reported that VIMS can be easily induced with camera rotations along the pitch and roll axes [16]. The movie was composed for a duration of two minutes. In the first minute, the camera was rotated along the pitch axis and in the second minute, the camera was rotated along roll axis. The stimulus was repeated five times making the total duration to be ten minutes.

3.7 Hardware configuration

The data recording and stimulus presentation was synchronized using E-prime software. The synchronization of the two devices was done so that both would have the same starting and ending times. E-prime was used as the controller for initiating both the devices. E-prime, NetStation, and Tobii were connected to an Ethernet switch with user defined IP address. Before starting E-prime, both the NetStation and Tobii computers were setup to the trigger point. When E-prime executes, it sends a trigger each to the IP address of NetStation and Tobii to start the recording and display the stimulus simultaneously.

3.8 Diagram of Hardware configuration

Figure 3.5 shows the layout of the hardware configuration and Figure 3.6 gives a brief block diagram of the experiment.

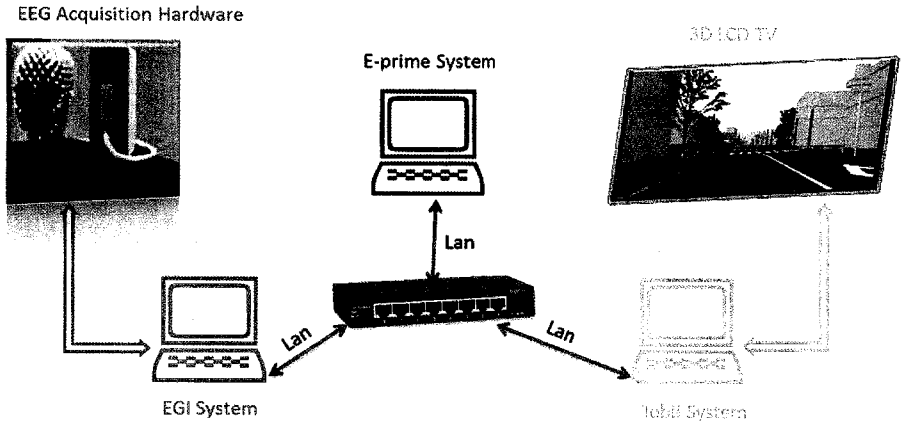


Figure 3.5: Hardware configuration of the three systems using a network adaptor through ethernet cables.

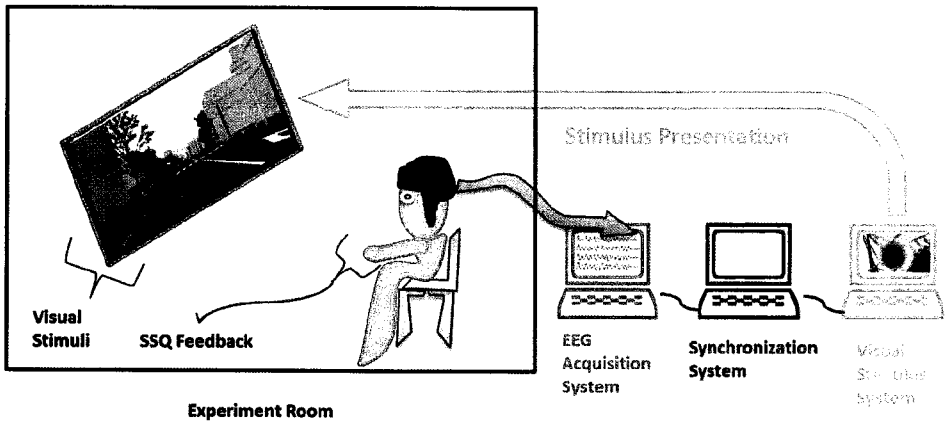


Figure 3.6: Block diagram of the experiment

CHAPTER 4

DATA PRE – PROCESSING AND DATA PROCESSING

This section provides a complete description on the subjective and objective data recorded. All the data was initially pre-processed before any further processing and analysis was performed. This chapter gives the details of pre-processing and how the analysis was done to obtain the results. EEG data analysis is discussed in detail as it was the main objective of the study. SSQ analysis was required to provide the ground truth for EEG results. Finally, ECG was analyzed to compare the results with the study in [57]. The analysis begins with the SSQ results then ECG and finally the features extracted from EEG are discussed.

4.1 Simulator Sickness Questionnaire (SSQ) Data

SSQ data was collected manually at the end of the experiment. Subjects were asked to read the symptoms carefully and rate their comfort level on the scale provided. See Appendix D for the SSQ.

4.1.1 Pre – Processing

Raw data for 46 participants was entered on MS Excel to get the final values of Nausea, Occulomotor, Disorientation and Total Score. The computed scores were finally analyzed on IBM SPSS software to find the significant mean differences between the 2D and 3D groups.

4.1.2 Analysis

The SSQ raw data was converted to the clusters of Nausea, Occulomotor and Disorientation. The conversion of raw data into the defined clusters is done using the formula given in [33]. Clustered Results from SSQ were exported to IBM SPSS software for final analysis. Independent sample t-test was applied on the data to find the significant differences between the 2D and 3D groups. Each cluster of Nausea, Occulomotor and Disorientation values were analyzed separately for independent sample statistics. Finally the total score of the SSQ was also compared.

4.2 Electrocardiography (ECG) Data

ECG analysis requires heart beat detection which can be used to find the heart rate variability. HRV analysis is a vastly used method among researchers. It provides a number of parameters that are used in identifying heart problems.

4.2.1 Pre Processing

To find the normal heart beat, a NetStation built-in algorithm was used. This algorithm gives an event log file that can be easily imported to MATLAB software. Further analysis was conducted on MATLAB.

4.2.2 Analysis

The ECG data recorded was analyzed to find the Heart Rate Variability (HRV) component, LF/HF ratio, which can be used as an index of sympathetic nerve activity. The QRS complexes detected were used to find the time interval between the two adjacent R waves. Next, the temporal frequency components of the R-R interval were calculated using Fast Fourier Transform (FFT) algorithm. It is assumed that the low frequency (LF) components are a marker of sympathetic modulations, which ranges

between 0.04 to 0.15Hz, while high frequency (HF) components are a marker of parasympathetic activity and ranges between 0.15 Hz to 0.4Hz [58]. It has been reported that heart rate variability can be helpful in predicting mental stress[59]. Therefore, if someone is watching a movie and suffering from sickness symptoms concurrently, he must be under stress, which can be detected from the HRV components.

4.3 Electroencephalography (EEG) Data

4.3.1 Background

Before proceeding to the processing and analysis of EEG, the features that are readily used in the studies of EEG should be discussed. In the literature review, the work done in the field of VIMS and EEG was discussed. Here, the features that are necessary to interpret the raw EEG data are presented. For this purpose, it is also important to have a little knowledge of how EEG is produced and recorded. The underlying electrophysiology of brain and the generators of scalp electric potentials should be understood before applying any technique to EEG raw data.

The brain can be divided into three main parts; cerebrum, cerebellum and brain stem. The main focus is the cerebrum, which is divided in to two halves called hemispheres. The outer part of the cerebrum is composed of the cerebral cortex. The Cerebral cortex is a folded structure having sulci and gyri. It is reported that most of the scalp potentials are recorded from the gyri [60]. The smallest unit of the brain is a neuron, which is an electrically excitable cell. It consists of an axon, cell body and dendrites. A dendrite receives a signal from other neurons through axons. The gap junction where the dendrite and axon joins is called the synapse. Cortical neurons can have up to 10^5 synapses. It has been discovered that a neuron has two types of inputs - excitatory or inhibitory. Excitatory Postsynaptic Potentials (EPSP) excites the target neuron to fire more action potential while Inhibitory Postsynaptic Potentials (IPSP) inhibits the target neuron from firing.

The first human EEG was recorded by Hans Berger in early 1920s. During the experiment, he discovered that brain waves produce signals which are near to sinusoidal signals (known as Alpha rhythms) in a wake state, even as the subjects are relaxed with their eyes closed [61]. The scientific community took 10 years to accept these scalp potentials as genuine brain waves. The scalp potentials are the recording of the underlying brain sources. When a number of neurons fire synchronously, then EEG electrodes can capture the electrical signals on the scalp. Thousands of neurons fire simultaneously to produce electrical signals that sum up to produce the EEG signal.

EEG uses a 10 – 20 international system to place the electrodes over the head. The electrodes are labeled according to the regions they cover. The electrodes are brought into contact with the head skin using some gel or salt solution which minimizes the resistance, providing a good conducting connection. The voltages from all the electrodes are then fed into a differential amplifier. The difference in the voltages between the recording electrodes and reference electrodes is amplified and digitized. The digitized data is then stored for future analysis. The frequency of the EEG signal can range up to 70 Hz.

There are a number of references used in EEG studies of which a few of them are Linked Ears or Linked Mastoid reference, Bipolar Recording and Average reference. Bipolar recording refers to potentials that are recorded between closely related electrodes. This technique is suitable for finding electrical changes within a specific region of the head. To improve the spatial resolution of the EEG using less number of electrodes, it is better to use bipolar recordings. In the Linked ears or Linked Mastoid reference, the reference electrode is usually placed on the ears or behind the ears on the mastoid bones. In [60], the authors explained the advantages and disadvantages of using a recording reference. From the discussed techniques a conclusion was drawn that Average reference is better, as compared to other techniques. It was also reported that an Average reference is preferred to be used with higher number of electrodes (i.e. up to 100 electrodes) [60].

4.3.2 Pre-Processing

Common artifacts that can be found in EEG readings are caused by eye blinks, muscle movement and line noise. The line noise artifact can be easily removed by applying a notch filter at 50 Hz. For the other artifacts such as eye blinks and muscle movements, different methods are available. To minimize muscle movement artifact, clear instructions were given to the participants not to move their head, swallow, yawn or blink during the recording. Head movements, swallowing and yawning are easily restricted; however, blinking is not in control of the participants. Thus data was checked for eye blink artifacts using NetStation built-in algorithm that marks the eye blinks. The event file for eye blinks can also be exported to MATLAB. NetStation uses Gratton et. al., algorithm to detect eye blinks [62]. The removal of eye blink artifacts was carried out using the same algorithm which is a regression based eye blink removal [62]. The blinks were already marked and the eye blink channel was specified. The algorithm subtracts the amplitude of the eye blink from the rest of the channels particularly in the regions that are marked with eye blinks. The complete flow chart for preprocessing is given below :-

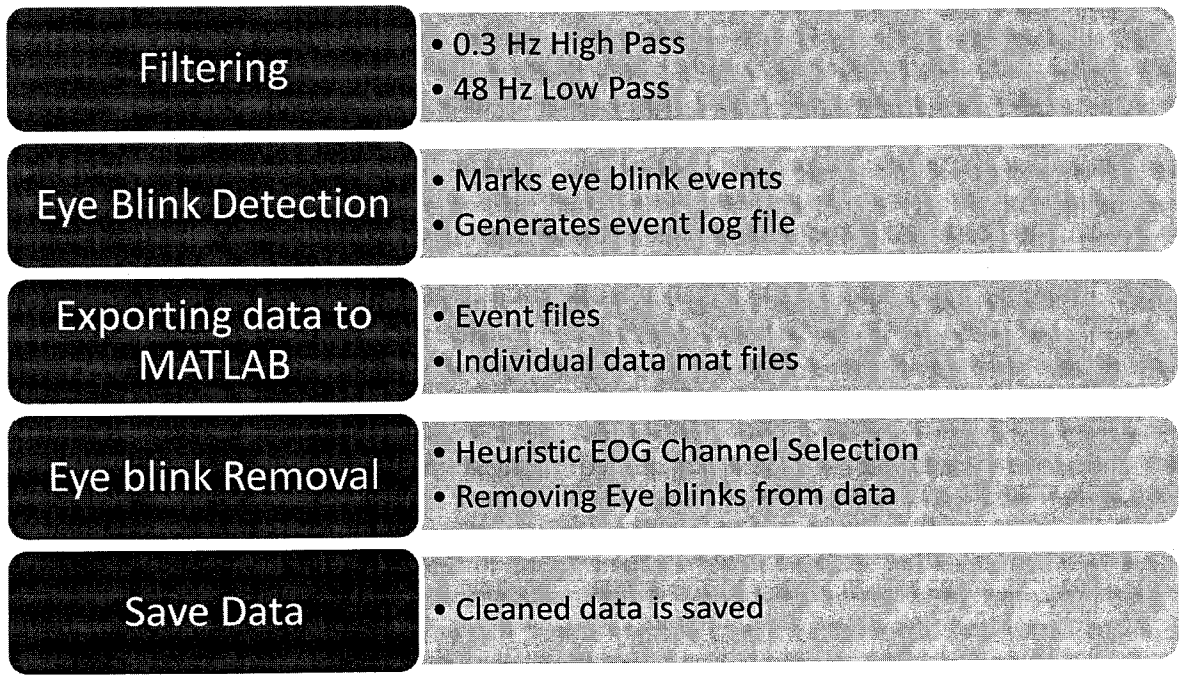


Figure 4.1: Steps in pre-processing of the EEG data.

4.3.3 Features Extracted

In this section, the features that are extracted from the EEG signals are discussed. The frequency analysis of the EEG signal was performed. In frequency analysis a time domain signal is decomposed into its frequency components using Short Time Fourier Transform (STFT). The transformation into frequency domain was done by using Welch's method. This gives the Power Spectral Density (PSD) of the signal over specified frequency bands. The description of the methods and the features are highlighted below.

4.3.3.1 *Frequency Feature*

A signal in time domain can be described as a mixture of sine and cosine waves. Therefore, any sinusoidal signal $\chi(t)$ can be represented as

$$\chi(t) = A\sin(2\pi ft + \Phi) \qquad \textbf{(4-1)}$$

Equation (4-1) has three parameters; Amplitude (A), Frequency (f) and Phase (Φ). A Fourier transform can decompose a time signal into its frequency components. The signals recorded from EEG are assumed to be sinusoidal i.e., composed of different frequency bands having rhythmicity. This regularity of a signal can be easily viewed by decomposing the signal into its component of sine and cosine functions as given by Fourier analysis.

From the Fourier analysis, one can easily find the amplitude spectra or power spectra of the signal. These analyses are more often computed using FFT. An EEG recording can be for duration of 3 minutes like the "eyes open" task and may even last up to hours and days. Therefore, it is not feasible to directly apply FFT over the whole recording. Instead FFT is commonly computed by dividing the signal into epochs of shorter length usually 1 to 8 seconds. Shorter epochs in the signal produce artifacts due to sudden changes at the end of the epoch. To remove these artifacts windowing is used. Windowing helps in smoothing the signal. It is assumed that EEG is a random signal generated by stochastic process. Therefore, it is better to obtain the power spectrum of the signal instead of the Fourier transform [63]. In this study Welch's

method was implemented to obtain the power spectral density of the EEG signal which is described below.

Welch Method

In Welch's method, the input signal x is divided into k overlapping segments according to window size and its overlapping integer (or their default values). If the window size is larger than the number of FFT points (NFFT), the signal is divided into NFFT–length segments and then, the last segment is padded with zeros.

The specified (or default) window is applied to each segment of x.

1. An N-point FFT is applied to the windowed data.
2. The (modified) periodogram of each windowed segment is computed.
3. The set of modified periodograms is averaged to form the spectrum estimate $S(e^{j\omega})$.
4. The resulting spectrum estimate is scaled to compute the power spectral density as

   $S(e^{j\omega})/F$, where F is

   I. 2π, when you do not supply the sampling frequency

   II. Sampling frequency, when you supply the sampling frequency

The number of segments k that x is divided into is set as:

- Eight, if you don't specify window length, or if you specify it as the empty vector "[ ]".
- $k = (m - o)/(l - o)$ if you specify window as a nonempty vector or a scalar

In this equation, m is the length of the signal vector x, o is the number of overlapping samples, and l is the length of each segment (the window length).

4.3.3.2 *Absolute Power*

The corrected data obtained from a total of 45 participants, 22 from the 3D-viewing group and 23 from the 2D-viewing group, each having data from 128 electrodes, were used to compute the absolute power. A time frequency analysis was performed over an epoch of 1 minute. For each epoch, PSD was computed using Welch's method using a window size of 500 samples and overlap of 50%. Thus, a 600 seconds recording yields 600 points. The frequency range was divided into delta (1.0 - 3.5 Hz), theta (4 - 7.5 Hz), alpha (8 - 12 Hz), beta (12.5 - 25 Hz), and high beta (25.5 - 30 Hz) bands.

4.3.3.3 *Relative Power*

Relative power can be defined as the ratio of a band power over the total power. It can be expressed as:

$$\left(\frac{Band\ Power}{Sum\ of\ power\ from\ 1\ to\ 30\ Hz}\right) \times 100 \qquad \textbf{(4-2)}$$

Relative power gives an idea of the actual contribution of a particular band in the overall EEG. It can be better observed if measured with small time intervals which can depict change in power contribution over time.

4.3.3.4 *Coherence*

The brain is largely interconnected with neurons communicating within different regions of the brain. Since there is a structural connection within the brain this connectivity is reflected through synchronous activity of the neurons. To interpret the connectivity between the regions it is necessary to evaluate them in terms of frequency bands. For example, in resting state with eyes closed synchronized alpha rhythms are produced in the occipital lobe at a frequency of 10 Hz. The information relying within the brain regions can be understood by analyzing the synchronous

activity of the two regions. This synchronous activity of the signals recorded from the two regions is computed by the function named coherence.

Coherence is a measure of phase synchrony between two different time series. If the phase difference between two time series is the same, then coherence will be equal to 1. If a signal is composed of only one frequency component, then at that particular frequency the coherence of the signal will be 1 provided the phase difference remains fixed. Coherence is usually computed over epochs and then averaged over the observations; therefore, coherence is a statistical measure. Mathematically coherence is can be represented as,

$$C^2(f) = \frac{|C_{xy}(f)|^2}{C_{xx} \times C_{yy}} \quad \textbf{(4-3)}$$

where C_{xy} is the cross-spectrum of the two signals X and Y. C_{xx} is the auto-spectra of the signal X and C_{yy} is the auto-spectra of the signal Y.

Equation (4-3) follows closely from the equation for a Pearson correlation coefficient (squared). The coherence is a more detailed measure because it is computed in terms of frequencies. The brain shows different properties at different frequency band therefore measuring the connectivity of two signals in relation to their frequency bands provides a clear picture of connectivity. Coherence can be easily computed using FFT algorithm. First the auto-spectrum of the two signals is computed. The auto-spectrum is computed in terms of power spectra as defined above. Then the cross-spectrum of the two signals together is computed as follows,

$$C_{xy} = \sqrt{(cospectrum(f)^2 + quadspectrum(f)^2)} \quad \textbf{(4-4)}$$

where cospectrum refers to the in-phase components of the signal and quadspectrum refers to the out-of-phase components of the signal.

This states that coherence is normalized amplitude of the cross-spectrum which is a complex number.

4.4 Feature Selection using Hypothesis Testing

Before discussing the details of feature selection a brief introduction of hypothesis testing is provided.

4.4.1 Hypothesis Testing

The t-test examines two hypotheses:

I. Two groups have equal mean (null hypothesis)

II. Two groups have unequal mean (alternate hypothesis)

Acceptance or rejection of these hypotheses is based on the result of the significance value also known as p-value. If the p-value is less than 0.05 the difference in the mean is reported to be significant, thus accepting the alternate hypothesis.

4.4.2 Feature Selection

The third objective of this study is to propose an objective indicator of VIMS using EEG signals. This means that those subjects who rated higher in symptoms of VIMS can be classified from those who reported lower in symptoms. To achieve this objective, all participants (2D and 3D) were categorized into two new groups. The group division is based on the ratings of the total score of SSQ. Those who reported higher in symptoms of VIMS were placed in the High group (24 participants) whereas, others who reported lower in symptoms of VIMS were placed in the Low group (21 participants). A rating of 35 was selected as the threshold for group division. In this way a two class problem was posed into a classification algorithm.

The same features discussed above were used for classification, which are absolute and relative power except coherence. Coherence is not used in classification because the result is not significantly different. The feature matrix is derived from features that were calculated over electrode locations for every one minute of the data.

Initially a total of 12800 (128 electrodes x 10 minutes x 10 attributes) features were obtained for each participant. Some of the electrodes (having artifacts) and time points of 1, 2, 9 and 10 were removed from feature matrix. An independent sample t-test was then applied on the remaining features.

A two tailed t-test with unequal variances was applied on every feature element in the two groups of high and low participants. The p-value of the outcome was set to a threshold value of 0.005 to select features that are maximally separable. This gives a total of 17 features that can be used to classify the data. Table 4.1 shows the electrode locations, time points and attributes which are selected after hypothesis testing. The location of the electrodes can be found in Figure 3.2.

Table 4.1: Features Selected after Hypothesis Testing

Electrodes	Time (min)	Attributes
2	6	RA
9	7	RB
22	7	A
23	7	RA
26	7	RA
29	3	RT
30	3	RT
33	8	RA
35	3	RT
36	3	RT
51	7	RA
59	7	RA
87	3	RT
97	8	RT
103	5	RT
105	5	RT
108	8	RA

R = Relative, A = Alpha, B = Beta, T = Theta

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Simulator Sickness Questionnaire (SSQ) Results

The SSQ scores for 19 participants from 2D movie-viewing and 20 participants from 3D movie-viewing are compared. The average SSQ scores for the 2D and 3D groups are presented in Figure 5.1. The figure shows sub scores for nausea (N), occulomotor (O) and disorientation (D) symptoms and also the total score (TS) from the SSQ. An independent sample t-Test was applied to find the difference between the 3D and 2D condition. The result shows that there is a significant difference in the mean score of nausea and total score (p-value < 0.05). This result is in agreement with the results from [57].

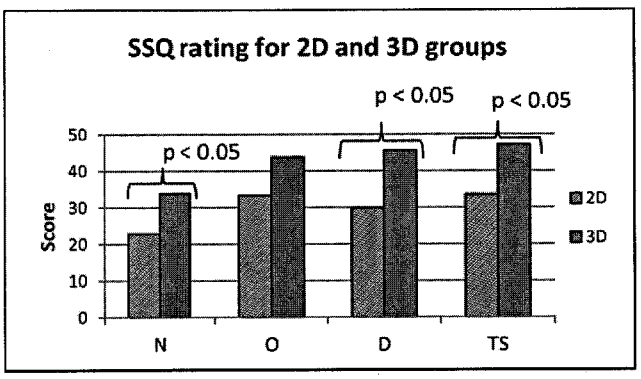


Figure 5.1: Average SSQ score for 2D and 3D condition

5.2 Electrocardiography Results

The mean values for LF/HF ratio for 2D and 3D VIMS condition are presented in Figure 5.2. The result indicates a significant difference at minutes 4, 7, 8, and 9 with p-value < 0.05. On average, the LF/HF ratio in the 2D condition is relatively higher than in the 3D condition.

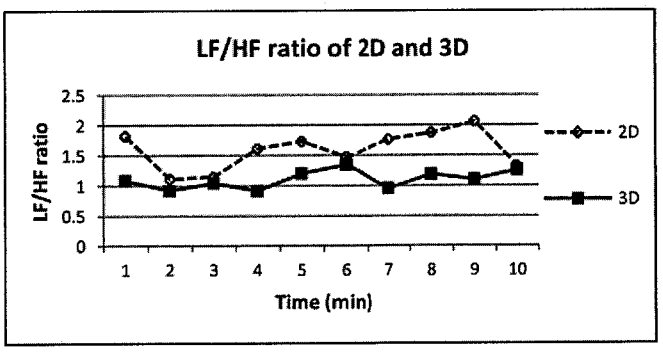


Figure 5.2: Ratio of LF/HF for 2D and 3D movie watching for VIMS condition.

The sympathetic activity helps the heart to work in stressful conditions by increasing the cardiac output. Conversely, the parasympathetic activity brings the heart activity to rest condition. Parasympathetic activity helps in preventing stressful conditions[53]. Since the ratio of LF/HF is higher in 2D-viewing than in 3D-viewing, HF is more dominant in the 3D condition. HF is accepted as the contributor of parasympathetic activity.

Participants were asked to sit in relaxed position and were naïve of the actual content of the movie. So if there is no adverse effect of stimulation on the participants the pumping activity of the heart should be normal. It can be interpreted that if there is no stressful condition on the participants, the parasympathetic system should not be activated. According to the curve of the 2D condition, initially the LF/HF ratio was high for the first minute and then drops down. Later on the LF/HF ratio increased which shows that LF is comparatively increasing than HF and hence the vagal activity is not very dominant. This means that the parasympathetic activity is not required to counter balance the sympathetic activity.

With the exception of minutes 5 and 6, the LF/HF ratio of the 3D condition is alternately increasing and decreasing, which shows that the sympathetic activity is counter balanced as each minute progresses. This shows that the parasympathetic nerve is continuously activated to bring the heart to resting condition.

The interpretation of LF and HF plays a crucial role in the findings. HF has been reported to increase with rotational stimuli while LF (when expressed in normalized units) should be increasing with mental stress [64]. Increase in sympathetic nervous activity has also been reported during motion sickness in virtual reality environments but results are not in relation with subjective ratings [65]. Increases in HF power have also been reported before generation of strong nausea [66]. These results do not have strong correlation with each other. The reason behind different results can be due to different experimental protocols. Therefore, the measure of LF/HF ratio over time would not be a very suitable measure for VIMS.

Therefore, it is important to have other measures such as visual responses and EEG signals that change in parallel to ECG signals and can help in identification of VIMS. In [67] an experiment involving a video game provides a relation between the two objective measurements, which are EEG and ECG.

5.3 Electroencephalography Results

Three parameters were computed to understand the underlying changes of the brain that might occur in VIMS condition. These parameters include Absolute power, relative power and coherence. Absolute power and relative power can be subdivided into delta, theta, alpha, beta and high beta band. The discussion on each of the parameter will be done separately in the next sections for better understanding of the results.

5.3.1 Absolute Power

Absolute power of the EEG signal was computed in short time intervals of 2 seconds with an overlapping window of 50%. The total duration of the signal was 10 minutes i.e. 600 seconds. For each participant, the absolute power was calculated for 128 electrodes, and decomposed into five bands. The power in every one minute was averaged to get only 10 values corresponding to 10 minutes of the data. This reduces the data into a matrix of 128 × 10 elements in five different bands. The band power of each participant was averaged over electrodes to produce an averaged band power of a group. This resulted in 10 minutes of data with each minute having 5 different bands. Each band has data from 128 electrodes. Data from each electrode is averaged over all the participants in that group to give one value. The data from each power band was used to produce the topographic scalp maps. 128 electrodes are used to plot the topographic maps in every one minute sample. This produces 10 topographic maps for one band.

In a similar fashion, a two independent sample t-test was applied to the data of eyes open and movie condition to find the significant changes in 2D-viewing and 3D-viewing data. Every one minute of the data is compared with eyes open condition. The p-value was computed for each minute of data for each electrode position. We then coded the different electrode positions as follows. If there is no significant difference between the two conditions for that electrode position, the coded value is 0

(green). The electrode position is coded as +1 (orange) if the average absolute power is significantly higher in the VIMS condition, and -1 (blue) if the average absolute power is significantly lower in the VIMS condition. The significant topographic plots which were created from these results are presented in Figure 5.4 and Figure 5.5. The annotation V(number) is the representation of VIMS topomaps with number representing the recording minute. Each of the frequency bands will be analyzed separately in the next subsections. Figure 5.3 shows the color representation for the topomaps.

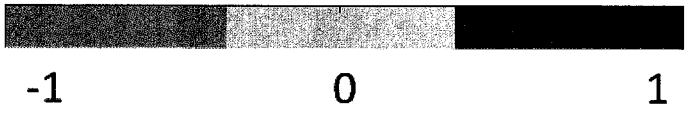


Figure 5.3: Color code of the topomaps

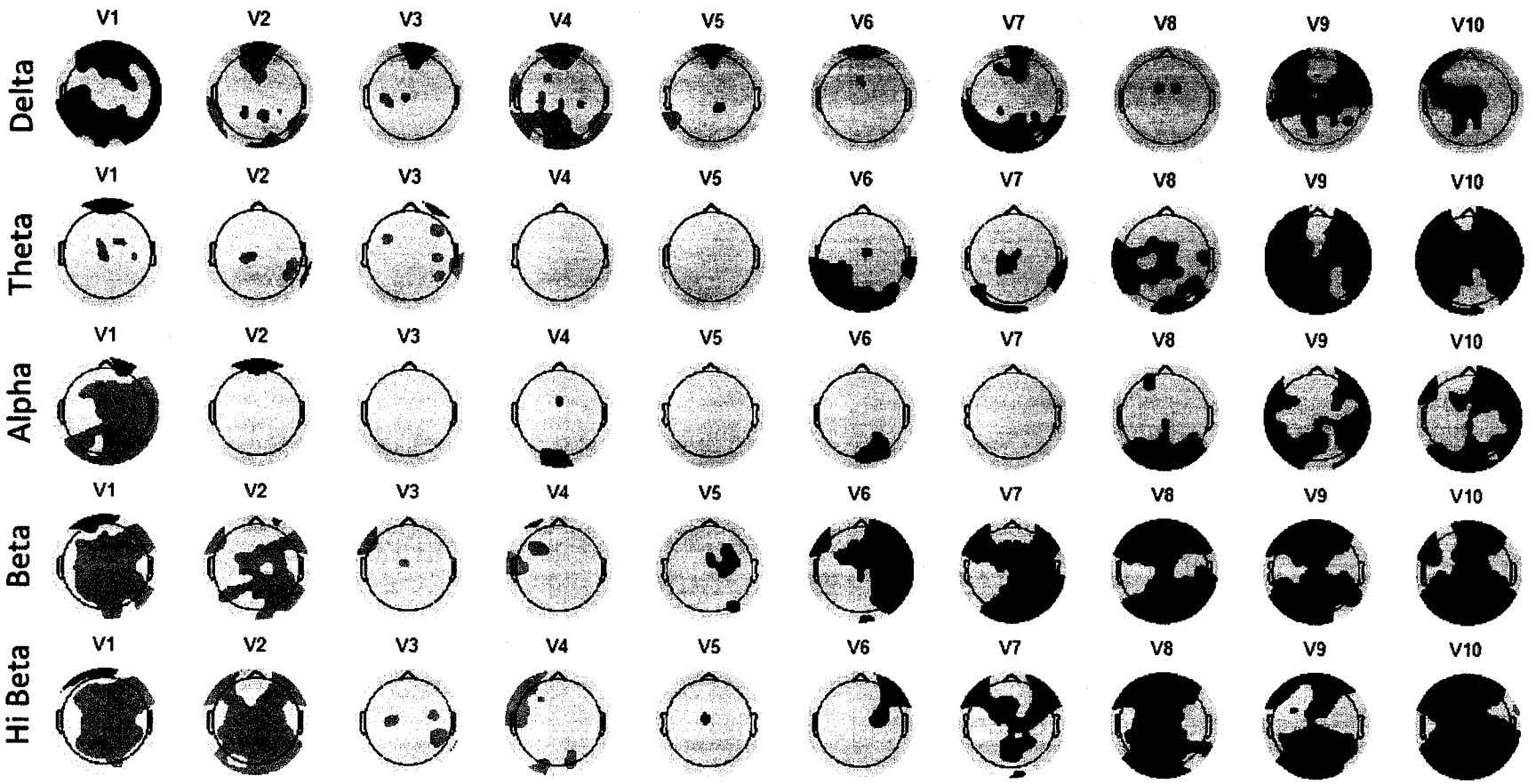


Figure 5.4: Average absolute power comparison of baseline and 2D group

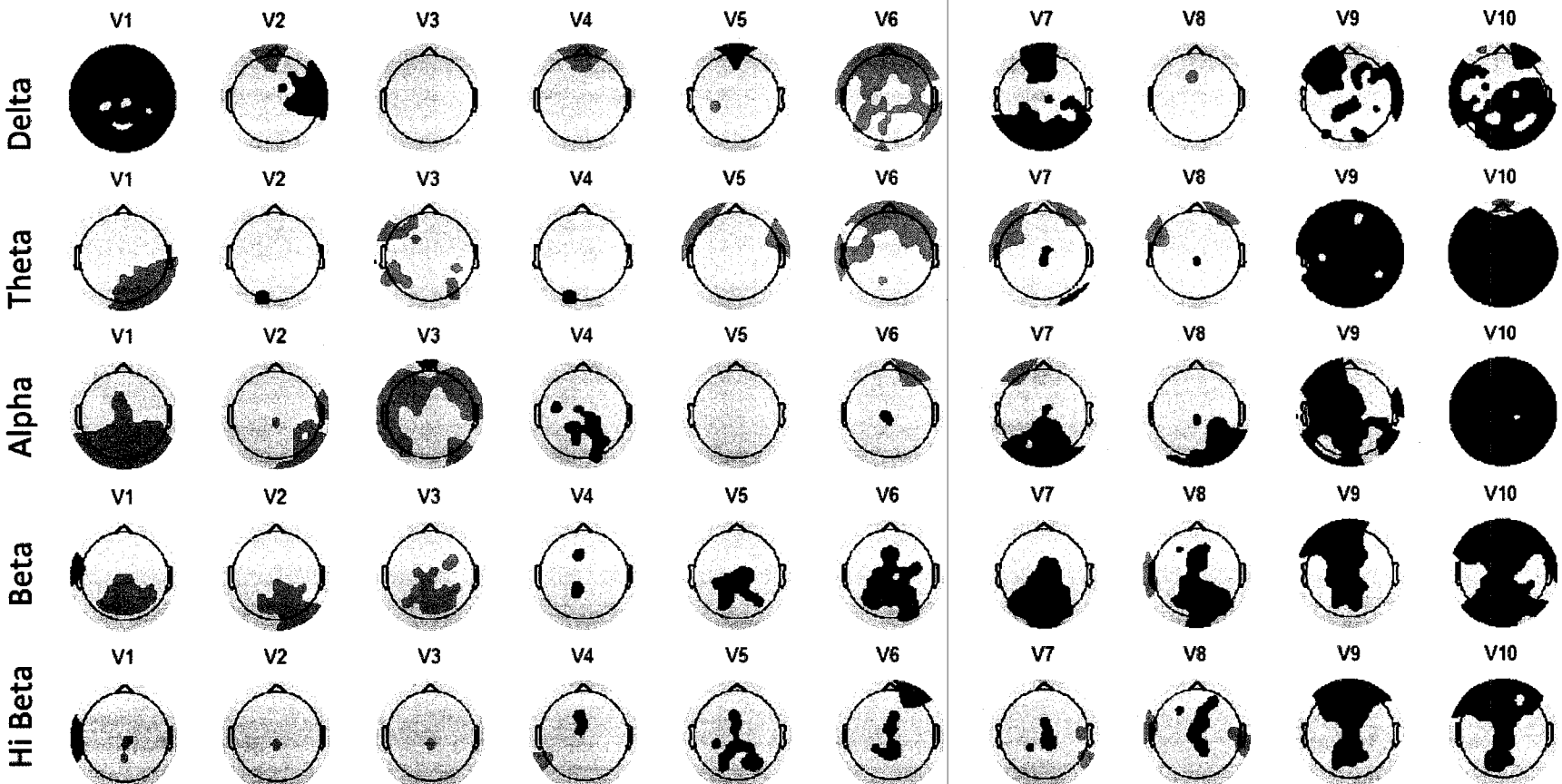


Figure 5.5: Average absolute power comparison of baseline and 3D group

5.3.1.1 *Delta Band*

From Figure 5.4 and 5.5 it is observed that delta band has a pattern throughout the VIMS condition. Comparing it with the movie task it is found that whenever the movie is in alternating phase the pattern of delta band changes. This pattern is visible in both 2D and 3D VIMS condition. The first phase of the movie was vertical movement of the camera along the pitch axis. In this phase the gaze of the subject could not be fixed on the screen as the view of the road was continuously moving up and down. Therefore, if the subject tried to fix their gaze there was still the chance of involuntary vertical eye movements.

Channels that have eye movement and eye blink artifacts are discarded from these topomaps. In the first minute of both the 2D and 3D condition, there is high activation in the delta band in certain regions of the brain. In the second minute there is less or insignificant delta activation in both 2D and 3D condition. Furthermore, compared to the eyes open condition, the delta band is clearly less activated in those regions. There is higher frontal delta activity during the odd minutes while frontal delta activity is lower during the even minutes. Since the phenomenon is found in both of the 2D and 3D conditions it is concluded that the vertical movement of the camera along the pitch axis causes a rise in the delta activity in the frontal region. Consider the even minutes of the movie in which the camera is moving in the roll direction. The center of the screen is almost fixed at a point while the rest of the surrounding is moving. If the subject fixates at the center of the screen, then this is similar to the baseline condition in which subject was asked to look at a particular point. The activity in VIMS case should be similar or higher than the baseline condition as subject was looking at images of moving stimulus. The brain encounters a problem when looking continuously at the images moving in the vertical direction and this increases the delta power in the frontal region as shown in Figure 5.4. In the alternating minute, the eyes do not move very much, so delta activity reduces compared to the normal baseline condition as the activity is decreased. The significant difference in the even minutes of the movie where the mean value of the VIMS is less than the mean value of the

baseline condition is assumed to balance the higher activity of the odd minutes. Comparing these findings from the literature presented in Table 2.5 it is found that increase in delta power is mostly reported in the frontal and temporal regions. This gives us an insight that the higher delta activity in VIMS condition occurs during vertical movement of the camera while delta activity decreases in rotational movements because stimulus becomes less effective.

5.3.1.2 *Theta Band*

In Figure 5.4 the topomaps show an increase in theta power compared to the baseline condition in the 6th, 7th, and 8th minutes in the posterior regions of the brain, while in Figure 5.5, the topomaps show decreased theta power in the 5th, 6th, 7th and 8th minutes in the fronto-temporal regions. The topomaps of the theta band power are different in the 2D and 3D conditions. In the literature, there are contradicting reports on the behavior of theta power during motion sickness condition. In [26-28, 43] it is reported that theta power increases over baseline condition in the frontal regions while [14] reports that theta power decreases in electrode Fz, as motion sickness increases. These results are contradictory and have ambiguous outcome that whether an increase in theta causes motion sickness or decrease in theta power causes motion sickness. In this work, an increase in theta power in posterior regions of the 2D group cannot be regarded as a motion sickness indicator as the above mentioned authors report an increase in power in the frontal region. In 3D group, participants reported more symptoms of motion sickness in the SSQ compared to the 2D group, but the power is decreased in the frontal region. This is similar to the results from [14] in which theta power decreased in Fz electrode while motion sickness rating increased.

5.3.1.3 *Alpha Band*

In [43] it is reported that alpha power increases in the parietal region with increase in subjective motion sickness level. In our study alpha power gradually increased in both 2D and 3D groups. Critically analyzing the significant topomaps shows that from the

4^{th} minute onwards alpha power increases in the posterior regions of the brain. In the 2D group, the 4^{th}, 6^{th}, and 8^{th} minutes of alpha power shows increased activity in the occipital region. Similarly, in the 3D group, it increased in the occipital regions in the 4^{th}, 7^{th}, and 8^{th} minutes. VIMS might have an effect on alpha power in the occipital region but studying the occulomotor part of the SSQ rating, it is found that the SSQ score reported by both groups are not significantly different. Therefore, the alpha power in occipital region is almost similar in both 2D and 3D groups.

5.3.1.4 *Beta Band*

Beta power is not very common in the study of motion sickness as it is mostly related to complex task and brain activity in cognitive states. The effect of beta power was studied because they are related to mental activity, cognition and awareness. Figure 5.4 and Figure 5.5 show that beta power gradually increased with time in all the brain regions in 2D group, while in the 3D group it did not increase in the frontal region.

5.3.1.5 *High Beta Band*

High beta shows a similar pattern to beta in the 2D group, while in the 3D group high beta activity is only significant in the central region. The effects of high beta have not been studied in motion sickness research so far. The result of the 3D group shows that in the high beta band, brain regions are not significant except central. Therefore, changes in high beta band cannot be reported as a part of motion sickness condition.

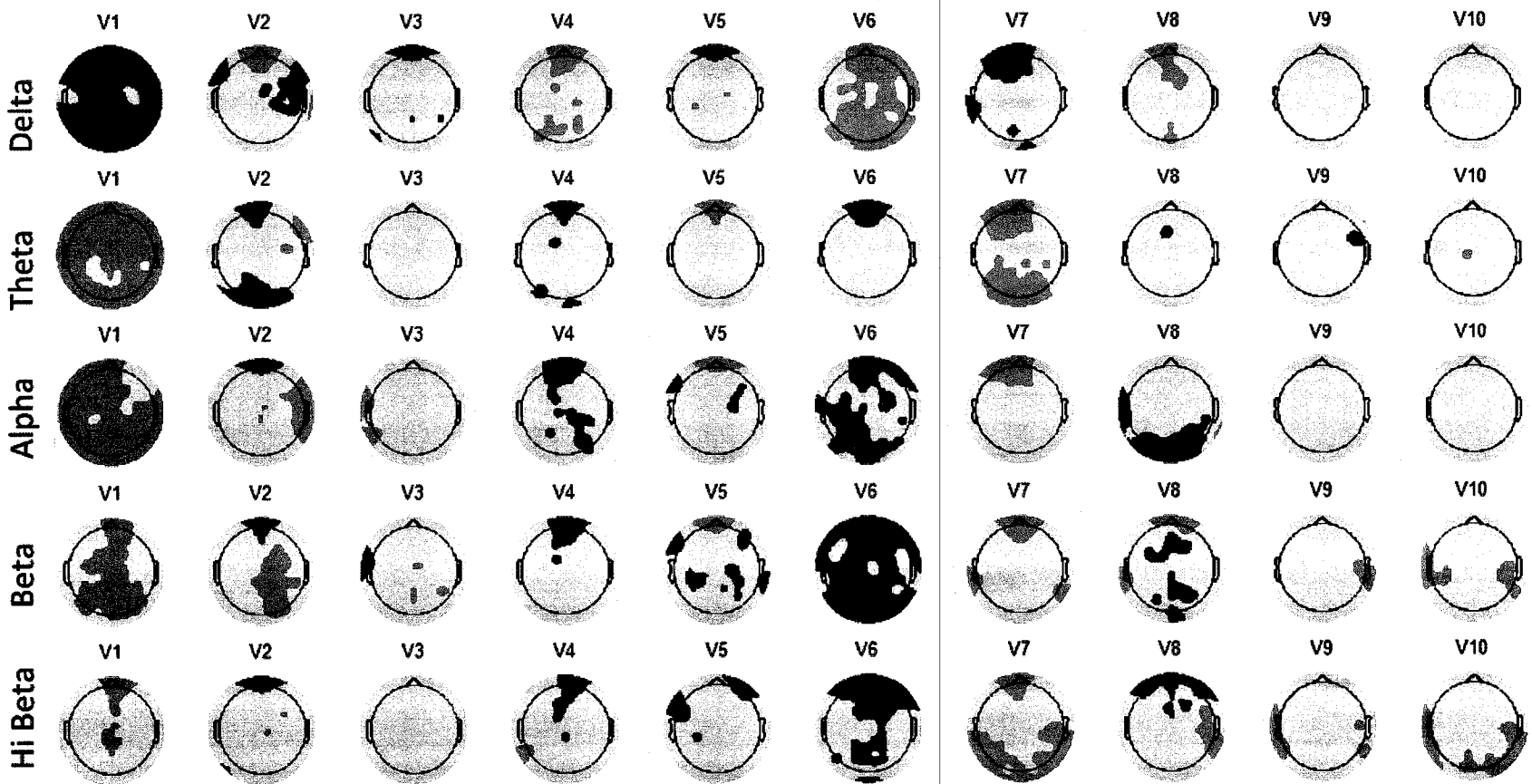


Figure 5.6: Average relative power comparison of baseline and 2D group

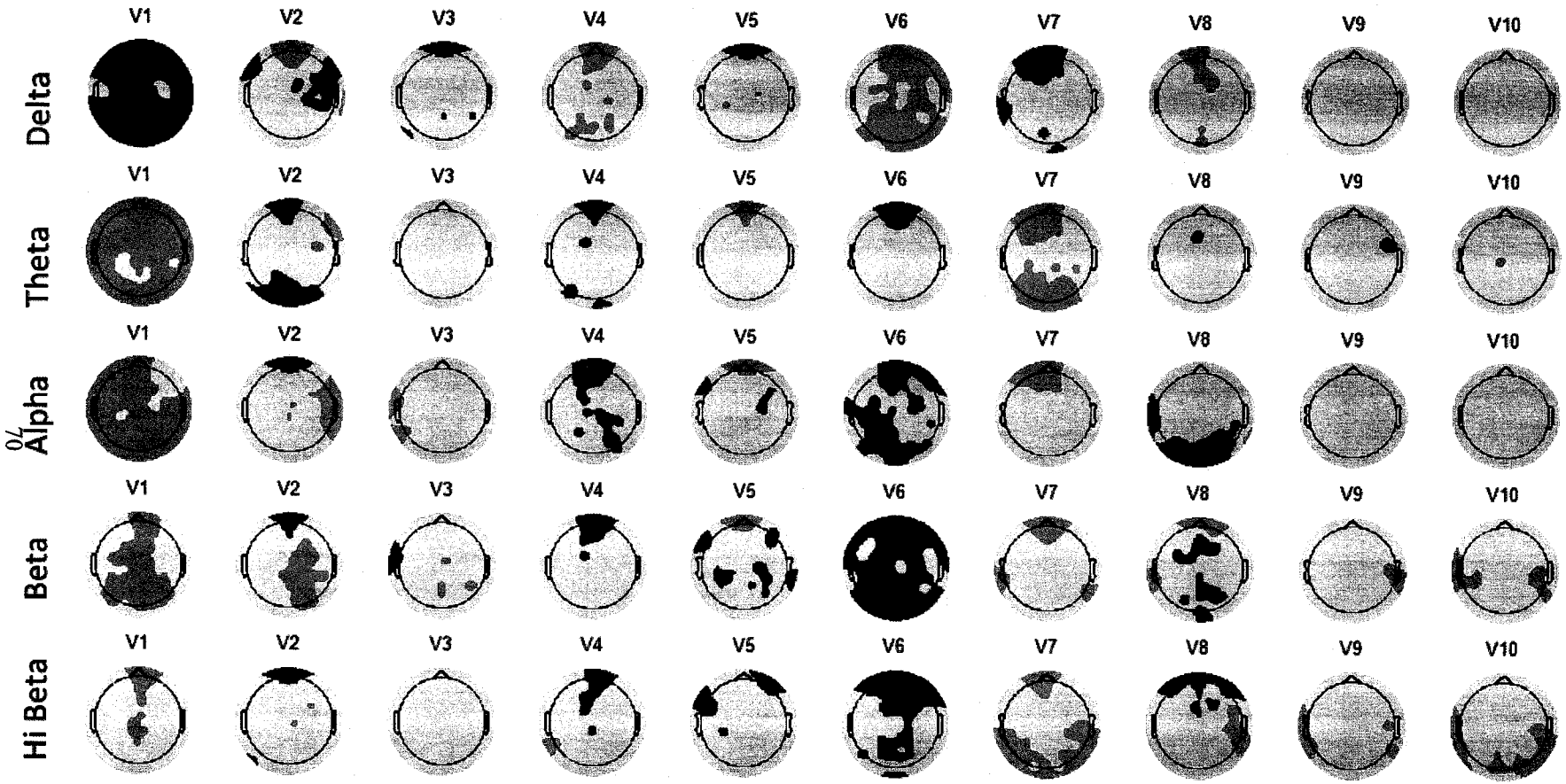


Figure 5.7: Average relative power comparison of baseline and 3D group

5.3.2 Relative power

Relative power is also computed in a similar manner as absolute power. Relative power is a percentage distribution of each band hence all the bands have to be interpreted together. Therefore, it is important to look at all bands at one time. Figure 5.6 and Figure 5.7 give an idea of how the relative power changes in the brain regions.

The relative delta power shows similar trends to the absolute delta power. An alternating change of power in the frontal region is prominent in both 2D and 3D conditions, as can be visibly seen on the topomaps. The first minute of both 2D and 3D conditions shows high activity in the delta band. This may be due to the introduction of the visual stimulus. Comparing the relative power of other bands in the first minute shows a similar pattern distribution like delta power but in opposite polarity. From the second minute in 2D group, the percentage distributions of bands are not very significant. Only frontal region shows a pattern which is inconsistent in some minutes. The percentage distribution is more consistent in 3D group. Starting from the first minute the trend follows as an alternate change in almost every band until 7^{th} minute. Since there is no other pattern found in the relative power it is difficult to conclude from these results.

Now comparing the other regions of the brain in both groups, most of the regions do not show significant results and have the same power distribution as in the baseline condition. Alpha band shows an increase in the power of the 2D group in the 2^{nd}, 3^{rd}, and 4^{th} minute. This change may have occurred due to adaptation to the stimulus and it is also possible that it represents motion sickness. It is reported in [43] that alpha power increases with subjective level of motion sickness. After the fourth minute the power of alpha band doesn't change in any of the regions, which indicates that the increase in the alpha power is not due to motion sickness. So the change in alpha band power for the first three minutes can be due to adaptation of the brain to the stimulus.

In the 3D group, the difference of relative power in the last four minutes is more visible in the temporal regions. The beta and high beta band powers are significantly low in the temporal regions in the 3D group. It is already discussed that the temporal region consists of a temporal vestibular cortex that is involved in body positioning. This region provides information to the sensory vestibular cortex about the orientation of the body posture. It is reported that beta waves are related to postural stability [68] and that lower levels of beta and high beta bands in this region can reduce the sense of body positioning and introduce effects of disorientation or dizziness in the subjects.

5.3.3 Coherence

Since the electrodes in a 128 channel EEG system are in very close vicinity to neighboring electrodes, the coherence is calculated in selected electrodes as in Figure 5.8-D. These electrodes are selected according to the international 10-20 system. Two types of coherence values are calculated - inter hemispheric coherence (Figure 5.8-A and B) and intra hemispheric coherence (Figure 5.8-C). Coherence within these electrodes was averaged between participants of the 2D and 3D groups. Independent sample t-test was applied to evaluate the significant difference in the coherence of different electrodes.

literature of section 2.4.1 it is found that the temporal, parietal and occipital regions should have some communication in motion sickness condition. Excluding alpha band rest of the bands show a significant difference in T5-P3 and excluding high beta band in T5-O1. In the 3D group, both electrode pairs give significantly high values in the delta, theta and beta bands. This shows that left temporal region is communicating with occipital and parietal region. According to section 2.4.1, the temporal lobe has the vestibular cortex and the parietal lobe has the primary vestibular cortex, which work together with visual and somatosensory regions. These areas have been reported to provide awareness of position or movement. Higher coherence values in the temporal and parietal region ensure that more information is transferred among the regions. The visual information is also causing disorientation, and this results in the temporal and occipital regions communicating more to stabilize the balance of the participant. These results strongly suggest that 3D participants have higher information processing in the frontal region. The temporal region of the 3D participants is also processing more information obtained from the parietal and occipital regions.

In the next 2 electrode pairs, the coherence of P3 electrode with Fp1 and F3 are observed. The coherence of these pairs is not significant in all the bands and also the values of coherence are very small. This concludes that the values are not coherent.

The O2-C4 and O2-Fp2 electrode pairs in Table 5.1 show significant results in the beta band, while O2-Fp2 also shows significantly different results in the delta band. It is apparent that the coherence from the 2D and 3D groups differ in these electrode pairs but the reason behind this difference is not very clear. They may have information interchange between these regions but the values of coherence are very small. Therefore, they should not be counted as coherent.

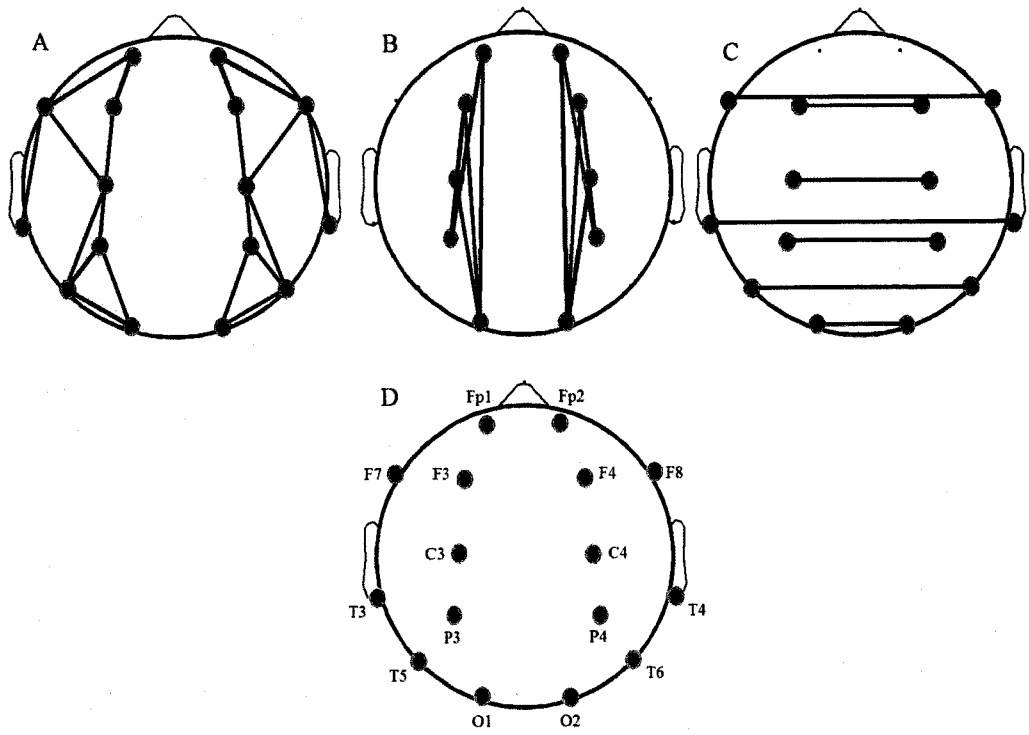


Figure 5.8: A,B and C shows coherence among electrodes. Black lines show non-significant coherence between electrodes and red lines show significant coherence between electrodes. D is only providing the labels.

The results from coherence are shown in Table 5.1. These are the significant results from selected electrodes and bands. In Table 5.1 p-values marked with red are significant at $p < 0.1$. There are a total of 10 electrode pairs that show significant results in at least one of the power bands. The electrode pairs in the frontal region show significant results in both hemispheres. The frontal lobe processes information and performs cognitive tasks. This difference in coherence values shows a difference in information processing by the brain. The coherence values in the 3D group is higher in all the bands. Higher coherence confirms that in 3D-viewing, the brain is processing more data compared to 2D-viewing. In terms of entertainment, if the brain is unable to understand the visual stimulus and requires more processing in the data, this can cause a problem for the viewers. This can be reported as a cause of headache or fullness of the head.

Moving on to next two electrode pairs of coherence which are T3-P3 and T3-O1, both are from left hemisphere and have a significant difference in values. From the

5.4 Feature Extraction for Classification

For the final classification of the data the features selected from hypothesis testing were used. The data was divided into two groups that are, one group with high VIMS symptoms rating, and another group with low VIMS symptoms rating. The feature classification was performed to fulfill the third objective that is to propose an objective indicator/measurement of VIMS using EEG signals.

Support Vector Machine (SVM) was used to classify the data into the two classes. The data was validated using a 10 fold cross validation. In a 10-fold cross-validation the final output is the average of each fold in which 90% data is used for training and 10% for testing. Therefore, in 10-fold cross-validation training and testing was done 10 times each. The final result is the average accuracy of all the 10 folds.

The classification was first done using the full set of 17 features as reported in Table 4.1. The accuracy using all the full feature set is 66.7%. The complete results are presented in Table 5.2 with the confusion matrix presented in Table 5.3. An attribute selection was performed to find the best features and remove the redundant features from the data set. An SVM classifier was used to select the features that could be used to classify VIMS accurately. Six features that are selected after the SVM attribute evaluation are presented in Table 5.4. Classification was performed using these features which give an accuracy of 77.8 %. The results are presented in table 5.5 and confusion matrix is presented in Table 5.6.

The two features of EEG that are selected for classification are relative theta and relative alpha. To find individual classification results of the two features the data was classified twice using each feature separately. The results for the relative theta are presented in table 5.7 with its confusion matrix in Table 5.8 and results for the relative alpha are presented in Table 5.9 with its confusion matrix in Table 5.10.

Table 5.1: Electrode Pairs Having Significant Coherence Values

S. No	Location	2D	3D	P-Value	2D	3D	P-Value	2D	3D	P-Value	2D	3D	P-Value	2D	3D	P-Value
		Delta			Theta			Alpha			Beta			High Beta		
1	Fp1 – F7	0.332	0.424	0.018	0.368	0.442	0.048	0.35	0.431	0.047	0.244	0.338	0.024	0.201	0.291	0.041
2	Fp1- F3	0.5	0.654	0.005	0.552	0.658	0.024	0.536	0.62	0.084	0.343	0.437	0.121	0.276	0.328	0.415
3	Fp2 – F8	0.311	0.293	0.791	0.366	0.391	0.477	0.344	0.42	0.043	0.264	0.341	0.055	0.216	0.286	0.096
4	Fp2 – F4	0.531	0.543	0.798	0.557	0.617	0.161	0.514	0.595	0.056	0.299	0.384	0.131	0.229	0.27	0.475
5	T5 – P3	0.697	0.78	0.051	0.732	0.804	0.069	0.735	0.758	0.47	0.636	0.706	0.03	0.613	0.688	0.046
6	T5 – O1	0.697	0.787	0.07	0.727	0.812	0.072	0.716	0.796	0.066	0.666	0.738	0.091	0.65	0.725	0.155
7	P3 – F3	0.162	0.193	0.272	0.15	0.173	0.397	0.1	0.127	0.284	0.064	0.114	0.08	0.071	0.117	0.199
8	P3 – Fp1	0.083	0.106	0.156	0.086	0.096	0.546	0.057	0.066	0.507	0.031	0.058	0.06	0.039	0.07	0.153
9	O2 – C4	0.063	0.072	0.555	0.06	0.063	0.794	0.043	0.056	0.309	0.018	0.041	0.058	0.024	0.051	0.118
10	O2 – Fp2	0.043	0.074	0.085	0.048	0.056	0.459	0.043	0.057	0.318	0.02	0.034	0.073	0.026	0.046	0.179

From classification results it is evident that relative theta can be used as a distinct feature to classify VIMS with relatively higher accuracy than other features. The relative theta is localized in the central region near electrodes C3, C4 and P4. In VIMS the effect of confusion and dizziness affects the functioning of the body that includes motor functions performed by the sensorimotor region of the brain located near the central sulcus. The effects of VIMS cause the central region of the brain to change its dynamics which are characterized by relative theta power. Hence, relative theta can be a suitable objective indicator/measurement of VIMS.

Table 5.2: Detailed Accuracy of 17 features

	TP Rate	FP Rate	Precision	Recall	F-Measure	ROC Area	Class
	0.667	0.333	0.636	0.667	0.651	0.667	L
	0.667	0.333	0.696	0.667	0.681	0.667	H
Weighted Avg.	0.667	0.333	0.668	0.667	0.667	0.667	

Table 5.3: Confusion Matrix of 17 features

a	b	Classified as
14	7	a = L
8	16	b = H

Table 5.4: Features selected after attribute evaluation

Feature	Time	Electrode
RA	7	23
RA	7	26
RT	3	29
RA	8	33
RT	8	97
RT	5	105

RT = Relative theta, RA = Relative Alpha

Table 5.5: Detailed Accuracy of 6 features

	TP Rate	FP Rate	Precision	Recall	F-Measure	ROC Area	Class
	0.81	0.25	0.739	0.81	0.773	0.78	L
	0.75	0.19	0.818	0.75	0.783	0.78	H
Weighted Avg.	0.778	0.218	0.781	0.778	0.778	0.78	

Table 5.6: Confusion Matrix of 6 features

A	b	Classified as
17	4	a = L
6	18	b = H

Table 5.7: Detailed Accuracy of the Feature Relative Theta

	TP Rate	FP Rate	Precision	Recall	F-Measure	ROC Area	Class
	0.667	0.125	0.824	0.667	0.737	0.711	L
	0.875	0.333	0.75	0.875	0.808	0.711	H
Weighted Avg.	0.778	0.236	0.784	0.778	0.775	0.711	

Table 5.8: Confusion Matrix of the Feature Relative Theta

a	b	Classified as
14	7	a = L
3	21	b = H

Table 5.9: Detailed Accuracy of the Feature Relative Alpha

	TP Rate	FP Rate	Precision	Recall	F-Measure	ROC Area	Class
	0.857	0.333	0.692	0.857	0.766	0.762	L
	0.667	0.143	0.842	0.667	0.744	0.762	H
Weighted Avg.	0.756	0.232	0.772	0.756	0.754	0.762	

Table 5.10: Confusion Matrix of the Feature Relative Alpha

A	b	Classified as
18	3	a = L
8	16	b = H

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

This study evaluates the symptoms of VIMS produced by 2D and 3D viewing using physiological data such as ECG and EEG. SSQ is used as the subjective evaluator of VIMS symptoms. The EEG data is used to generate topographic maps which provide the significant information of time-frequency analysis over brain regions. SSQ result reports that participants of 3D group rated higher VIMS symptoms than 2D group. Topographic maps show that theta power decreases in the frontal region and beta power decreases in the temporal region. The decreasing effect of theta and beta power is also reported by Min et. al., [14] and Kim et. al., [45] respectively. It is also observed that roll and pitch motion in the stimulus affects the delta band power.

After calculating the frequency band power a feature selection was performed to find the feature that could classify VIMS in participants of this study. Feature selection was done to find the objective feature that can be proposed as an objective indicator/measurement of VIMS. For this purpose participants were rearranged according to VIMS rating of SSQ. Participants rating below 35 on SSQ were labeled as low and participants rating above 35 were labeled as high. Feature selection was done using hypothesis testing which reduces the number of features and eliminates features that are redundant. From the feature selection it was found that relative theta power observed over central region of the brain can be used to classify the data into two classes of VIMS.

The classification was performed using SVM classifier. Relative theta gave a classification accuracy of 77.8 % which proves that VIMS can be classified using relative theta power recorded over the central regions of the brain.

6.2 Future Recommendations

Modification and advancements in the study that could extend the scope of this work are recommended as follows.

- The limitation of this study is that it induced motion sickness using a specialized movie shown in 2D and 3D stereoscopy. Since viewers of 3D stereoscopy are watching 3D movies that entertain them. Therefore, a survey can be done to find movies that are reported to induce VIMS symptoms. These movies can then be used in future experiments.

- In this study, participants who recently watched 3D movies were excluded. The reason to exclude such participants was that their brain might have adapted to view stereoscopic content. The study can be modified in a way that experiment should be performed on those participants who have watched 3D movies and have experienced VIMS symptoms and excluding those participants who do not suffer from VIMS when they watch 3D movies. This will give more insight of what are the other major factors that affect the people particularly those who are suffering from 3D stereoscopy.

- Finally, advanced techniques of EEG source localization can be implemented which will help to find the deep brain regions that are activated in the VIMS condition. This will give researchers an idea of origination of VIMS in the brain.

REFERENCES

[1] M. Yasu and M. Shiraki. (2009, 09-Mar 2012). *Sony's Stringer Sees 3D as Next $10 Billion Business* Available: http://www.bloomberg.com/apps/news?pid=newsarchive&sid=adp8a7FrDg.E

[2] K. Yoo-chul. (2010, 09-Mar 2012). *Samsung Aims to Sell 2 Mil. 3D TVs in 2010.* Available: http://www.koreatimes.co.kr/www/news/tech/2011/03/129_61416.html

[3] W. Xiao and W. Fei, "A study of stereoscopic display technology and visual fatigue caused by viewing stereoscopic images," in *Proc. IEEE 2nd International Conference on Computing, Control and Industrial Engineering (CCIE)*, 2011, pp. 379-382.

[4] D. Hurst. (2010, 12-Dec 2011). *How watching 3D films can be bad for your brain.* Available: http://www.dailymail.co.uk/health/article-1271618/How-watching-3D-films-bad-brain.html

[5] J. Steenhuysen. (2010, 23-Dec 2011). *3D movies a headache for some.* Available: http://www.abc.net.au/science/articles/2010/01/11/2789551.htm

[6] A. J. Benson and F. CuB, "Motion sickness," *Resource Utilization and Development: A Perspective Study of Madhya Pradesh, India,* p. 1059, 1992.

[7] K. Ukai and P. A. Howarth, "Visual fatigue caused by viewing stereoscopic motion images: Background, theories, and observations," *Displays,* vol. 29, pp. 106-116, 2008.

[8] B. C. Daugherty, A. T. Duchowski, D. H. House, and C. Ramasamy, "Measuring vergence over stereoscopic video with a remote eye tracker," in *Proceedings of the 2010 Symposium on Eye-Tracking Research Applications*, Austin, Texas, 2010, pp. 97-100.

[9] W. J. Tam, F. Speranza, S. Yano, K. Shimono, and H. Ono, "Stereoscopic 3D-TV: Visual Comfort," *IEEE Transactions on Broadcasting,* vol. 57, pp. 335-346, 2011.

[10] M. Lambooij, "Visual Discomfort and Visual Fatigue of Stereoscopic Displays: A Review," *J. Imaging Sci. Technol.,* vol. 53, p. 030201, 2009.

[11] A. G. Solimini, "Are There Side Effects to Watching 3D Movies? A Prospective Crossover Observational Study on Visually Induced Motion Sickness," *PLoS ONE,* vol. 8, 2013.

[12] M. Pölönen, T. Järvenpää, and B. Bilcu, "Stereoscopic 3D entertainment and its effect on viewing comfort: Comparison of children and adults," *Applied Ergonomics,* vol. 44, pp. 151-160, 2013.

[13] J. T. Reason and J. J. Brand, *Motion sickness*: Academic Press, 1975.

[14] B.-C. Min, S.-C. Chung, Y.-K. Min, and K. Sakamoto, "Psychophysiological evaluation of simulator sickness evoked by a graphic simulator," *Applied Ergonomics,* vol. 35, pp. 549-556, 2004.

[15] B. Keshavarz, H. Hecht, and L. Zschutschke, "Intra-visual conflict in visually induced motion sickness," *Displays,* vol. 32, pp. 181-188, 2011.

[16] H. Ujike, T. Yokoi, and S. Saida, "Effects of virtual body motion on visually-induced motion sickness," in *Engineering in Medicine and Biology Society, 2004. IEMBS '04. 26th Annual International Conference of the IEEE*, 2004, pp. 2399-2402.

[17] N. Sugita, M. Yoshizawa, A. Tanaka, K. Abe, T. Yambe, S. Nitta, *et al.*, "Evaluation of the effect of visually-induced motion sickness based on pulse transmission time and heart rate," in *SICE 2004 Annual Conference*, 2004, pp. 2473-2476 vol. 3.

[18] K. Fujita, "Influence of attention and predictive visual cue on motion perception and sickness in immersive virtual environment," in *Engineering in Medicine and Biology Society, 2004. IEMBS'04. 26th Annual International Conference of the IEEE*, 2004, pp. 2415-2416.

[19] M. Abe, M. Yoshizawa, N. Sugita, A. Tanaka, S. Chiba, T. Yambe, *et al.*, "Estimation of Effects of Visually-Induced Motion Sickness Using Independent Component Analysis," in *Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE*, 2007, pp. 5501-5504.

[20] M. Abe, M. Yoshizawa, N. Sugita, A. Tanaka, S. Chiba, T. Yambe, *et al.*, "A method for evaluating effects of visually-induced motion sickness using ICA for photoplethysmography," in *Engineering in Medicine and Biology Society, 2008. EMBS 2008. 30th Annual International Conference of the IEEE*, 2008, pp. 4591-4594.

[21] "Viewing condition for the subjective assessment of HDTV image quality: Rec.ITU-R BT.710-4.."

[22] T. Kiryu, G. Tada, H. Toyama, and A. Iijima, "Integrated evaluation of visually induced motion sickness in terms of autonomic nervous regulation," in *Engineering in Medicine and Biology Society, 2008. EMBS 2008. 30th Annual International Conference of the IEEE*, 2008, pp. 4597-4600.

[23] H. Ujike, K. Ukai, and K. Nihei, "Survey on motion sickness-like symptoms provoked by viewing a video movie during junior high school class," *Displays,* vol. 29, pp. 81-89, 2008.

[24] H. Ujike, "Estimation of Visually Induced Motion Sickness from Velocity Component of Moving Image Virtual and Mixed Reality." vol. 5622, R. Shumaker, Ed., ed: Springer Berlin / Heidelberg, 2009, pp. 136-142.

[25] K. Sakamoto, S. Aoyama, S. Asahara, K. Yamashita, and A. Okada, "Measurement of visual fat igue for large-sized TVs in a home viewing environment," in *Consumer Electronics, 2009. ISCE '09. IEEE 13th International Symposium on*, 2009, pp. 738-742.

[26] W. E. Chelen, M. Kabrisky, and S. K. Rogers, "Spectral analysis of the electroencephalographic response to motion sickness," *Aviation Space and Environmental Medicine,* vol. 64, pp. 24-29, 1993.

[27] J. P. Wu, "EEG changes in man during motion-sickness induced by parallel swing," *Space Medicine and Medical Engineering,* vol. 5, pp. 200-205, 1992.

[28] C. D. Wood, J. J. Stewart, M. J. Wood, F. A. Struve, J. J. Straumanis, M. E. Mims, *et al.*, "Habituation and motion sickness," *Journal of Clinical Pharmacology,* vol. 34, pp. 628-634, 1994.

[29] J. Waddington and C. M. Harris, "Human optokinetic nystagmus: A stochastic analysis," *Journal of Vision,* vol. 12, November 8, 2012 2012.

[30] G. Cuiting, J. Ji, and R. So, "Could OKAN be an objective indicator of the susceptibility to visually induced motion sickness?," in *Virtual Reality Conference (VR), 2011 IEEE*, 2011, pp. 87-90.

[31] S. Hu, K. A. McChesney, K. A. Player, A. M. Bahl, J. B. Buchanan, and J. E. Scozzafava, "Systematic investigation of physiological correlates of motion sickness induced by viewing an optokinetic rotating drum.," *Aviation, Space, and Environmental Medicine,* vol. 70, pp. 759-765, 1999.

[32] C.-T. Lin, S.-W. Chuang, Y.-C. Chen, L.-W. Ko, S.-F. Liang, and T.-P. Jung, "EEG effects of motion sickness induced in a dynamic virtual reality environment," in *Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE*, 2007, pp. 3872-3875.

[33] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, "Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness," *The International Journal of Aviation Psychology,* vol. 3, pp. 203-220, 1993/07/01 1993.

[34] B. Keshavarz and H. Hecht, "Validating an Efficient Method to Quantify Motion Sickness," *Human Factors: The Journal of the Human Factors and Ergonomics Society,* vol. 53, pp. 415-426, August 1, 2011 2011.

[35] H.-C. O. Li, J. Seo, K. Kham, and S. Lee, "Method of Measuring Subjective 3-D Visual Fatigue: A Five-Factor Model," in *Digital Holography and Three-Dimensional Imaging*, St. Petersburg, Florida, 2008, p. DWA5.

[36] A. G. Solimini, G. La Torre, A. Mannocci, D. Di Thiene, and A. Boccia, "Prevalence of symptoms of visually induced motion sickness and visual stress during and after viewing a 3D movie," *European Journal of Public Health,* vol. 20, pp. 242-242, Nov 2010.

[37] Y. C. Chen, J. R. Duann, C. L. Lin, S. W. Chuang, T. P. Jung, and C. T. Lin, "Motion-sickness related brain areas and EEG power activates," vol. 5638 LNAI, ed, 2009, pp. 348-354.

[38] S. Yano, S. Ide, T. Mitsuhashi, and H. Thwaites, "A study of visual fatigue and visual comfort for 3D HDTV/HDTV images," *Displays,* vol. 23, pp. 191-201, 2002.

[39] J. F. Golding, "Motion sickness susceptibility," *Autonomic Neuroscience: Basic and Clinical,* vol. 129, pp. 67-76, 2006.

[40] S. D. Young, B. D. Adelstein, and S. R. Ellis, "Demand characteristics in assessing motion sickness in a virtual environment: Or does taking a motion sickness questionnaire make you sick?," *IEEE Transactions on Visualization and Computer Graphics,* vol. 13, pp. 422-428, 2007.

[41] W. Chun-Shu, K. Li-Wei, C. Shang-Wen, J. Tzyy-Ping, and L. Chin-Teng, "EEG-based evaluation system for motion sickness estimation," in *Neural Engineering (NER), 2011 5th International IEEE/EMBS Conference on*, 2011, pp. 100-103.

[42] M. Abe, M. Yoshizawa, N. Sugita, A. Tanaka, S. Chiba, T. Yambe, *et al.*, "Physiological Evaluation of Effects of Visually-Induced Motion Sickness Using Finger Photoplethysmography," in *SICE-ICASE, 2006. International Joint Conference*, 2006, pp. 2340-2343.

[43] Y. C. Chen, J. R. Duann, S. W. Chuang, C. L. Lin, L. W. Ko, T. P. Jung, *et al.*, "Spatial and temporal EEG dynamics of motion sickness," *NeuroImage,* vol. 49, pp. 2862-2870, 2010.

[44] C. Strychacz, E. Viirre, and S. Wing, "The use of EEG to measure cerebral changes during computer-based motion-sickness-inducing tasks," in *Proc. SPIE 5797, Biomonitoring for Physiological and Cognitive Performance during Military Operations,* , Orlando, FL, USA, 2005, pp. 139-148.

[45] Y. Y. Kim, H. J. Kim, E. N. Kim, H. D. Ko, and H. T. Kim, "Characteristic changes in the physiological components of cybersickness," *Psychophysiology,* vol. 42, pp. 616-625, 2005.

[46] Y. Yi-Hsin, L. Pei-Chen, K. Li-Wei, C. Chun-Hsiang, K. Bor-Chen, and L. Chin-Teng, "An EEG-based classification system of Passenger's motion sickness level by using feature extraction/selection technologies," in *Neural Networks (IJCNN), The 2010 International Joint Conference on*, 2010, pp. 1-6.

[47] L. W. Ko, C. S. Wei, T. P. Jung, and C. T. Lin, "Estimating the level of motion sickness based on EEG spectra," vol. 6780 LNAI, ed, 2011, pp. 169-176.

[48] W. Chun-Shu, C. Shang-Wen, W. Wan-Ru, K. Li-Wei, J. Tzyy-Ping, and L. Chin-Teng, "Implementation of a motion sickness evaluation system based on EEG spectrum analysis," in *Circuits and Systems (ISCAS), 2011 IEEE International Symposium on*, 2011, pp. 1081-1084.

[49] R. S. Kennedy, J. Drexler, and R. C. Kennedy, "Research in visually induced motion sickness," *Applied Ergonomics,* vol. 41, pp. 494-503, 2010.

[50] D. M. Hoffman, A. R. Girshick, K. Akeley, and M. S. Banks, "Vergence-accommodation conflicts hinder visual performance and cause visual fatigue," *Journal of Vision,* vol. 8, 2008.

[51] K. Dongchan, J. Yong Ju, K. Eunwoo, R. Yong-Man, and P. HyunWook, "Human brain response to visual fatigue caused by stereoscopic depth perception," in *Digital Signal Processing (DSP), 2011 17th International Conference on*, 2011, pp. 1-5.

[52] L. Eui Chul, H. Hwan, and P. Kang Ryoung, "The comparative measurements of eyestrain caused by 2D and 3D displays," *Consumer Electronics, IEEE Transactions on,* vol. 56, pp. 1677-1683, 2010.

[53] J. E. Hall and A. C. Guyton, *Guyton and Hall textbook of medical physiology*. Philadelphia, Pa.: Saunders/Elsevier, 2011.

[54] W. D. Dupont and W. D. Plummer Jr, "Power and sample size calculations: A review and computer program," *Controlled Clinical Trials,* vol. 11, pp. 116-128, 1990.

[55] M. E. McCauley, *Research Issues in Simulator Sickness: Proceedings of a Workshop*: Washington, D.C.: National Academy Press., 1984.

[56] K. Zadnik, D. O. Mutti, G. L. Mitchell, L. A. Jones, D. Burr, and M. L. Moeschberger, "Normal Eye Growth in Emmetropic Schoolchildren," *Optometry & Vision Science,* vol. 81, pp. 819-828, 2004.

[57] H. Ujike and H. Watanabe, "Effects of stereoscopic presentation on visually induced motion sickness," in *Proceedings of SPIE - The International Society for Optical Engineering*, San Francisco, California, USA, 2011, pp. 786314-6.

[58] M. Malik, "Heart rate variability: Standards of measurement, physiological interpretation, and clinical use," *Circulation,* vol. 93, pp. 1043-1065, 1996.

[59] A. R. Subahni, L. Xia, and A. S. Malik, "Association of mental stress with video games," in *Proceedings of the 4th International Conference on Intelligent and Advanced Systems*, Kuala Lumpur; Malaysia, 2012, pp. 82-85.

[60] P. L. Nunez and R. Srinivasan, *Electric fields of the brain: the neurophysics of EEG*: Oxford University Press, USA, 2006.

[61] L. F. Haas, "Hans Berger (1873-1941), Richard Caton (1842-1926), and electroencephalography," *Journal of neurology, neurosurgery, and psychiatry,* vol. 74, p. 9, 2003.

[62] G. Gratton, M. G. H. Coles, and E. Donchin, "A new method for off-line removal of ocular artifact," *Electroencephalography and Clinical Neurophysiology,* vol. 55, pp. 468-484, 1983.

[63] N. V. Thakor, *Quantitative EEG analysis methods and clinical applications*: Artech House, 2009.

[64] A. Malliani, F. Lombardi, and M. Pagani, "Power spectrum analysis of heart rate variability: a tool to explore neural regulatory mechanisms," *British Heart Journal,* vol. 71, pp. 1-2, January 1, 1994 1994.

[65] S. Ohyama, S. Nishiike, H. Watanabe, K. Matsuoka, H. Akizuki, N. Takeda, *et al.*, "Autonomic responses during motion sickness induced by virtual reality," *Auris Nasus Larynx,* vol. 34, pp. 303-306, 2007.

[66] L. T. LaCount, V. Napadow, B. Kuo, K. Park, J. Kim, E. N. Brown, *et al.*, "Dynamic cardiovagal response to motion sickness: A point-process heart rate variability study," in *Proceedings of the 36th Annual Conference of Computers in Cardiology*, Park City; UT, 2009, pp. 49-52.

[67] A. R. Subhani, L. Xia, and A. S. Malik, "Association of Autonomic Nervous System and EEG Scalp Potential During Playing 2D Grand Turismo 5," in *Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE*, 2012, pp. 3420-3423.

[68] M. Zaepffel, R. Trachel, B. E. Kilavik, and T. Brochier, "Modulations of EEG Beta Power during Planning and Execution of Grasping Movements," *PLoS ONE,* vol. 8, p. e60060, 2013.

APPENDICES

APPENDIX A

EYE EXAMINATION FORM

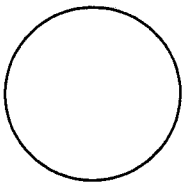
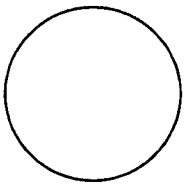
A) DemographicData Date:_____

1. IC NO :_____ Research ID _____
2. Age : _____Years
3. Sex : M / F
4. Race: Malay ☐
   Chinese ☐
   India ☐
   Others ☐
5. History of Motion Sickness: Yes/No
6. Past Medical History

   DM ☐
   HPT ☐
   IHD ☐
   Asthma ☐

	RIGHT	LEFT
Visual Acuity		
Refraction		

B) Eye Examination

RIGHT EYE			LEFT EYE	
		PUPIL		
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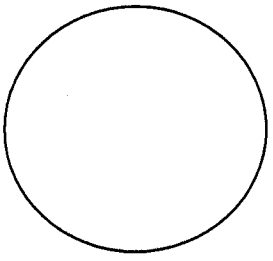			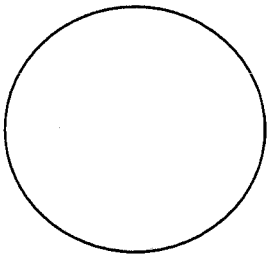	
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APPENDIX B

MOTION SICKNESS SUSCETIBILITY QUESTIONNAIRE

Demographic Data

English Form

Date :- _____

1	First Name	
2	Last Name	
3	Gender	
4	E mail	
5	Age	
6	Phone no.	
7	Handedness	
8	Nationality	
9	Race	
10	Eye Sight (Y/N) if 'Y' state the power	
11	Daily Medication (Y/N)	
12	Smoking (Y/N)	
13	Neurological Disease Epilepsy, Seizures or migraine (Y/N)	
14	Systemic problem Asthma, Blood pressure, hyper tension or diabetes (Y/N)	
15	Eye Disease or surgery (Y/N)	
16	Ear problem or surgery (Y/N)	
17	Watched 3D within 3 months (Y/N)	
18	Semester	

Motion Sickness Susceptibility Questionnaire Short Form (MSSQ - Short)
Your **CHILDHOOD** Experience Only (before 12 years of age) Your Experience over the last 10 years (approximately), for each of the following types of transport or entertainment please indicate.
For example if you have never travelled in a car, then tick in the **never travelled** box under Cars. If you have felt sick some times while travelling in a car, then tick in **sometimes felt sick** box under Cars.

Childhood	never travelled	Never felt sick	Rarely felt sick	sometimes felt sick	frequently felt sick
Cars					
Busses					
Trains					
Aircraft					
Small boats					
Ships e.g. channel ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big dippers, Funfair rides					

Adult	never travelled	Never felt sick	Rarely felt sick	sometimes felt sick	frequently felt sick
Cars					
Busses					
Trains					
Aircraft					
Small boats					
Ships eg channel ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big dippers, Funfair rides					

APPENDIX C

CONSENT FORM

RESEARCH INFORMATION

Research Title: **Evaluation of Visually Induced Motion Sickness from 3D viewing using Neuroimaging and processing techniques**

Researcher's Name: **Syed Ali Arsalan Naqvi**

MMC Registration No. : _____

INTRODUCTION

You are invited to take part voluntarily in a research study of visually induced motion sickness from 3D Movies and images.

Your participation in this study is expected to last up to 3 hour. Up to 30 subjects will be participating in this study.

PURPOSE OF THE STUDY

The purpose of this study is to determine how does your brain perceive information presented in 3D compared to 2D in terms of:

- Visually Induced Motion Sickness (VIMS)
- Visual strain
- Understanding of displayed contents

It is also possible that information collected in this experiment will be used in future research.

QUALIFICATION TO PARTICIPATE

Requirments for participation in this study:

- Enrolled in a university program.
- Age from 18 to 40 years and are able to give consent.

You cannot participate in this study if:

- You do not give consent.
- You have any head injury or neurological desease like epilepsy, seizures and migraine or any other forms of psychological disorders.
- You have any eye disease, eye surgery or any history of eye injury or trauma
- You are under any type of daily medication.
- You have any type of skin allergy.

STUDY PROCEDURES

At your arrival to the experiment room, you will be given this Research information form, If you agree to participate, you will have to sign a consent form. Your head will be measured to place an electrode cap. Two points will be marked on your forehead at the centre of your head for exact placement of the cap.

The impedance of all the electrodes will be measured and Electrocap electrodes may be abraded if they show high impedance. Two ECG sensors will be applied onto the second rib below the right and left shoulder blades. The application area will be cleaned and abraded to make good contact.
Two velcro straps will be snug around your fore finger and middle finger to measure your skin conductance. The electrodes leads will be connected with these straps.

Eye gaze recording will be done through an eye tracking device. You will be asked to report about sickness level continuously on a sickness scale. This will be done by an input key from an input device. Reporting will be on regular interval of 1 minute.

After all this setup, the experiment will start.The experiment flow is as under:

1- 5 minutes eyes-closed test
2- 5 minutes eyes-opened test
3- 10 minutes movie viewing
4- Fill in questionnaire

RISKS

There exists the possibility of risk and discomfort occurring during the test that could include skin irritation, allergy, or tears in eyes. To minimize these conditions, you will be frequently asked by the experimenter if you are experiencing any discomfort and your electroencephalogram will be closely monitored.

REPORTING HEALTH EXPERIENCES

If you have any injury, bad effect, or any other unusual health experience during this study, make sure that you immediately tell the experimenter.

PARTICIPATION IN THE STUDY

Your taking part in this study is entirely voluntary. You may refuse to take part in the study or you may stop participation in the study at anytime, without a penalty or loss of benefits to

which you are otherwise entitled. During this 3 hours session, if you feel any discomfort, pain, feel sleepy, you tell the researcher in charge to stop recording and give you some rest. Your participation may also be stopped by the researcher in charge without your consent, if: you do not follow the instructions, blink/roll/move your eyes too much, feeling sleepy during the recording. In this case you will be given RM 20.00 to compensate your spent time. If you successulycomplete the whole experiment then you will be given RM 50.00 to compensate your spent time.

QUESTIONS

If you have any question about this study or your rights or regarding the Ethical Approval or any issue / problem related to this study, please contact;

Prof Dr Wan Hazzabah
Department of Opthalmology
HUSM

CONFIDENTIALITY

Your information will be kept confidential by the study staff and will not be made publicly available unless disclosure is required by law.

Data obtained from this study that does not identify you individually will be published for knowledge purposes.

Your medical information may be held and processed on a computer.

By signing this consent form, you authorize the record review, information storage and data transfer described above.

SIGNATURES

To be entered into the study, you or a legal representative must sign and data the signature page.

Subject Information and Consent Form (Signature Page)

Research Title: *Evaluation of Visually Induced Motion Sickness from 3D viewing using Neuroimaging and processing techniques*

Researcher's Name: *Syed Ali Arsalan Naqvi, Nasreen Badruddin, Aamir S. Malik*

To become a part this study, you or your legal representative must sign this page. By signing this page, I am confirming the following:

- I have read all of the information in this Subject Information and Consent Form **including any information regarding the risk in this study** and I have had time to think about it.
- All of my questions have been answered to my satisfaction.
- I voluntarily agree to be part of this research study, to follow the study procedures, and to provide necessary information to the doctor, nurses, or other staff members, as requested.
- I may freely choose to stop being a part of this study at anytime.
- I have received a copy of this Subject Information and Consent Form to keep for myself.

Subject Name (Print or type) **Number**	**Subject Initials** and
Subject I.C No. (New) (Old)	**Subject I.C** No.
Signature of Subject or Legal Representative	**Date** (dd/MM/yy) (Add time if applicable)
Name of Individual Conducting Consent Discussion (Print or Type)	
Signature of Individual Conducting Consent Discussion	**Date** (dd/MM/yy)
Name & Signature of Witness	**Date** (dd/MM/yy)

Note: i) All subject/subjects who are involved in this study will not be covered by insurance.

Subject's Material Publication Consent Form
Signature Page

Research Title: *Evaluation of Visually Induced Motion Sickness from 3D viewing using Neuroimaging and processing techniques*

Researcher's Name: *Syed Ali Arsalan Naqvi, Nasreen Badruddin, Aamir S. Malik*

To become a part this study, you or your legal representative must sign this page.

By signing this page, I am confirming the following:

- I understood that my name will not appear on the materials published and there has been an effort to make sure that the privacy of my name is kept confidential although the confidentiality is not completely guaranteed due to unexpected circumstances.
- I have read the materials or general description of what the material contains and reviewed all photographs and figures in which I am included that could be published.
- I have been offered the opportunity to read the manuscript and to see all materials in which I am included, but have waived my right to do so.
- All the published materials will be shared among the medical practitioners, scientists and journalist world wide.
- The materials will also be used in local publications, book publications and accessed by many local and international doctors world wide.
- I hereby agree and allow the materials to be used in other publications required by other publishers with these conditions:
- The materials will not be used as advertisement purposes or as packaging materials.
- The materials will not be used out of context – i.e.: Sample pictures will not be used in an article which is unrelated subject to the picture.
- There may be financial implications associated with the data or findings of this study. I agree that I will not be entitled to receive any financial compensation or claim any financial value except the already agreed honorarium for this study.

Subject Name (Print or type)	**Subject Initials** or **Number**
Subject I.C No.	Subject's Signature / **Date** (dd/mm/yy)
Name and Signature of Individual Conducting Consent Discussion	**Date** (dd/mm/yy)

APPENDIX D

SIMULATOR SICKNESS QUESTIONNAIRE

Name: _____ ID: _____

Sickness Questionnaire

SYMPTOM CHECKLIST

Please fill in this questionnaire. Circle below if any of the symptoms apply to you now.

1. General discomfort	No	Slight	Moderate	Severe
2. Fatigue	No	Slight	Moderate	Severe
3. Headache	No	Slight	Moderate	Severe
4. Eyestrain	No	Slight	Moderate	Severe
5. Difficulty focusing	No	Slight	Moderate	Severe
6. Salivation increase	No	Slight	Moderate	Severe
7. Sweating	No	Slight	Moderate	Severe
8. Nausea	No	Slight	Moderate	Severe
9. Difficulty concentrating	No	Slight	Moderate	Severe
10. "Fullness of the head"	No	Slight	Moderate	Severe
11. Blurred vision	No	Slight	Moderate	Severe
12. Dizziness eyes open	No	Slight	Moderate	Severe
13. Dizziness eyes close	No	Slight	Moderate	Severe
14. Vertigo	No	Slight	Moderate	Severe
15. Stomach awareness	No	Slight	Moderate	Severe
16. Burping	No	Slight	Moderate	Severe