EEG Alpha Power: An Indicator of Visual Fatigue

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***Abstract*—There have been reports that some people who watch 3D movies experience motion sickness symptoms. In this research work, the change in dynamics of mental activity of subjects is evaluated to understand the reason behind the sickness. Cortical activity of the brain recorded from subjects who watch a stimulus (movie) on 2D and 3D TV. We propose that brain waves recorded using EEG device can be analysed using signal processing techniques and statistical methods. This will help in distinguishing between viewers of 2D and 3D stimulus, as well as being helpful in finding brain related areas that are active during the prevalence of motion sickness.**

***Keywords*—Visual Fatigue, Electroencephalography, Motion Sickness, Alpha Power**

I. INTRODUCTION

Electroencephalography (EEG) is one of the imaging techniques that is used to record the electrical activity of the brain. The raw data from the brain can be recorded through electrodes that are placed on the scalp. These signals are then transmitted to a differential amplifier to amplify the difference between the two electrodes. The waves recorded from EEG are divided into 5 bands, that are Delta (0.5 – 4 Hz), Theta (4 – 7Hz) Alpha (8 – 12Hz), Beta (12 – 35Hz), & Gamma (35 – 100Hz). The raw data is composed of composite signals of all the bands that are further divided into the defined bands by filtering the waves. Delta waves are usually present in adults during sleeping conditions and normally not present when awake. If delta waves are found in waking condition then it is said that there is some sort of abnormality. Theta waves are found in relaxed states. Alpha waves are mostly found in the posterior part of the brain during relaxed or eyes closed conditions, and diminish when there is mental exertion. Beta waves are fast activity waves associated with movement.

We have found a problem that has been a topic of research for past 60 years because its symptoms cannot be diagnosed directly through any particular device; that is "motion sickness". Initially it was a problem for pilots and sailors but now it is more common in daily life for those who play video games and watch television for an extended period of time. This type of condition is often called "Cyber Sickness". If there is a conflict between the vestibular system and visual system of a person then this conflict will lead him to motion sickness [1]. This conflict can also be induced by visual conflict even though there is no feeling of motion or movement. This kind of motion sickness, which is induced due to visual cues and when no external effects of movement are present, is called visually induced motion sickness or VIMS.

In the next section we will discuss the background studies of motion sickness and VIMS, recent research on VIMS and proposed indicator of motion sickness. Section III provides the methodology of the experiment. Section IV is on data acquisition and data processing. Section V contains the result and discussion, and Section VI concludes the paper.

II. BACKGROUND

A. Motion Sickness

Motion sickness has been a topic of research for the past 60 years. The most common method used by researchers to evaluate the sickness level of a subject is in the form of questionnaires [2]. For the evaluation of simulator sickness or any type of motion sickness induced by visual or vestibular cues, the most popular questionnaire used by researchers is the "simulator sickness questionnaire" (SSQ) introduced by R.S Kennedy in 1993 [3]. Authors use different methods to induce VIMS; examples include using an optokinetic drum and Virtual reality (VR) environments. VR environments can be generated using two different devices such as a head mounted display and large projection screens.

An optokinetic drum is a type of stimulus that produces VIMS. The subject is placed inside the drum in a stationary position and the drum, which has horizontal lines or patterns, and the drum is rotated around the head of the subject. This optokinetic drum can also be virtually implemented by placing a cylinder around the subject and having three projectors project the rotating image around the subject [4].

In experiments involving virtual reality environments, the subject is placed in an enclosed space and fully surrounded by the virtual environment that simulates a real scenario These VR experiments can uses head mounted devices or large projection screens. Researchers have found that large screens cause more symptoms of motion sickness compared to head mounted devices because the field of view is more than 180 degrees [5].

In [6], R.S Kennedy reported that VIMS symptoms can be categorized into three different types - nausea, occulomotor, and disorientation. Some of the symptoms related to each category are shown in Figure 1.Before the genesis of VIMS these symptoms start to prevail in the subject, and occulomotor symptoms are commonly found during or before VIMS.

The occulomotor symptoms are independently recorded and observed by the authors for the evaluation of stereoscopic technology, because they cause visual discomfort or visual fatigue.

It is also important to determine the types of stimulus that can produce VIMS. For example, it is found that movies with a

978-1-4799-4653-2/14/$31.00

lot of motion, specifically in the rotational direction is more likely to induce motion sickness [7]. The rotational components can be further divided into its components; that are roll, yaw and pitch components. Results show that motion in the roll direction produces the highest level of sickness.

B. Techniques used to evaluate motion sickness

In this section, we will discuss techniques used to evaluate motion sickness. There are two methods of evaluating the sickness, one is from subjective point of view and the second is recording the objective measurements and correlating it with the symptoms of the sickness. Subjective scores of the sickness are measured using questionnaires and the most popular is the simulator sickness questionnaire (SSQ) as mentioned previously. Researchers also use self-made questionnaires with questions related to symptoms present in VIMS. There is also the Motion sickness questionnaire (MSQ) [8] and fast motion sickness questionnaire (FMS) [5]used by researchers. Continuous evaluations of the images are also done by input from the subject every minute or for every scene. This is done on a predefined scale of comfort and discomfort of the particular scene.

Objective parameters are also recorded in correlation with the subjective values of VIMS. When the symptoms of sickness are induced then there is a change in the physiological parameters of the body e.g. the heart rate, palpitation and blood pressure. With the availability of neuroimaging techniques, researchers are moving towards studying the activity of the brain to measure the symptoms. These techniques have recently been applied in the field of VIMS. EEG is the technique used in [9-11]due to its high temporal resolution

Heart rate activity, blood pressure, pulse transmission time (PTT), respiration rate, and photoplythesmography (PPG) were used independently in correlation with subjective ratings to find the effects of VIMS on subjects [12-14]. The stimulus used for this purpose was a moving image shown on a large screen. Recently, these parameters of autonomic nervous activity (ANA) are used as a reference to neuroimaging techniques because the changes of ANA can be caused by other factors as well. For example, the heart rate can increase if there is feeling of fear or excitement. Blood pressure (BP) depends on the physical environment and has a poor temporal resolution. Therefore PTT was introduced by researchers as an alternative measurement because it is cost effective and easy to use [12]. Kiryu et. al., [13] used the respiration rate and used a combination of the R-to-R peak interval of the heart rate, blood pressure and respiration. From the integration of subjective scores and ANA, the authors claimed to have found the component of images that cause VIMS, although these were not reported.

In [15], the researchers were able to determine the camera motion and the motion components that cause VIMS and found that the roll motion in the rotational direction produces the highest sickness scores. However, the drawbacks in those experiments were that the objective parameters related to ANA are not recorded. In [16], the eye movement index is recorded, and from these it was found that movements of 30 to 60 deg/s in roll direction with temporal speed of 0.1 to 0.2 Hz can cause VIMS.

C. EEG as objective parameter

Previously researchers used EEG to evaluate the motion sickness with different stimuli including pre coriolis stimulation (rotating chair), or using both visual and vestibular inputs for complete motion sickness sensation. Chelen et. al., [9] in 1993 performed the spectral analysis of brain waves recorded during pre coriolis stimulation, using a 14 channel EEG based on the international 10 – 20 system, to record the waves. The electrodes were invasive and placed inside the scalp. Frontal electrodes with eye motion artifact were not used for spectral analysis. Their results show that during motion sickness, the energy in delta and theta bands increased.

Most of the work done in the field of motion sickness from 2007 onwards, use virtual reality based 3D environments. Both visual and vestibular stimulations are used to induce motion sickness, and EEG is recorded throughout the experiment. In 2007 Lin et al. [8]recorded a 32 channel EEG using international 10-20 electrode placement. For subjective evaluation they used their own motion sickness questionnaire based on 10 items. Their experiment was based on 10 min baseline recording driving on straight road, 40 min motion sickness recording driving on curving road and 15 min rest recording, at end MSQ was taken.

The basic signal analysis approach involved artifact removal, Independent component analysis (ICA), useless component rejection, epoch extraction, Event related spectral perturbation and finally, observation of motion sickness related brain dynamics. It is found that in the parietal region, alpha waves were showed higher energy levels.

Chen et. al., [17] improved the results and explained the

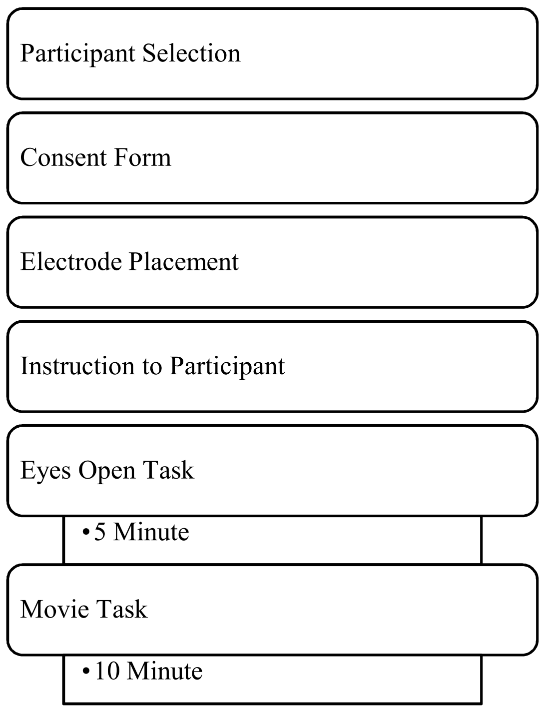

Figure 1. Flow chart of the Experiment

procedure in detail. Experimental setup was the same but a continuous rating system was used to rate the feeling after every minute through a joy stick. The method included EEG artifact removal, ICA decomposition, IC clustering, Time frequency analysis of clustered ICs, correlating the time frequency results with averaged continuous reporting of subjects, and then finding the MS related spectral changes in each subject. Their results were in correlation with previous results as alpha power increased with the MS level in parietal region. The results also showed that motor region was showing higher power of theta band due to movement i.e. sensorimotor inputs. There was delta power increase as well in occipital region during curve road section and this can be due to motion sickness.

More recently, authors from the described study attempted to estimate the level of motion sickness and to develop a machine learning algorithm to predict the level of sickness from the EEG spectra.

From the spectra of EEG they move on to apply principal component analysis and then apply estimating algorithms that are; linear regression, radial basis function neural network and support vector regression [18, 19]. These studies have not been studied extensively.

III. Methodology

A. Participants

Participants were recruited for the experiment from Universiti Teknologi PETRONAS. They belong to different races and regions of the world. Both international and local students were allowed to participate in the study. They were asked to complete a written consent form, before they could participate. Any participant with a history of head injury, trauma or any neurological disorder was excluded from the study.

B. Experiment

All the participants were asked to watch a movie on a 42” LCD TV. The participants were naïve from the content of the movie. The movie consisted of specialized rotational scenes. The scene is the driver’s view of a car moving along a road but the camera was additionally rotated on the pitch and roll axis. This stimulus was requested from the authors of [20]. It was reported that this stimulus can produce symptoms of VIMS on a notable scale. The flow of the experiment is given Figure 1.

IV. Data Acquisition and Processing

The data was collected from 6 participants who were asked to watch a movie. The data was recorded using 128 channels Hydro Cel Geodesic Sensor Net (HC-GSN 128 channel). The sampling rate for recording was set to 250 samples per second. During acquisition participants were asked to sit and relax and were given instructions not to move their head and body. They were also asked to minimize eye blinking during recording. Data was recorded using Electrical Geodesic Inc. (EGI amplifier). A band pass filter of 0.3Hz to 70Hz was applied after the recording to minimize the noise. A notch filter of 50 Hz was also applied to remove line noise that was added from the power sources.

After the filtering, data was pre-processed again in NetStation software as line noise of 50 Hz was still interfering with few channels. It was passed through a band pass filter of 0.3 Hz to 48 Hz. After that an Artifact detection algorithm was implemented to detect eye blinks in the data. Later all the data was exported and processed using MATLAB.

The data from 6 participants was analysed using EEGLAB software where the power spectrum of the data was computed using Fast Fourier Transform (FFT) with a window length of 512 and 1024 frequency points.

V. Results and Discussion

We compared two conditions of the participants which are eyes open and movie watching condition. The data of all the channels from each participant was transformed into frequency domain using FFT. The power of all the channels was computed by squaring the amplitude of the frequency domain signal. The power signal from 128 channels was averaged out to get a single power spectrum for each participant. The averaged power spectrum for each participant is presented in Figure 2 and Figure 3 for eyes open and movie condition, respectively.

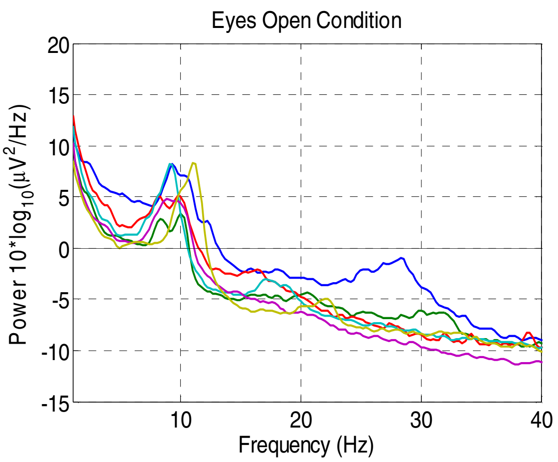

Figure 2. Average spectral power measurements for all channels, eyes open condition. alpha peak is dominant in almost all the participants.

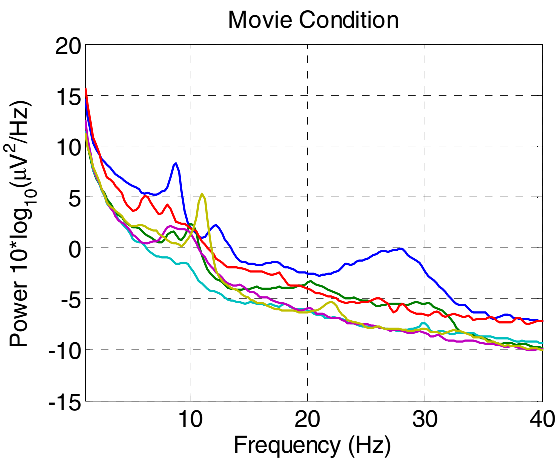

Figure 3. Average spectral power measurements for all channels, movie watching condition, alpha peak is diminished in most participants.

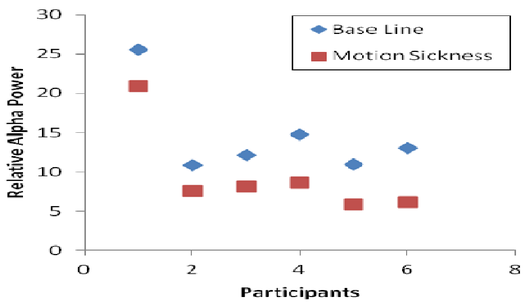

Figure 4. Relative power of participants

From Figure 2, we can see that there is a peak around 10 Hz that is in the alpha region. The peak around these values usually depicts that subjects are in relaxed condition. In Figure 3, we can see a difference in the alpha power compared to with eyes open condition. To analyse the data quantitatively we move further to compute the relative alpha power. Relative alpha power is computed by dividing the alpha power from the total band power from 1 to 30 Hz and multiplying it with 100. This gives us the relative alpha power for each channel. The alpha power from each channel averaged over the electrodes to have a single value for each participant.

Figure 4 shows the relative alpha power of the participants. It is evident that relative alpha power is higher in eyes open condition compared to movie condition. The drop in alpha power is expected to occur due to changes in brain activity. It can be inferred that the movie changes the mental activity of the participant that cause them to be in a condition which makes them uncomfortable. The discomfort from watching the movie produces fatigue which causes the alpha power to decrease. The decrease in alpha power due to movie watching can be interpreted as an indicator of visual fatigue. The relation of alpha power with visual fatigue is made due to the changes in the power caused by viewing conditions. Furthermore, investigation is required to find the brain areas that are more likely to get fatigued or acts differently in the condition of discomfort. A channel wise study of the experiment might give the answer to the question that which regions of the brain are more disturbed due to visual fatigue.

VI. CONCLUSION

From the results we conclude that there is a change in the electrical activity of the brain. After watching the movie the alpha power is reduced. From this change in brain activity we deduce that participant is not comfortable from watching the movie. Therefore, this discomfort can be reported as visual fatigue because it occurs due to visual changes in the stimulus. Hence, changes in the alpha power can be analysed in detail to find the effect of motion sickness caused by viewing different stimuli i.e. movies having extra pitch and roll motion as well as 3D stereoscopic movies.

ACKNOWLEDGMENT

This research is supported by the Universiti Teknologi PETRONAS Short-Term Internal Fund (STIRF) 13/2011.

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