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Does 3D Produce More Symptoms of Visually Induced Motion Sickness?

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Abstract— **3D stereoscopy technology with high quality images and depth perception provides entertainment to its viewers. However, the technology is not mature yet and sometimes may have adverse effects on viewers. Some viewers have reported discomfort in watching videos with 3D technology. In this research we performed an experiment showing a movie in 2D and 3D environments to participants. Subjective and objective data are recorded and compared in both conditions. Results from subjective reporting shows that Visually Induced Motion Sickness (VIMS) is significantly higher in 3D condition. For objective measurement, ECG data is recorded to find the Heart Rate Variability (HRV), where the LF/HF ratio, which is the index of sympathetic nerve activity, is analyzed to find the changes in the participants' feelings over time. The average scores of nausea, disorientation and total score of SSQ show that there is a significant difference in the 3D condition from 2D. However, LF/HF ratio is not showing significant difference throughout the experiment.**

I. Introduction

3D technology is gaining popularity worldwide, and this technology is not limited to entertainment only. We can now find 3D technology in different fields such as medical science, sports and even primary education. Researchers are even investigating on how 3D technology can enhance the cognitive ability of the humans[1]. The growth of 3D technology means that future viewing devices will be mostly in 3D including large screen TV's, computer screens, smart phones and tablet PC's. Most cinemas are showing 3D movies and new 3D movies are released every few months. Even though 3D movies are entertaining to watch, some viewers experience negative side-effects that discourage or prevent them from watching 3D movies.

According to [2], watching 3D movies can cause visual fatigue and discomfort. A number of factors have been discussed in their review including Accommodation-convergence conflict and other factors related to parallax, depth and binocular mismatches in 3D. Researchers have reported that watching movies in 3D produces higher level of discomfort compared to 2D [3].

The rest of the paper is organized as follows. Section II discusses background theory of visual fatigue and visually induced motion sickness (VIMS) and briefly explains the idea of the conducted experiment. Section III provides details about the experiment and participant selection. Section IV discusses the results from subjective rating and objective recordings. In Section V, we present discussions on the findings. Section IV gives the overall conclusion of the work performed based on the results achieved.

II. Background

A. Visual system and Visual fatigue

Focusing of any object on the retina is done by the process of accommodation and vergence. The two processes take place simultaneously to produce a clear image of the object. Focusing of lens produces image to be properly focused on the retina. This focusing is done by the process of accommodation. Vergence is the inward and outward movement of both eyes in horizontal direction because of near and far objects. The point where two eyes coincide is the focus point and at the same time accommodation makes the lens to focus on the same point. The point of focus for eyes is the same while the peripheral vision is different hence making a complete picture. The brain fuses the two pictures making it one. In 3D stereoscopy, humans are frequently focusing on objects in different frames and producing vergence-accommodation response more often. This may be the cause of visual fatigue and visual discomfort during watching 3D. A survey reports that large binocular disparity in 3D images can create problem for the brain to fuse the two images thus producing visual fatigue [4]. The severity of fatigue depends upon susceptibility of a person to motion sickness.

B. VIMS

The problem of visual fatigue varies from person to person and often leads to motion sickness. A percentage of the population viewing 3D movies suffer from symptoms such as headache, dizziness and nausea. A study [5] reports that 5% of viewers of 3D movies experienced nausea and disorientation regardless of the duration of the movie. Initiation of the symptoms of VIMS is mostly from the ocular part. Eye strain, focusing difficulties and discomfort in watching are the basic terms that are used to identify occulomotor symptoms. A research was done in which 171 adults took part [6]. They watched a 3D movie and then responded to a questionnaire at three different points in time.

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The results from the questionnaire indicate there is a high prevalence of VIMS when watching 3D movies and the research concluded that increasing the numbers of 3D movies might increase the risk to public health.

C. Objective

The concept of the experiment is to stimulate the brain with a movie that can induce motion sickness on a notable scale. The stimulus was presented in both 2D and 3D to find the difference in the level of motion sickness induced. The study follows an independent design with randomized trials. This was done to ensure that the study is not biased and there is no effect of boredom or adaptation to the stimulus.

III. Methodology

A. Sample Size

The sample size for the experiment is calculated from the freely available software PS (Power and sample size calculation) [7] using uncorrected chi-squared test. Participants are allocated to either 2D or 3D movie watching by stratified sampling method. Stratified sampling was done on the IBM SPSS software.

B. Sample size formula

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

α = significance level, 0.05

P = power of the study, 80%

p_1 = probability of motion sickness in 2D case, 30 %

p_2 = probability of motion sickness in 3D case, 70 % selected for fixed base simulators with Computer Integrated Graphics

n = 23 participants for one group

The probability of motion sickness in 3D is set to 70% based on the percentage of motion sickness occurrence for fixed base computer integrated graphic simulators [8].

C. Participants

Students from Universiti Technologi PETRONAS were recruited for the experiment. They are from different races and geographical regions. All participants were asked to give written consent before participating and were free to withdraw from the experiment at any time. Before the experiment, a complete eye assessment was performed by an ophthalmologist. This includes visual acuity, refraction and fundus examination. Participants fulfilling the inclusion criteria are included in the study. The study had received ethical approval from Universiti Sains Malaysia.

D. Stimulus

The stimulus used is a view captured from a camera while moving along streets, where the camera is rotated on the pitch and roll axes. Each rotation has duration of one minute and repeated alternately. Amplitude of rotation was 30 degrees with temporal frequency of 0.167Hz. The stimulus was obtained and used with permission from the authors of [9]. It has been reported that this stimulus produces VIMS with average severity level i.e. neither high nor low.

E. Measurements

The measurements include both physiological and psychological data. The psychological data is measured using the Simulator Sickness Questionnaire (SSQ) [10]. The participant is given the SSQ at the end of the movie. Two versions of the SSQ are used – the first one is in Malay [11] and the other one is in English. For the physiological data, electroencephalography (EEG) and electrocardiography (ECG) are recorded simultaneously.

F. Apparatus

The full experimental setup included three computers with E-Prime, Net Station, and Tobii Studio software. The stimulus is presented on a 40" Passive 3D LCD TV (LG). E-prime is used to synchronize Tobii Studio and Net Station. Tobii Studio is used to present the movie on the 3D screen, while Net Station is used to acquire the physiological data i.e. EEG and ECG. ECG is recorded using two Ag-AgCl electrodes placed just above the clavicle, with a sampling rate of 250Hz.

G. Procedure

The experimental procedure includes three tasks; an eye close (EC) task for 5 minutes, eye open (EO) task for 5 minutes, and watching the movie for 10 minutes. EC and EO are performed as routine recordings for EEG. The average duration for an experiment is 1.5 hours.

H. Pre-Processing

The data is first preprocessed on the Net Station software with a band pass filter of 0.3Hz – 48Hz to remove unwanted noise. A Net Station built in algorithm for QRS complex detection is run to find the peaks of QRS complex in ECG data. The processed file is then exported in .mat format with individual arrays of signals and events for further processing in MATLAB.

I. ECG Data 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 already detected are used to find the time interval between the two adjacent R waves. Next, the temporal frequency components of the R-R interval are calculated using 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 [12]. It has been reported that heart rate variability can be helpful in predicting mental stress [13]. Hence, we can say that if someone is watching a movie and suffering from sickness symptoms at the same time, he must be under stress, which can be detected from the HRV components.

IV. 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 1. The figure shows sub scores for nausea (N), occulomotor (O) and disorientation (D)

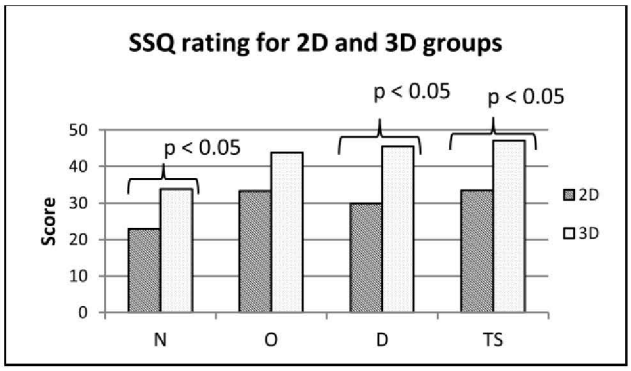

Figure 1. Average SSQ score for 2D and 3D condition

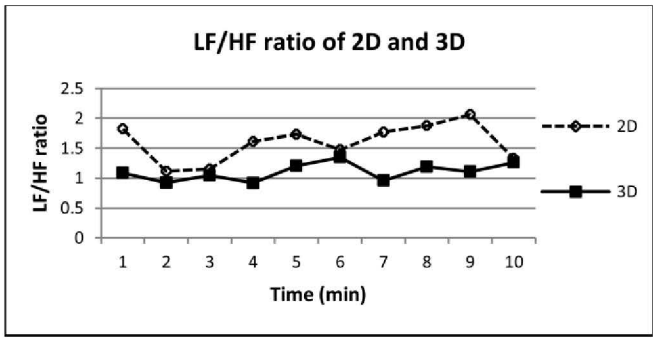

Figure 2. Ratio of LF/HF for 2D and 3D movie watching for VIMS condition.

symptoms and also the total score (TS) for 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 [9].

The mean values for LF/HF ratio for 2D and 3D VIMS condition are presented in Figure 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. The average values for 2D and 3D movie watching are presented in Table I with their corresponding p-values.

V. Discussion

Even though not all participants who watch 3D movies get sick, from the SSQ results, we can deduce that in general, the 3D movie induces higher levels of motion sickness symptoms compared to the 2D movie. We can explain the results of the LF/HF ratio as follows. 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[14]. Since the ratio of LF/HF is higher in 2D than in 3D, thus HF is more dominant in 3D. 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 in a way that if there is no stressful condition on the participants, the parasympathetic system should not be activated. If we analyze the curve of 2D condition with respect to time, initially it was high for the first minute and drops down. Later on the curve is increasing 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, whereas the 3D curve is continuously changing which shows that the sympathetic activity is counter balanced as each minute progresses. Only at the 6th minute the ratio increases compared to the 5th minute, while the trend in the curve changes at every minute. 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 [15]. 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 [16]. Increases in HF power have also been reported before generation of strong nausea [17]. These results do not have strong correlation with each other. The reason behind different results can be due to different experimental protocols. 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 changes in parallel to ECG signals and can help in identification of VIMS. In [18] the experiment on a video game provides a relation between the two measurements that are EEG and ECG and thus it is applicable to implement and find the correlation between the two objectively measured signals in this experiment as well.

VI. Conclusion

Participants watching 2D report significantly lower symptoms of motion sickness from the participants who watched 3D. The participants were unaware of symptoms reported from other viewers and was shown stimulus only once. From this we come to conclude that 3D stereoscopy produces higher symptoms of VIMS. We also came to a

TABLE 1 Average values of LF/HF ratio for 2D and 3D movie with VIMS condition.

Minute	VIMS condition		
	3D	2D	p-value
1	1.086	1.822	0.064
2	0.922	1.114	0.213
3	1.046	1.151	0.339
4	0.915	1.615	0.014
5	1.207	1.732	0.186
6	1.348	1.477	0.262
7	0.957	1.769	0.016
8	1.189	1.875	0.042
9	1.107	2.063	0.013
10	1.261	1.326	0.289

conclusion that many studies have reported contradictory results from the LF and HF component of HRV analysis and that there is a major role of the experimental protocol on the ECG data. The results from our experiment contradicts the results presented in [9]. This may be due to the fact that our study is based on independent sample while in the previous study, the same participants undergo both 2D and 3D viewing. There are two cases in this kind of study.

- In the first case, participants watch 2D first and then 3D.
- In the second case, participants watch 3D first and then 2D.

For the first case participants might have some interest to watch the movie again in 3D, as there is a factor of depth involved. For the second case when they already have seen the movie in 3D there might be a loss of interest and effect of boredom induced which might have affected the results of these participants. The EEG data was also collected during experiment. Therefore, analysis of EEG would give more insight of each participant's behavior and might help in understanding the ECG data, if any relationship exists.

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