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3D Fatigue from Stereoscopic 3D Video Displays: Comparing Objective and Subjective Tests using Electroencephalography

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***Abstract*—The use of stereoscopic display has increased in recent times, with a growing range of applications using 3D videos for visual entertainment, data visualization, and medical applications. However, stereoscopic 3D video can lead to adverse reactions amongst some viewers, including visual fatigue, headache and nausea; such reactions can further lead to Visually Induced Motion Sickness (VIMS). Whilst motion sickness symptoms can occur from other types of visual displays, this paper investigates the rapid adjustment triggered by human pupils as a potential cause of 3D fatigue due to VIMS from stereoscopic 3D displays. Using Electroencephalogram (EEG) biosignals and eye blink tools to measure the 3D fatigue, a series of objective and subjective experiments were conducted to investigate the effect of stereoscopic 3D across a series of video sequences.**

Keywords—3D, 3D video, stereoscopic display, 3D fatigue, VIMS, EEG

I. INTRODUCTION

Stereoscopic technology is used to increase the depth of the 2D image [1]. The human eye acts like a camera to capture images with the retina, effectively the image sensor. The left and right eyes capture two separate images, and the fusion of the two images in the brain forms a single image with depth to create a 3D image. The growth of 3D display technology has led to the proliferation of 3D movies on the commercial market. However, reports of some audiences experiencing side-effects such as eyestrain, headaches and nausea after watching 3D movies has led to researchers' conducting studies to find that people may feel uncomfortable or have visual fatigue while watching or after watching stereoscopic movies or images [2].

Quan et al. [3] studied 3D visual attention and the perception of 3D content; however, it is important to differentiate between the perception of 2D and 3D content by end-users. Naqvi et al. [4] proposed a method to compare both 2D and 3D stereoscopic videos and investigate Visually Induced Motion Sickness (VIMS) and the ratio of low frequency to high frequency components in video content, verifying that 3D stereoscopic videos produced more pronounced symptoms of VIMS. Liu et al. [5] proposed an alternative method to recognize the dominance level of emotion interaction using an EEG approach; however, this method used auditory stimulus only and did not consider visual stimulus.

Whilst existing research explores VIMS in 3D stereoscopic displays, few studies have investigated VIMS from EEG signals using high quality video stimulus. Therefore, this paper explores a series of objective and subjective tests to investigate 3D fatigue in order to identify the effects of VIMS. In the following, Section II discusses the background theory underpinning visual fatigue and experimental methodology undertaken. Section III describes the proposed experimental process, detailing the objective and subjective evaluations. Section IV presents and discusses the experimental results obtained, whilst Section V concludes this paper.

II. BACKGROUND

To study the functional changes in the human body that may occur in response to viewing 3D stereoscopic images or videos, a number of measurement tools to assess visual fatigue symptoms such as VIMS and SSQ are discussed as follows.

A. VIMS

The most common subjective evaluation of VIMS is the Simulator Sickness Questionnaire (SSQ) [6]. The SSQ is used to assess motion sickness [7], and the questionnaire for the 3D fatigue test includes the following parameters: general discomfort, difficulty focusing eyestrain, increased salivation, difficulty concentrating, headache, blurred vision, vertigo, nausea, burping and dizziness, tired eyes, double vision, heart palpitations, etc. Experiments conducted by Solimini et al. [8] examined VIMS when watching 3D movies, where the experimental results indicated that viewers might have an increased risk of potential health problems such as photosensitive epilepsy in future when increasingly watching 3D movies.

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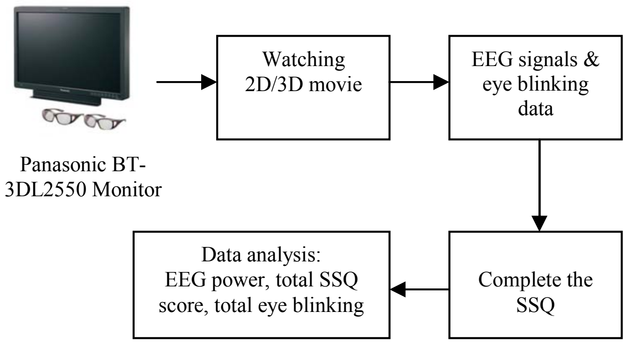

Fig. 1. Proposed experimental methodology

B. EEG

Electroencephalography (EEG) is a technique to record and interpret bioelectrical activities in the brain, and can reflect the recognition of emotions in humans [9] [10]. EEG signals are classified into delta, theta, alpha, beta and gamma waves, according to the following frequency bands [9]:

- Delta waves (1-3Hz): related to deep sleep
- Theta waves (4-8Hz): correlated to emotional stress for adults
- Alpha waves (9-14Hz): reflect physical relaxation, meditation and creative visualization
- Beta waves (15-30Hz): reflect current emotional state and focus level
- Gamma waves (above 30Hz): can be used to diagnose some brain illnesses

Existing research indicates that brain wave responses to emotional patterns are associated with alpha wave properties [11]. Such associations can be observed through non-invasive multi-channel EEG recordings and experiments based on the International Federation of Clinical Neurophysiology (IFCN) standards [12] [13].

III. Proposed Methodology

Fig. 1 illustrates the proposed experimental methodology. For the subjective assessments, a series of 2D and 3D video sequences were displayed to stimulate brain activity and therefore potentially induce visual fatigue. EEG tests and eye detection methods were used to measure the level of visual fatigue.

Firstly, when a participant viewed a 2D or 3D movie, EEG signals and eye blinking data are captured by brainwave software from the NeuroSky Mindwave EEG headset and eye detection software from the Mindwave Eye. The brain wave software was used to record EEG signals, whilst the eye detection software can track the eye blinking during the experiment, assisted by an embedded camera in the computer. Subsequently, the participants were required to complete the SSQ after each video sequence. The captured biosignal data and SSQ scores were then analyzed to study the fatigue level, total SSQ scores, and total eye blinking frequency across all the video sequences.

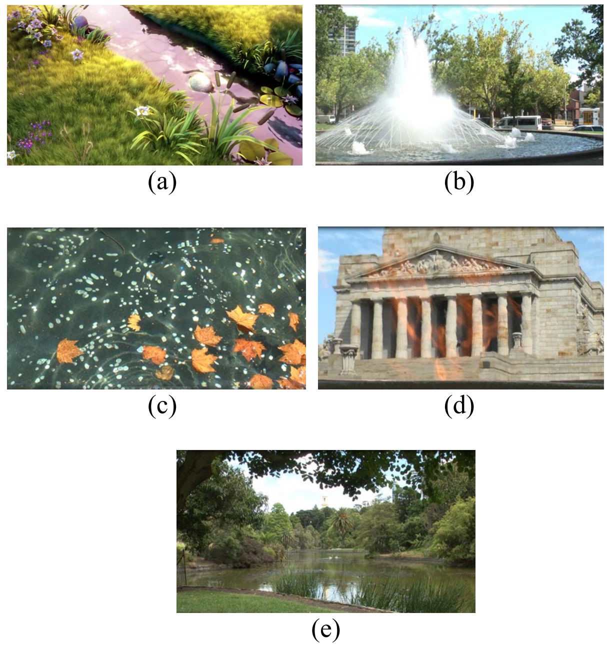

Fig. 2. Video sequences extracted from 5 database sequences including: (a) 'Sunflower', (b) 'Water fountain', (c) 'Wishing well', (d) 'Shrine of Flame', and (e) 'Garden'

A. Experimental Appatatus

The experiment utilized two computers equipped with a NeuroSky Mindwave headset and accompanying brain wave and eye detection software. The 3D stereoscopic video sequences were presented on a 25.5'' Panasonic BT-3DL2550 Full HD LCD 3D monitor. All 2D and 3D video sequences were recorded and displayed in 1920x1080 HD resolution, sequences were extracted from the RMIT3DV [14] and Big Buck Bunny [15] databases, as shown in Fig. 2. If a database video sequence was shorter than 5 minutes, the sequence was repeated to achieve the required duration of 5 minutes.

B. Experimental Procedures

Based on the THX Cinema Certification specification [16], participants sat in front of the 3D monitor at a 0.9m viewing distance with 36 degree viewing angle to watch a 2D movie for 5 minutes. The corresponding EEG and eye movement data were captured and collected. After a 5-minute rest, the participants watched the same video sequence in 3D for 5 minutes and the EEG and eye movement data were again recorded. The participants were then asked to complete the SSQ. Following this experimental procedure for each 2D/3D video sequence pair, each participant was required to watch 5 sets of 2D and 3D video sequence pairs to complete the experiment. The paired video sequences were shown in random to prevent bias, where the average duration of the experiment was 1.5 hours.

C. EEG Data Analysis

Hirvonen et al. [17] proposed the use of brain wave energy test methods for the measurement of 3D fatigue, with reference to

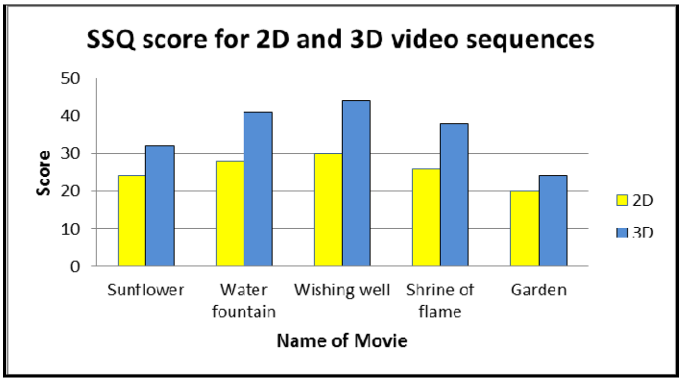

Fig. 3. Average SSQ score for 2D and 3D video sequences

TABLE I. TOTAL EYE BLINKING FOR 2D AND 3D VIDEO SEQUENCES

Name of Movies	***2D***	***3D***
	Eye Blinking in 5 minutes	*Eye Blinking in 5 minutes*
Sunflower	56.4	54.3
Water fountain	53.7	49.2
Wishing well	50.4	45.3
Shrine of flame	57.8	55.2
Garden	63.4	60.1
Average	**56.3**	**52.8**

the International Federation of Clinical Neurophysiology (IFCN). Equations (1) and (2) below calculate the power of brain wave energy corresponding to EEG frequency bands:

$$Power_1 = (Alpha + Theta) / Beta \quad (1)$$

$$Power_2 = (Alpha + Theta) / (Alpha + Beta) \quad (2)$$

where:

$$(Power_{1,2} < 0.05) = \text{Low fatigue level}$$

$$(Power_{1,2} > 0.05) = \text{High fatigue level}$$

That is, the metrics proposed by Hirvonen et al. [17] correlate brain wave energy to varied degrees of fatigue.

IV. RESULTS AND DISCUSSION

For the experiments conducted in this paper, fifteen participants (12 males and 3 females) aged from 18 to 38 years old were required to wear a brainwave headset. Prior to the experiment, participants completed 3D vision tests based on ITU-R BT.2021 standard [18].

A. Simulator Sickness Questionnaire (SSQ)

Fig. 3 shows the average SSQ score across all participants for 2D and 3D video sequences. For all movies, the total SSQ scored in 2D condition is lower than in the 3D condition. The result suggests that the VIMS in 2D condition is lower than in 3D condition.

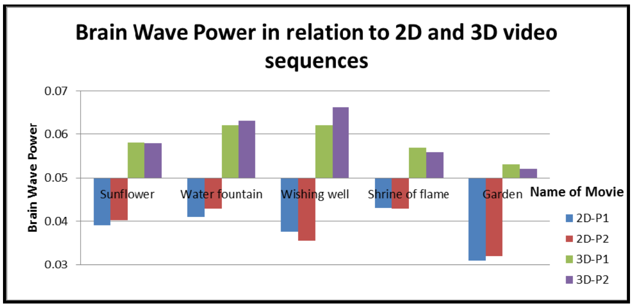

Fig. 4. The brain wave power distribution of 15 participants in relation to 2D and 3D video sequences

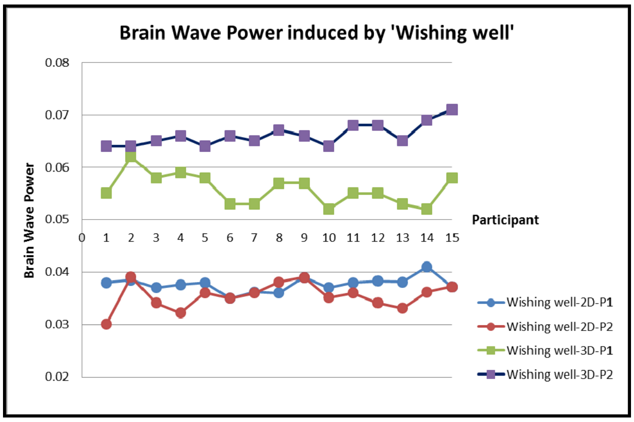

Fig. 5. The brain wave power distribution of 15 participants for 'Wishing well' video sequence

B. Eye blinking activity

Table I shows the average frequency of eye blinks in a 5-minute period of each video sequence. Across all 15 participants testing 5 video sequences in both 2D and 3D, from Table I it can be seen that the frequency of eye blinking in 2D condition are greater than in 3D condition. The result reflects that the visual fatigue in 2D condition may be lower than in 3D condition.

Among five 3D movies, the 'Wishing well' video sequence caused the least eye blinking, possibly due to the rapid water movement, unstable lighting conditions and shadows from the water and also interactions with objects underwater. Similarly, the 'Water fountain' video sequence may have also caused less eye blinking, as the water fountain is the main object focus of the scene, where the water movement also rapidly changes.

C. EEG brain activity

Fig. 4 shows the brain wave power across all 5 video sequences in 2D and 3D, where P1 and P2 represents the brain wave power calculated from Equations (1) and (2), respectively. The average brain wave powers of all 3D movies were higher than the fatigue threshold level of 0.05 (as discussed in Section IIIC), representing a higher level of visual fatigue for viewers. In contrast, it can be seen from Fig. 4 that all 2D movies exhibited brain wave power under the fatigue threshold. Whilst Fig. 4 illustrates the brain wave power averaged across all participants, further analysis for each participant across all 3D movies found that more than 90% of the brain wave power from individual participants watching 3D videos was higher than the fatigue threshold level.

As the 'Wishing well' video sequence caused the highest fatigue level as shown in Fig. 4, the brain wave power for each participant is shown in Fig. 5. There were significant differences of two brain wave powers in which suggesting different emotion recognition of human from two different brain wave powers discussed in [17]. The highest level of fatigue and nausea was recorded when the participants watched the 'Wishing well' video sequence suggests that 3D video sequences that contain over-distorted images, time-varying depth perception and high frequency of motion changes may lead to visual fatigue. The 'Garden' video sequence caused the lowest fatigue level, potentially due to the minimal on-screen motion and smaller parallax.

V. Conclusion

The experiments conducted in this paper have investigated 3D fatigue using the relative brain wave power of four EEG frequency bands, eye blink detection, and evaluation using the Simulator Sickness Questionnaire (SSQ). The preliminary experimental results indicated that participants watching 2D video sequences exhibited more eye blinking (and therefore less visual fatigue), and a lower EEG calculated fatigue level than when watching 3D video sequences. Consistent with the research findings in [4], the experimental results suggest that 3D stereoscopic videos may result in higher VIMS. In future, to increase the accuracy of the VIMS evaluation, an extensive SSQ should be conducted in order to compare the questionnaire results with the fatigue level experimentally recorded with biosignals. In addition, a medical grade EEG apparatus that can operate with up to 16 contact points simultaneously for the collection of brain waves may also result in more accurate EEG recordings. Finally, the sequence of watching 2D and 3D movies might also influence the results. Therefore, further investigation can be conducted to investigate how the order of 2D and 3D video viewing may affect the behavior of participants and the level of visual fatigue.

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