Evaluation of Passive Polarized Stereoscopic 3D Display for Visual & Mental Fatigues

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Abstract—Visual and mental fatigues induced by active shutter stereoscopic 3D (S3D) display have been reported using event-related brain potentials (ERP). An important question, that is whether such effects (visual & mental fatigues) can be found in passive polarized S3D display, is answered here. Sixty-eight healthy participants are divided into 2D and S3D groups and subjected to an oddball paradigm after being exposed to S3D videos with passive polarized display or 2D display. The age and fluid intelligence ability of the participants are controlled between the groups. ERP results do not show any significant differences between S3D and 2D groups to find the aftereffects of S3D in terms of visual and mental fatigues. Hence, we conclude that passive polarized S3D display technology may not induce visual and/or mental fatigue which may increase the cognitive load and suppress the ERP components.

Index Terms— **event-related potential (ERP), passive polarized stereoscopic 3D, visual and mental fatigues, and P300**

I. Introduction

The stereoscopic 3D (S3D) technologies have been growing in the entertainment market, especially in two commonly used 3D display technologies—active shuttered and passive polarized. Active shuttered 3D creates the illusion of a 3D image by using active shuttered glasses and shows the images alternatively in a sequential manner to each eye in synchronization with the refresh rate of the screen. The glasses containing liquid crystal and a polarizing filter turn into darken alternately one eye lens and then the other when voltage is applied [1]. Passive polarized 3D projects each image with mutually orthogonal polarizations and each eye perceives different image simultaneously due to polarizing glasses.

Despite the rapid and growing developments in the 3D technology, 3D visual discomfort, visual fatigue, and mental fatigue continue to be reported [2, 3]. The visual discomfort is a perceived degree of annoyance assessed by the viewers themselves during watching S3D contents or any negative sensation related to a given visual task [2]. It can be measured by simply asking the viewers to report his experience of watching S3D contents. However, it may appear and disappear rapidly by either the viewer close his eyes, divert focus from the screen or terminating the visual task. In contrast, the visual fatigue and mental fatigue are supposed to have longer rise and fall time than visual discomfort. The presence of visual and mental fatigues may be evaluated with subjective method i.e. one or several symptoms reported by the viewers (e.g. nausea) and also by objective measurement such as eye blinking rate [4, 5] and event-related potentials (ERPs) [3, 6]. In addition, the visual and mental fatigues continue for some time even the S3D watching is finished. It may not be diagnosed instantly in conjunction with a certain S3D based visual task [2]. In this paper, we only focus on the visual and mental fatigues and objective assessment of passive polarized S3D display using ERP.

Many studies had used subjective and objectives methods for measurements of visual and mental fatigues, such as questionnaire based subjective assessment, pupil tracking & eye blinking rate and bio-signals based objective evaluation [3-5, 7]. Event related potentials (ERP) are an objective measurement method of visual and mental fatigues, which directly reflects the cognitive state of the brain [7]. P300 (P3) component is strongly associated to the level of attention and reflects the degree of stimulus processing cognitively [8]. It has been shown that the P3 amplitude provoked by cognitive task loading decreases due to increase in the cognitive task difficulty [8]. Therefore, it is useful to assess the depth of cognitive information processing. The visual and mental fatigues induced by cognitive loading due to watching S3D videos can be measured by the ERP components i.e. decreased P3 amplitude and prolong P3 latency reveal that visual and mental fatigues are induced [7, 9, 10]. However, the previous studies reported the visual and mental fatigues for active shuttered 3D display [9, 11]. Thus, an important question arises that whether the passive polarized S3D display also induces such effects (visual and mental fatigues) as reported for active shuttered 3D display. In addition, the previous studies used ERP as objective

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measurement for visual and mental fatigues but did not consider the intelligence ability of the participants which is correlated with the ERP components, e.g. high P3 amplitude at centro-parietal regions is positively correlated with individuals' intelligence ability [12]. Thus, if two separate groups of participants are exposed to 2D and S3D contents then their intelligence ability may be a factor of biasness if it is not controlled. Moreover, the previous studies did not use 'stereoscopic 3D visual stimuli' in the ERP tasks. They have used 2D based visual stimuli in the oddball task [10, 13]. It is obvious that visual or mental fatigues often disappear after some time of 3D visualization. Therefore, in this study the visual stimuli in the oddball task were 3D based for S3D group and 2D based for 2D group. Thus, if fatigues are occurred in the S3D group due to S3D visualization, it should not disappear in the ERP recording. This study evaluates the visual and mental fatigues using ERP for passive polarized S3D display and compared with traditional 2D display by employing a sample of sixty-eight healthy participants. The participants are equally categorized into 2D and S3D groups; while their age and fluid intelligence ability are tightly controlled between groups.

On the basis of technological differences between active shuttered and passive polarized displays and considering the related studies investigating the visual and mental fatigues of active shuttered 3D display [9, 11], we hypothesized that the amplitude of P3 of S3D group would be reduced if visual and/or mental fatigues occur as compared to 2D group. The basis of our hypothesis is that relatively less attentional resources are available when an individual is in a cognitive fatigue state which resists to focus and divide attention between visual stimuli [13]. Thus, affects the P3 amplitude and latency. Furthermore, the P200 (P2) of ERP is associated with the secondary processing of visual input and partially involved in cognitive processing [14]. Therefore, P2 component is included in the analysis.

The rest of the paper is organized as follows. Section II describes the materials and methods. Experimental results are described in Section III. Then follows the discussion part in Section IV and Section V concludes the paper.

II. MATERIALS & METHODS

A. Participants

Sixty-eight healthy university students (age: 18-30 years; $M=23.66$, $SD=\pm3.63$) were recruited to evaluate the visual and mental fatigues due to S3D visualization. They had normal vision and were free from medication and neurological disorders. All signed an informed consent document prior to beginning the trials. This study was approved by Ethics Coordination Committee of the Universiti Teknologi PETRONAS, Malaysia.

B. Experimental material & display technology

Stereoscopic 3D animated videos were used from 'Designmate, Inc.', which is commercially available at (www.designnmate.com). The selected animations were related to human anatomy and functions. Further, a '41' inch LG Passive Polarized 3D display with refresh rate 240-fps was used for visualization in this study. Visual stimuli 5cm large 'box (standard) and sphere (target)' were created using Autodesk 3d studio max 2012 for oddball paradigm (see, Fig. 1). Two cameras were used with 6cm distance between them to create separate images for left and right eyes with appropriate disparity. The left and right images were then rendered using stereo-photo maker (http://stereo.jpn.org/eng/stphmkr/) to generate stereoscopic 3D visual stimuli.

C. Experimental Tasks

Raven's Advanced Progressive Matrix (RAPM) is a non-verbal standard psychometric test used to measure fluid intelligence ability (for more detail about RAPM and its procedure, see [15]). Oddball paradigm is a commonly used task for cognitive and attention measurement in ERP studies. In this study, two visual stimuli—box and sphere shapes of size 5cm were used as standard and target stimuli, respectively (see, Fig. 1). For each trial, a standard (box) or target (sphere) stimulus was presented for 500ms with an inter-trial-interval (ITI) of 500ms between trials. The task required subjects to press "0" when a target stimulus appeared and 'not to respond' for a standard stimulus. Reaction time and correct target detection were recorded.

D. Experiment Procedure

Each participant was seated in a partially sound-attenuated room and briefed on the procedure. Each participant was asked to perform the RAPM test, which lasted in 40 minutes. After the RAPM test, an EEG cap was set as per procedure, which was followed by watching the stereoscopic 3D videos (2D group watched the videos in 2D mode and S3D group watched in 3D mode). The duration of watching videos was 30 minutes long. At the end of this session, participants were asked to perform the oddball task, which lasted about four minutes. A forty-one inch TV screen at a distance of 1.5 m from the participant was used. EEG signals were recorded using 128 channels Hydro-Cel Geodesic Net. The sampling rate was 250 samples per seconds and the impedance of all the electrodes was kept below 50 kΩ (recommended by manufacturer) and referenced to the central electrode position Cz.

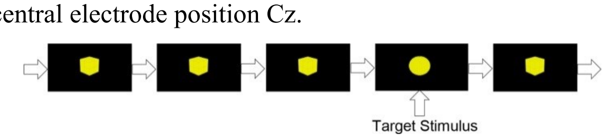

Fig. 1. Visual stimuli of oddball task (Box represents the standard stimulus and Sphere represents the target stimulus)

E. ERP Analysis

The continuous EEG data of each subject are preprocessed with Net-Station v4.5.4 (Electrical Geodesic, Inc. Eugene, OR, USA). The step by step process of ERP extraction is described here.

- The EEG signals were band passed (0.3-30 Hz, roll off 12dB octave) to remove DC components and high frequency muscular artifacts.
- Next, each individual EEG trial was segmented by using a 600ms window that comprised a 100ms pre-stimulus period as a baseline followed by a 500ms post-stimulus period.
- Individual trials were rejected, if containing artifacts (eye blinks and eye movements) i.e. the EEG amplitude exceeded maximum amplitude of ±90μV in any segment is excluded.
- All segments were manually visualized and contributions were rejected from electrodes that had lost contact in the event of widespread drift [16]. Bad channels were discarded from the segments before averaging using spherical spline method [17].
- There were a total of 135 trials in the oddball task, in which 40 trials contained target stimulus and 95 trials contained standard stimulus.
- Subsequently, individual averaged waveforms were computed for each experimental condition (target and standard). An averaged of retained good segments after artifact rejection in the individual averaged waveforms for target and standard condition in 2D and S3D group are 37.56 (±2.8) & 83.00 (±16.8), 36.56 (±4.1) & 78.12 (±17.2); respectively.
- Data were then re-referenced from a single vertex (Cz) to the averaged reference. Finally, a baseline correction was performed for each individual averaged waveform (per experimental condition) by subtracting the average voltage value, as computed in the baseline period, from the entire segment.

The locations of midline electrodes (Fz, Cz, and Pz) were selected for the ERP analysis [6, 7]. Mean response accuracy of oddball target detection and mean response times were computed for both groups. The ERP components P2 and P3 amplitudes and latencies were analyzed in 180-275ms and 275-500ms time window after the onset of target stimulus in the oddball paradigm.

III. Experimental Results

The mean age in years is 23.04±3.10 and 23.28±3.18 and mean RAPM score is 23.08± 6.16 and 23.18±5.77 for 2D and S3D group, respectively.

TABLE I
MEAN AND STANDARD DEVIATION OF ERPS AMPLITUDES

Group	P2 amplitude			P3 amplitude		
	Fz	Cz	Pz	Fz	Cz	Pz
2D						
Mean	4.06	4.23	3.22	3.86	5.04	5.46
SD ±	3.33	2.00	2.08	3.09	3.01	3.24
S3D						
Mean	4.05	4.02	2.91	4.08	5.21	5.14
SD ±	2.12	2.21	2.34	2.25	2.09	2.90

An independent t-test demonstrates that the response accuracy and response time are not significantly different between the S3D and 2D groups for the oddball paradigm ($t(66)=0.038$, $p>0.05$, Cohen's $d=0.01$; $t(66)=-0.278$, $p>0.05$, Cohen's $d=0.07$; respectively). We compare the P2 and P3 amplitudes and latencies in the oddball paradigm of both groups (Table I & II).

TABLE II
MEAN AND STANDARD DEVIATION OF ERPS LATENCIES

Group	P2 Latency			P3 Latency		
	Fz	Cz	Pz	Fz	Cz	Pz
2D						
Mean	253.44	258.72	226.72	303.68	408.32	396.68
SD ±	23.36	11.87	41.19	21.66	47.34	41.77
S3D						
Mean	252.75	255.62	211.50	336.31	412.62	395.75
SD ±	20.03	11.05	44.96	49.39	30.19	43.17

Boneferroni correction is employed to adjust the p-value for multiple independent t-tests and control the risk of type-I error in the ERP data analysis.

P2 Amplitude: For P2 amplitudes, an independent t-test shows that the P2 amplitudes are not significantly different between groups at Fz ($t(60)=0.025$, $p>0.05$, Cohen's $d=0$), Cz($t(60)=0.384$, $p>0.05$, Cohen's $d=0.1$), and Pz ($t(60)=0.542$, $p>0.05$, Cohen's $d=0.14$) sites. There are six potential outliers removed from the analysis of P2 and P3 amplitudes comparison. Hence, the degree of freedom (df) is 60 in the t-test results.

P3 amplitude: an independent t-test demonstrates that the P3 amplitudes are not significantly different between groups at Fz ($t(60)=-0.321$, $p>0.05$, Cohen's $d=0.09$), Cz($t(60)=-0.258$, $p>0.05$, Cohen's $d=0.07$), and Pz ($t(60)=0.399$, $p>0.05$, Cohen's $d=0.11$) sites.

P2 & P3 latencies: For P2 and P3 latencies, an independent t-test shows that the latencies of P2 and P3 components are not significantly different between the groups, except the P3 at Fz where the p-value=0.019. However, this p-value is also greater than the Boneferroni corrected alpha (0.016). Thus, the result of P3 latency at Fz may not be considered as significantly different. Fig. 2 presents the distribution of P2 & P3 amplitude and latency for both groups.

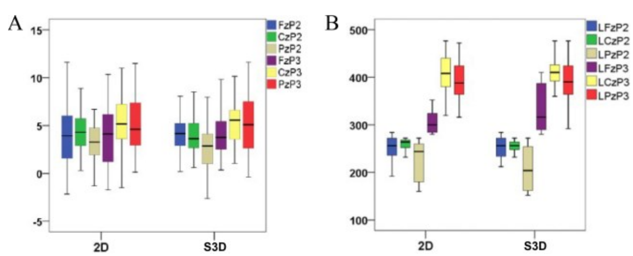

Fig. 2. Box plots of (A) P2 and P3 amplitude and (B) latency distribution at midline sites (Fz, Cz, and Pz).

IV. Discussion

In this study, visual and mental fatigues for passive polarized S3D videos and the S3D based visual stimuli in the oddball task are investigated. We have hypothesized that if visual and/or mental fatigues occur, the participants of S3D group would show reduced P3 amplitude and prolong P3 latency. However, no such after-effects of passive polarized stereoscopic 3D display on the ERPs components are found. The ERPs components P2 and P3 amplitude and latency did not show any significant differences between groups that can be linked to visual fatigue or mental fatigue due to watching S3D video or use of S3D visual stimuli in the oddball task (see Fig. 3).

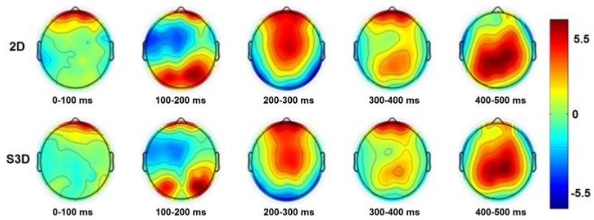

Fig. 3. Topographic maps of mean amplitude averaged over 100 ms time window from 0 to 500 ms (post-stimulus period) for both groups.

Both groups are treated equally in the experiment and only the mode of the display is different, i.e. S3D group watched the videos and performed the oddball task in 3D display mode while 2D group watched and performed the oddball task in 2D display mode. Therefore, these results suggest that there are no aftereffects of the stereoscopic 3D display technology in term of visual and mental fatigues that is measurable on ERP components as previously reported for active shuttered stereoscopic 3D technology [9, 11].

The authors assumed the following possible reasons that S3D group shows similar results in oddball task compared to 2D group.

- The visualization of S3D contents up-to 30 minutes duration may not induce enough visual or mental fatigues which are measurable using ERP parameters.
- The S3D materials used in this study are academic based and may not contains such scenes which are capable of capturing high attention of the viewers, for example a collision scene in an action 3D movies may capture high attention of the viewers.
- The age range of the participants used in this study is 18-30 years. It may be possible that this age range of the viewers perceived little or no effects of 3D visualization in term of visual or mental fatigues.
- The passive polarized S3D display technology used in this study presents different images to both left and right eye simultaneously. This may avoid the occurrence of corresponding problem [18] in the binocular fusion which may induces the visual and mental fatigues as reported in early studies for active shuttered 3D display [9].

These assumptions need further investigation, which may be implemented in future studies by adding more measurement parameters such as eye blinks, ECG signals, EEG signals, and subjective questionnaire.

V. Conclusion

The ERP components (P2 & P3) are used to evaluate and compare the S3D display with traditional 2D display. The division of the participants into two groups (2D and S3D) was based on the mean score of the fluid intelligence (RAPM test) and the mean age. Thus, we conclude that the passive polarized stereoscopic 3D display may not induce any such visual and/or mental fatigue, at least not to an extent that is observable by an oddball task—well established event related potentials paradigm for cognitive measurement. Future studies may be implemented to investigate the effects on longer duration of watching S3D contents with both passive polarized and active shutter 3D technologies to confirm and validate the results of this study.

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