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Effects of Stereoscopic 3D Display Technology on Event-related Potentials (ERPs)

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Abstract—**The purpose of this study is to explore the effects of stereoscopic 3D (S3D) display technology on event-related brain potentials (ERPs). A sample of thirty-four healthy participants was subjected to an oddball paradigm after being exposed to stereoscopic 3D contents with passive polarized display or traditional 2D display. The participants were randomly assigned to two groups—2D group and S3D group; in such a way that their intelligence ability and age were controlled between the groups. The behavioral and ERP results did not show any significant differences between S3D and 2D groups for either ERP components (amplitude and latency) or accuracy and response time of the target detection. These results suggest that passive polarized S3D display technology may not induce any effects (cognitive or visual fatigue) which may disturb the ERP components.**

I. Introduction

The stereoscopic 3D (S3D) display technologies have been developing in the entertainment market since the successful launch of 3D movie "Avatar" by Nickelodeon Animation Studios, USA in the year 2009. Due to the stereopsis, S3D heighten viewers' interest and sense of immersion. However, a number of negative effects of viewing S3D contents have been reported such as visual and cognitive fatigues, visually induced motion sickness (VIMS) and symptoms of visual discomfort. Such negative effects have been measured by subjective and/or objective assessment methods, e.g. asking the viewers to fill a structure questionnaire after S3D viewing and recording event-related brain potentials (ERPs) [1-4]. ERP is objective measurement method of the cognitive and visual fatigue, which directly reflects the cognitive state of the brain, especially the P300 (P3) component [5]. As the S3D visualization involved cognitive processing and the ERPs have high temporal resolution and can provide continuous monitoring of neuronal changes. Thus, the visual and cognitive fatigues induced by viewing S3D can be measured by the ERPs components (amplitudes and latencies).

Recently, few studies have proposed that visual and cognitive fatigues may be due to cognitive strain provoked by viewing S3D which may result in decaying selective attention [6, 7]. The neurons involved in the processing of attended stimuli (target) fire more strongly as compared to other neurons processing the unattended stimuli (non-target) [3]. However, cognitive fatigued persons may be in troubled recognizing target and non-target information, resulting unable to effectively focus on target stimuli and these individuals are easily distracted. The previous ERPs studies investigated the visual and cognitive fatigues due to viewing S3D contents have used active shuttered S3D displays and compared with 2D display. In addition, these studies employed a single group of participants exposed to same contents both in S3D and 2D displays. The use of same contents may be biased due to watching two times (one time in 3D and again in 2D). More importantly, the visual and cognitive fatigues due to S3D visualization using passive polarized 3D display are not clear.

The purpose of this study is to evaluate the effects (visual and cognitive fatigues) of passive polarized S3D display technology and compared with traditional 2D technology. On the basis of previous related studies reported the visual and cognitive fatigue induced by watching S3D [3, 7], we assumed that the amplitude of ERP components of S3D group would be reduced if cognitive and visual fatigue occurs as compared to 2D group. Therefore, we employed two homogenous groups of participants, which are controlled in term of intelligence ability, age and gender, exposed to S3D contents using passive polarized 3D display. One group watched the contents using the 2D mode of the display and other group watched using S3D mode. Immediately, after visualization session, both groups performed the oddball paradigm, where ERPs were recorded. The P200 (P2) and P300 (P3) amplitudes and latencies were computed and compared using statistical tests. This paper is organized as follows: Section II describes details of the methodology; Section III presents our results and discussion; and Section IV concludes the paper.

II. Methods

A. Study Participants

A sample of thirty-four healthy participants (age: 18-30 years; M=23.11, SD=3.71) were recruited for the experiment. All the participants signed an informed consent document before starting the experiment. All of them had normal or 'corrected to normal' vision and were free from any neurological disorders and medication. The protocol of this study was approved by the Ethics Coordination Committee of the Universiti Teknologi PETRONAS, Malaysia.

B. Stimulus

Autodesk 3ds studio max 2012 was used to construct stimuli (standard: 5cm large box; target: 5cm sphere) for oddball paradigm. For stereopsis, two cameras placed at distance of 6cm away from each other were used to create

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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. Raven's Advanced Progressive Matrix (RAPM) Test

The RAPM [8] is a non-verbal test used to measure reasoning and intellectual ability of an individual. This test was used to control the intelligence ability of two groups. The detail structure of this test and the administration procedure can be found in the previous studies [8-11].

D. Oddball Paradigm

The visual oddball paradigm/task is widely reported task for ERPs studies. In this study, visual stimuli are presented to assess neural activity during cognitive and attention demanding events. All participants performed the visual oddball task where box and sphere shapes were used as standard and target stimuli, respectively. The task consists of 135 trials, in which 95 trials consist of standard stimulus and 40 trials consist of target stimulus. The presentation duration of each stimulus was 500ms and there was 500ms inter-trial-interval (ITI) between consecutive trials. Participants were instructed to respond as quickly as possible by pressing '0' button if target stimulus is displayed or otherwise 'not to respond' while avoiding errors. Response time and correct target detection were recorded. The duration of the task was approximately four minutes and it was performed immediately after viewing S3D or 2D contents. This task was modified according to [12].

E. Stereoscopic 3D Contents and Display Technology

Stereoscopic 3D animated contents (video) were used from Designmate, Inc., which is commercially available at (www.designmate.com). The selected animations are related to human anatomy and functions. A '41' inch LG 3DTV with passive polarized glasses was used in this study. The spatial resolution was 1920×1080 pixels and the refresh rate was 240-fps.

F. Procedure and EEG Recording

In the experiment, each participant was seated in a partially sound-attenuated room and explained the procedure of the experiment. The experiment consists of three tasks: (1) RAPM test, (2) watching 3D/2D contents, and (3) Oddball task. First, each participant was asked to perform the RAPM test, which was completed in 40 minutes. A five minutes time was given to the participant to relax. Then, the participants watched the stereoscopic 3D contents. If the participant belongs to S3D group then contents were displayed on TV while S3D mode was on, else participant belongs to 2D group, so contents were presented on TV with 2D mode. The viewing distance was 1.5 meter and duration of the contents was 30 minutes. After the 3D viewing session, an EEG cap was set, as per procedure, and participants were asked to perform the oddball task, which lasted about four minutes. The oddball paradigm was implemented with the E-Prime Professional 2.0 (Psychology Software Tools, Inc., Sharpsburg, PA). EEG signals were recorded using 128 channels HydroCel Geodesic Net with 250 samples per seconds and the impedance of all the electrodes was kept below 50 KΩ and referenced to the central electrode position Cz.

G. Preprocessing and ERP Extraction

The raw EEG recordings of each participant were preprocessed using Net-Station v4.5.4 (Electrical Geodesic, Inc. Eugene, OR, USA). A brief description of the preprocessing and ERP extraction is provided as follow.

- First, a band pass filter was used (0.3-30Hz, roll off 12dB octave) to remove DC components and high frequency muscular artifacts from the raw EEG.
- Next, each participant EEG recording was segmented by using a 600ms window that consisted a 100ms pre-stimulus duration as a baseline and a 500ms post-stimulus duration.
- Each EEG segment was checked for artifacts, and rejected, if containing artifacts (eye blinks and eye movements) i.e. the EEG amplitude exceeded maximum amplitude of ±90μV in any segment was excluded.
- In addition, all segments were manually visualized and contributions were rejected from electrodes that had lost contact in the event of widespread drift [13]. Certain channels were discarded from the segments because detected as 'bad channels' before averaging using spherical spline method [14].
- After removing artifacts, 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 were 33.53 (±5.04) and 77.88 (±18.8), 36.29 (±4.1) and 76.47 (±19.2), respectively.
- Then the averaged waveforms were re-referenced from a single vertex (Cz) to the averaged reference. At last, a baseline correction was performed for each individual averaged waveform (per experimental condition).

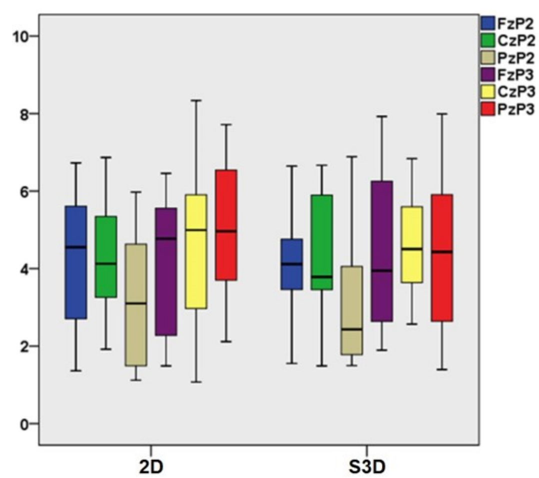

Figure 1. Distribution of ERP P2 and P3 Amplitudes for 2D and S3D group. The y-axis represnets the amplitude in (μV)

Although the EEG data were recorded from 128 electrodes position over the scalp, but the ERPs were extracted from the midline electrodes (Fz, Cz, Pz). The reason of analyzing these three electrodes was based on previous study investigated P3 in digit learning task [15]. The distribution of ERP amplitudes and latencies (P2 and P3) are shown in Fig. 1 and Fig. 2; respectively.

H. Statistical Analysis

All the data analysis was carried out with IBM SPSS Statistics 20.0 (SPSS Inc., USA). Since two groups and three electrodes were included in the analysis. Thus, independent t-test was used with Boneferroni correction to control the risk of type-I error due to multiple t-tests. Mean response accuracy of Oddball target detection and mean response time was computed. Further, 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.

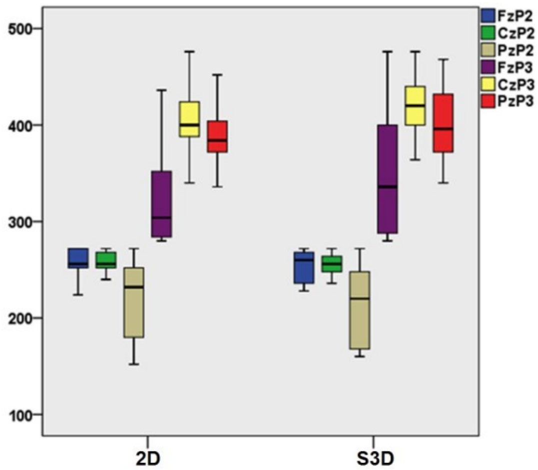

Figure 2. Distribution of ERP P2 and P3 latencies for 2D and S3D group. The y-axis represnets the latency in (ms)

III. Results and Discussion

A. Behavioral Results

The S3D and 2D groups were controlled in term of intelligence, age and gender. Mean and standard deviation of RAPM test and age for S3D and 2D groups were 23.53 (±4.11) and 23.47 (±4.72), 23.11 (±3.70) and 23.11 (±3.95), respectively. All recruited participants were male in both groups. The analysis of t-test demonstrated that the response accuracy and response times were not significantly different between the S3D and 2D groups for the oddball paradigm (t(32)=0.178, p>0.05, Cohen's d=0.01; t(32)=-0.238, p>0.05, Cohen's d=0.07; respectively).

B. ERP Results

To explore the effects of S3D displays technology as compared to 2D display, a comparison of ERPs components (amplitudes and latencies) was made for both the groups. The risk of type-I error due to multiple comparisons in the ERPs data analysis was minimized by employing Bonferroni correction. Accordingly, the p-value was adjusted to 0.0167 instead of 0.05 for independent t-test. The averaged waveforms of standard and target stimuli for both groups are shown in Fig. 3.

- P2 Amplitude: For P2 amplitudes, an independent t-test showed that the P2 amplitudes were not significantly different between groups at Fz (t(32)=0.286, p>0.05, Cohen's d=0), Cz(t(32)=0.147, p>0.05, Cohen's d=0.1), and Pz (t(32)=0.095, p>0.05, Cohen's d=0.14) sites.
- P3 Amplitude: An independent t-test demonstrated that the P3 amplitudes were not significantly different between the groups at Fz (t(32)=-0.095, p>0.05, Cohen's d=0.09), Cz(t(32)=-0.216, p>0.05, Cohen's d=0.07), and Pz (t(32)=0.721, p>0.05, Cohen's d=0.11) sites.
- P2 and P3 latencies: For P2 and P3 latencies, an independent t-test showed that the latencies of P2 and P3 components were not significantly different between the groups.

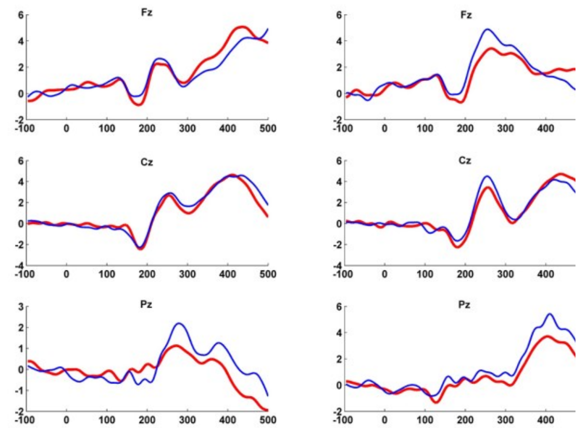

Figure 3. Averaged waveform of P3 for standard stimuli (left) and target stimuli (right) of 2D (blue, thin line) and S3D (red, thick line) groups at midline (Fz, Cz, and Pz) sites.

In this study, the aftereffects of S3D contents and the S3D based visual stimuli in the oddball stimuli were investigated. The ERPs components were used to evaluate and compare the S3D technology with traditional 2D technology. The division of the participants into two groups (2D and S3D) was based on the mean score of the intelligence (RAPM) test and the mean age. This confirmed that the two groups participated in the experiment are homogenous in term of cognitive processing. The behavioral and ERPs analysis showed that there were no statistical significant differences between 2D and S3D groups (see Fig. 4). Although two different groups of participants were used in the study, but they were controlled by the intelligence ability, age and gender. The use of different groups of participants allowed us to present the same visualization contents both in 2D and in S3D mode, i.e. avoided the unfairness of watching the same visualization contents for two times by a single group of participants. Therefore, these results suggest that there are no aftereffects of the stereoscopic 3D display technology in term of cognitive and visual fatigue on the event related potentials components as previously reported for active shuttered stereoscopic 3D technology [3, 7]. These studies reported reduced ERPs amplitudes and prolong latencies. The active shuttered S3D technology employing active shutter glasses, which shows left and right images to corresponding eye alternatively in synchronization with the refresh rate of the display. Although the active shuttered glasses are synchronized with the screen and there is minimum chances of dis-synchronization of left and right images in the brain. However, 3D visualization for longer time may cause the visual and cognitive fatigues due to the binocular fusion of alternate images in the human visual system. In case of passive S3D display, there is no possibility of dis-synchronization of left and right images in the binocular fusion process of visual system, because both eyes perceive visual information simultaneously.

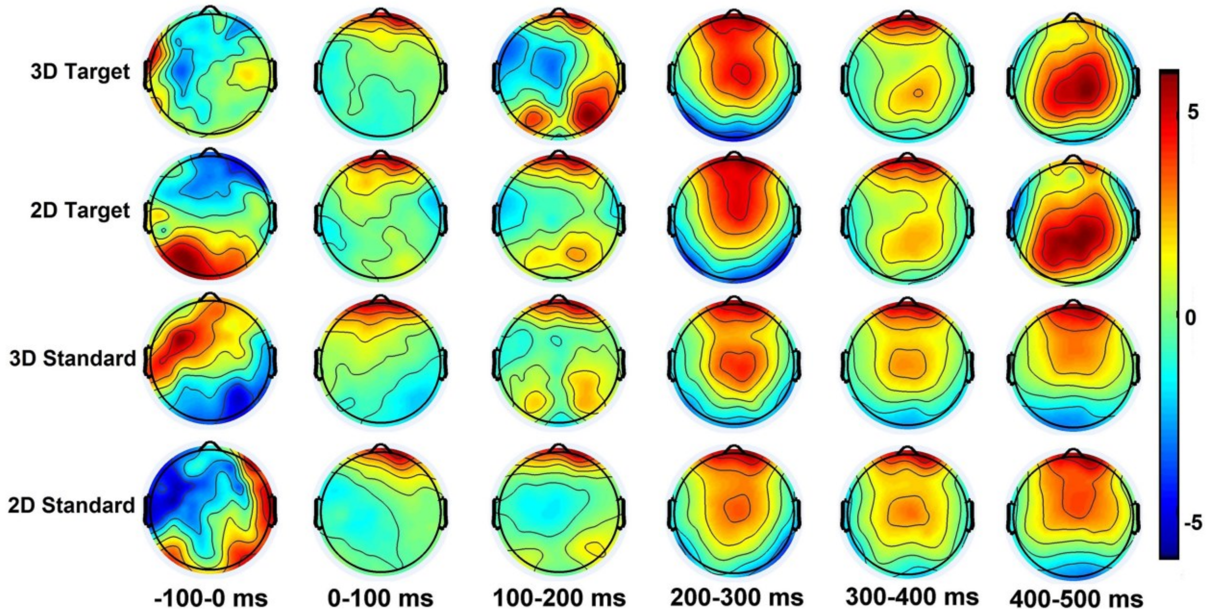

Figure 4. Average ERP responses of 2D and S3D groups from 128 scalp locations. Topographic maps of mean amplitudes averaged over a 100ms time window from 0–500ms (post-stimulus period) and 100-0ms pre stimulus for oddball paradigm. The first row of the topographic maps represents the 2D group and the second row represents the S3D group, respectively.

IV. CONCLUSION

This study found no such effects of passive polarized stereoscopic 3D display technology on the ERPs components. The use of stereoscopic 3D visual stimuli in the oddball paradigm did not show any significant neurological effects that can be linked to visual fatigue or cognitive fatigue due to watching S3D video or S3D visual stimulus. Both groups (2D and S3D) performed almost same. Hence, we conclude that the passive polarized 3D display technology may not induce such cognitive and visual fatigue, which have been reported in the literature using active shutter 3D technology. Future studies may be implemented to investigate longer duration of watching S3D contents with passive polarized technology to confirm and validate the results of this study.

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