EEG Topographical Maps Analysis for 2D and 3D Video Game Play

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***Abstract*— Despite the growth of 3D applications, the effects of 3D technology on humans are relatively unknown and are still inconclusive. As we aimed to investigate the general effect of 3D game, we analyzed the dynamical changes in human brain using the EEG power absolute and coherence measures from brain topomaps. Our findings showed an increase in theta and alpha bands at the frontal and occipital regions for 3D game play, while in 2D, higher beta and gamma activity was observed especially in temporal lobes. We also found similar results for 3D Active versus 3D Passive where 3D Passive theta and alpha power was relatively higher. Based on these results, we could deduce that 3D game play required more data processing which involved working memory as well as attention. Even with differences in activation, the overall user preference was equally divided for 3D Active and 3D Passive.**

Keywords*— EEG, 3D game, power spectral, coherence, working memory

I. INTRODUCTION

Stereoscopic vision is the ability to see in three dimensions. For humans, we could perceive the world in 3D mainly because of the separation of the two eyes (i.e., horizontal disparity), that creates two images with different depth information, where our brains fuse these images in order to produce that sense of depth perception [1]. The application of this concept has mainly been applied to develop the 3D technology. To date, there are two major types of 3D TVs that are available for consumer namely, 3D Passive and 3D Active.

The 3D passive uses polarized glasses (cinema type), that filter certain kinds of light that enter each eyes to create the depth illusion as the polarized images are presented simultaneously on the screen. Conversely, the active shutter glasses used in 3D active technology works by closing the right and left lenses alternatively at a very high speed. As this happens, only one eye get to see the intended image while the other eye is blocked temporarily.

Placing these two technologies side to side, the 3D active would cost more than the 3D passive since its technology is rather sophisticated and the glasses also require batteries to keep running. In addition to the cost, user may find uncomfortable when viewing using the active shutter glasses for a longer period of time due to its weight compared to the passive polarized glass.

Previous EEG research had proven that the alpha (8-12 Hz) and theta (4-7 Hz) bands are well suited to monitor the changes in attention and cognitive demands when a mental task is performed [2-7]. Also, it was found that the alpha power over the parietal region increased as well as the theta power at the midline frontal (Fz) area when subjects' overall performance was claimed to be improved in accomplishing certain working memory tasks [8].

Furthermore, in another 2D game study, theta activity was found to be increased gradually over the frontal midline region while the parietal alpha activity was slowly decreased during the game play for an hour period [9]. The same increase in the prefrontal cortex activation was found in a subject who played shooting video game at master level as reported by a functional near-infrared spectroscopy (fNIRS) study [10]. This high activation in the frontal lobe suggests that video game play involved many cognitive tasks which need to be controlled by the executive functions that are often associated with the frontal region.

In this research, we aimed to investigate further the effects of playing video game in 3D, where the topographical maps of absolute power difference and coherence were analyzed. We hypothesized that playing game in 3D mode would require more visual and mental processing tasks than in 2D. Also, the difference in brain activity between 3D Active and 3D Passive game play was explored.

II. METHODOLOGY

A. Subjects

A total of 29 subjects (24 male, 5 female), aged between 19 – 25 years old participated in the study. However, sample size was reduced to 26 subjects (22 males, 4 females; mean age 21.73 ± 1.59) due to data corruption. All selected subjects had no unknown cognitive impairments and had normal or corrected-to-normal vision. Also, subjects were informed about the experiment protocol and recording were obtained with subjects' approval through a written consent. The level of mastery for video game was almost equal and none had experience in playing any 3D game in the past.

B. EEG Data Acquisition

We recorded EEG data from 19 scalp locations based on the international 10-20 system (Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, Fz, Cz and Oz channels)

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and ear-linked was used as reference. EEG signals were band-pass filtered at 0.5 to 100 Hz and sampled at 256 Hz.

Each recording session involved five different conditions in the sequence of five minutes of eye-closed, five minutes of eyes open, 20 minutes of video game play in 2D, 3D passive and 3D active modes. Also, 5-10 minutes breaks were given at the end of each game play to allow subjects to rest and to fill up a questionnaire regarding to their experience when playing the game in different visual modes. For 3D sessions, two 3DTVs were used: i) LG 42-inch TV with passive polarized glasses (3D Passive) and ii) Sony 40-inch TV with active shutter glasses (3D Active). Subjects were seated at a distance of 2.0 meters away from the screen. Within the time frame, every subject was asked to complete five levels of car racing game (Gran Turismo 5, Polyphony Digital) using PlayStation 3 game consoles.

In order to minimize the exposure effects, all participants were asked to practice once before playing the actual game. This will reduce the learning effect which may be caused when playing a new game or playing in the 3D mode (active or passive) for the first time. To randomize the order of the experiment, half of the subjects played game in 3D active first, followed by 3D passive while another half played the game firstly in 3D passive then in 3D active. Apart from that, for the analysis, only the middle levels (level 2, 3 and 4) were considered. That is, level 1 and level 5 were excluded due to the excitation and fatigue factor respectively, that might be induced in these levels.

C. *Preprocessing Data*

Prior to data analysis, we performed several preprocessing steps where artifacts like line noise, eye blinks, eye movements, and jaw tension were removed from the recorded data. The corresponding analysis results were presented in the form of topographical maps generated by NeuroGuide software.

D. *EEG Absolute Power Difference*

The EEG amplitude is simply the square root of power given that the absolute power, P is defined as,

$$P = \frac{V^2}{R} \tag{1}$$

where V is the absolute voltage measured at each electrode, and R is the respective scalp resistance. The EEG power was computed in the following sub-divided EEG bands; delta (1-4 Hz), theta (4 – 8 Hz), alpha (8-12 Hz), beta (12 – 25 Hz), high beta (25 – 30 Hz), gamma (30 – 35 Hz) and high gamma (35 – 50 Hz). As the power values were obtained, the absolute power difference between any two conditions was computed. Here we performed the absolute power difference test as well as the paired t-test to test the significance difference between two groups of different conditions.

In the analysis, the 2D game play condition was set as the baseline since there was no visual stimulation involved at rest conditions (i.e., eyes-closed and eyes-open). The comparative analyses were made as follows:

- 2D versus 3D Active
- 2D versus 3D Active
- 3D Passive versus 3D Active

E. *EEG Coherence*

This EEG parameter measures how similar are the signals at two different electrodes. As defined by [11], coherence Γ, is given by

$$\Gamma^2{}_{xy}(f) = \frac{(G_{xy}(f)^2)}{(G_{xx}(f)G_{yy}(f))}, \tag{2}$$

where is the cross-power spectral density while and are the corresponding auto-power spectral densities. For all pairwise combinations of 19-channels in all EEG bands, the power spectra for x and y are initially computed and followed by the normalized cross-spectra. During this complex computation, the cospectrum, r and quadspectrum, q were produced and the coherence was finally computed as

$$\Gamma^2{}_{xy}(f) = \frac{r^2{}_{xy} + q^2{}_{xy}}{G_{xx}G_{yy}}. \tag{3}$$

III. RESULTS

A. *Absolute Power Difference*

First, we compared the EEG power during game play for 2D and 3D modes (Active and Passive). Our results showed that the power for all bands except delta, during 3D Active game play was noticeably higher than in 2D in the pre-frontal and frontal regions (theta); in the frontal except in temporal and occipital regions (alpha); and especially in pre-frontal region (beta and gamma).

As for 3D Passive versus 2D, the absolute power during 3D Passive game play was also found higher in the lower frequency bands (theta and alpha) but this time, the power was exceptionally higher in the occipital region compared to 3D Active – 2D. However, 2D power particularly in the temporal areas was higher than 3D Passive as observed in beta and gamma bands.

Next, we evaluated the absolute power difference between 3D Active and 3D Passive. While 3D Active power was found higher in the frontal region (theta), these results again confirmed our findings as we found that the occipital power was significantly higher in 3D Passive as found previously (3D Passive vs. 2D). However, the power difference in other EEG bands was not apparent when comparing these two 3D technologies. The resulting absolute power difference between two corresponding groups for theta and alpha bands are as shown in the first column in Table I and Table II, respectively. The first row (a) displayed the power difference map for 2D versus 3D Active condition, the second row (b) showed the result for 2D versus 3D Passive and the third row (c) described the result for 3D Active versus 3D Passive.

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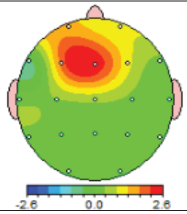
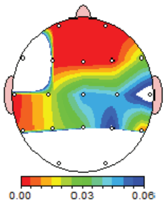
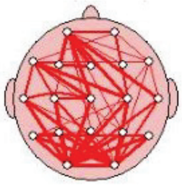
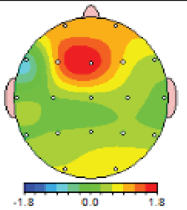
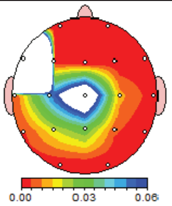
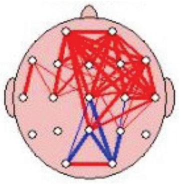
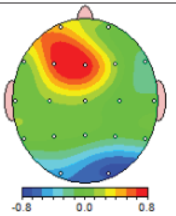
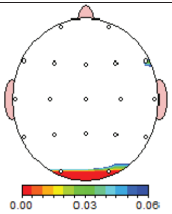
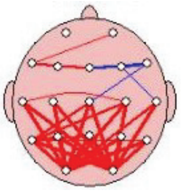
TABLE I. ABSOLUTE POWER AND COHERENCE DIFFERENCE BETWEEN CONDITIONS FOR THETA BAND (4-8 HZ)

Absolute Power Difference (µV)	**Absolute Power Difference** (P-value)	**Coherence Difference** (P-value)
(a) 2D versus 3D Active		
		
(b) 2D versus 3D Passive		
		
(c) 3D Passive versus 3D Active		
		

To clarify the color codes used in the topographic maps, here we explain the absolute power difference for 3D Active versus 3D Passive as depicted in the first column, last row (c) in Table I. The red color shown in this figure represents that the theta power in 3D Active game play at the frontal region (Fz and F3) was found higher compared to 3D Passive. However, the theta power in 3D Active at the occipital region was relatively lower than in 3D Passive (i.e., theta power at occipital region for 3D Passive was higher than the 3D Active power) as indicated in the blue color.

To further verify these absolute power difference results, we performed a paired t-test analysis with P-value < 0.05 to test the significance of the difference between two groups. The statistical results are displayed in the second column in Table I and II, for theta and alpha bands, respectively. The red color indicates the difference was very significant (P<0.001) while the blue color indicates that the power difference was not significant or almost no difference between groups. As expected, the statistical test results supported our earlier findings.

B. *Coherence Difference*

Virtually, the brain cortex is connected to all other parts of the brain and these connections can be described by the coherence map that consists of the corresponding P-value for each group comparison. The coherence difference maps for theta and alpha are as shown in the last column for all three comparison groups, in Table I and Table II, respectively. The statistically significant coherence is shown as a line connecting two electrodes. The red lines indicate increased coherence (integral effect) while the blue lines indicate decreased coherence (differential effect). The significance of the coherence is defined by the thickness of the lines (i.e., thin line represents P-value less than or equal to 0.05; medium-thick line indicates P-value less than 0.025 while the thick line dictates P-value less than or equal to 0.01).

From this study, we found that the coherence between the brain regions was mostly higher in 3D Active compared to 2D. For instance, the global increase in coherence was very significant (P<0.001) in both theta and alpha bands. However, we found that in beta band, only the left hemisphere were highly coherent with the central motor region (CMR), parietal and occipital regions while the coherence in the right hemisphere was almost insignificant. Interestingly, we also observed a significant increased interhemispheric coherence that is; two regions from different brain hemispheres were actively connecting to each other. As we compared the coherence in 3D Passive to 2D, the results were comparable to the 3D Active in most bands except for theta and alpha (see Table I and Table II, second row (b)). In this case, only the frontal regions seemed to have increased coherence whereby in the temporal and posterior regions, there was a decrease or almost no significant changes in the coherence. Despite that, it is worth noting that this finding offers an agreement with the previous absolute power results, as it was found that both alpha and theta power in the frontal region were increased.

Finally, the t-test results for the coherence between 3DA versus 3DP were computed. Overall, an increased coherence in 3D Active was detected particularly across the occipital, parietal, CMR and temporal regions in delta, theta and alpha bands. For 3D Passive, coherence was significant between the pre-frontal and frontal regions and between bilateral occipital lobes (O1, O2) in the alpha band (see Table II, third column and last row) as well as between the prefrontal, frontal, CMR, parietal and occipital regions in beta band.

IV. DISCUSSION

Owing to fact the 3D visualization has substantially additional depth information compared to 2D; our brain requires more resource allocation to process the complex 3D content. We expected that there will be a high activation in the respective brain regions and EEG bands that correspond to short term memory, working memory, visual attention and encoding and retrieval for complex visual tasks. This statement was evident as our results showed a significant power increase for both 3D modes compared to 2D particularly in the frontal region areas for theta and alpha bands. Remarkably, this finding was also accompanied by lower power for 3D at higher frequency bands (beta and gamma) found in the temporal region. From the 3D Active and 3D Passive comparison, we found that only the occipital power was statistically significant especially in the alpha and theta bands.

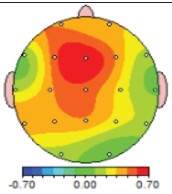
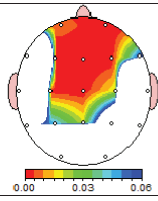
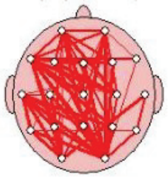
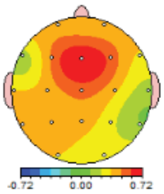
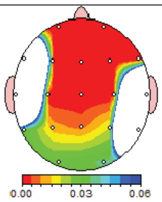
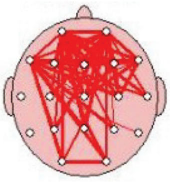
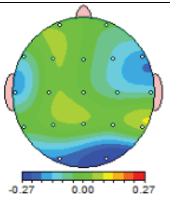
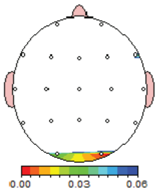
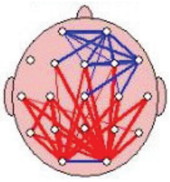
Although high alpha activity was generally attributed with eyes-closed condition, it can also reflect active processing due to memory manipulations or it reflects inhibition of regions that are not required for the task as proposed by [12-14].

Apart from theta, high alpha activity also demonstrates an optimum memory performance. Here, 3D Passive theta and alpha power was higher than in 3D Active might be because of the images were projected simultaneously through the passive polarized glasses which is close enough to our natural 3D perception and can be easily fused by our brain. However, the images generated by the 3D Active shutter glasses were not natural enough and was seen as almost similar to 2D, hence resulting in lower power activation in theta and alpha bands.

In general, the increase in information sharing between the occipital regions and other areas of cortex was clearly significant. The coherence results for 3D Passive versus 2D confirmed our earlier findings where there was an active interaction within the frontal region electrodes indicating that the frontal lobe performs the brain's executive functions to govern the many cognitive tasks involving working memory and motor tasks. Similarly, there was also a distinct connection between the frontal and occipital regions.

On a further note, the difference in coherence between 3D Active and 3D Passive was again found to be highly coherent exclusively in the occipital region that were mostly connected to parietal and central regions. However, there was also a noticeable decrease in coherence at the right frontal region in the alpha band.

TABLE II. ABSOLUTE POWER AND COHERENCE DIFFERENCE BETWEEN CONDITIONS FOR ALPHA BAND (8-12 HZ)

Absolute Power Difference (μV)	**Absolute Power Difference** (P-value)	**Coherence Difference** (P-value)
(a) 2D versus 3D Active		
		
(b) 2D versus 3D Passive		
		
(c) 3D Passive versus 3D Active		
		

V. CONCLUSION

In summary, this research explored the relationship between game play in different mode of visualization (2D or 3D) and the neuronal oscillatory power and coherence in different frequency bands. Our findings suggest that 3D gaming results in global arousal for memory processes (higher 3D power in lower frequency bands) while local processing (auditory process) is suppressed (higher 2D power in the upper frequency bands).

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