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Association of Autonomic Nervous System and EEG Scalp Potential During Playing 2D Grand Turismo 5

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Abstract— **Cerebral activation and autonomic nervous system have importance in studies such as mental stress. The aim of this study is to analyze variations in EEG scalp potential which may influence autonomic activation of heart while playing video games. Ten healthy participants were recruited in this study. Electroencephalogram (EEG) and electrocardiogram (ECG) signals were measured simultaneously during playing video game and rest conditions. Sympathetic and parasympathetic innervations of heart were evaluated from heart rate variability (HRV), derived from the ECG. Scalp potential was measured by the EEG. The results showed a significant upsurge in the value theta Fz/alpha Pz ($p<0.001$) while playing game. The results also showed tachycardia while playing video game as compared to rest condition ($p<0.005$). Normalized low frequency power and ratio of low frequency/high frequency power were significantly increased while playing video game and normalized high frequency power sank during video games. Results showed synchronized activity of cerebellum and sympathetic and parasympathetic innervation of heart.**

I. INTRODUCTION

Cognitive activation such as mental stress, emotions and depression influences autonomic activation of the heart. In extreme conditions, this cardiac activation can be complicated and lead to human death. Autonomic nervous system (ANS) is responsible to connect the heart with the brain. ANS shows initial expressions of mental activation such as stress in early stages. It consists of sympathetic nervous system (SNS) and parasympathetic nervous system (PSNS). The latter is responsible of inhibitory response. Sympathetic and parasympathetic innervations of the heart have excitatory and inhibitory behavior, respectively [1]. Myocardial depolarization increases with sympathetic innervation of the heart which can cause tachycardia. However, parasympathetic innervation of the heart reduces depolarization which eventually reduces the heart rate and causes bradycardia.

Heart rate variability (HRV) patterns are the most readily existing measures that can determine SNS or PSNS innervation of the heart [2]. The power spectrum HRV is integrated into three bands: very low frequency (VLF) (<0.04 Hz), low frequency (LF) (0.04 Hz - 0.15 Hz) and high frequency (HF) (0.15 Hz – 0.4 Hz) [3]. The HF component of HRV is influenced by parasympathetic activity. The LF component follows to both sympathetic and parasympathetic mediations. However, the LF and HF can also be represented in relative power, called normalized unit (nu), where nu is the power of LF or HF divided by the total power minus the VLF power. LF in normalized form is attributed to sympathetic activity. The ratio of LF and HF power (LF/HF) is representation of sympathetic to parasympathetic distribution or a reflection of sympathetic attribution.

Electroencephalogram (EEG) is a noninvasive technique to measure scalp potential. EEG scalp potential signals from the surface of the head provide a host of information about the brain dynamics. EEG is rich in temporal information as compared to other neurological modalities such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) [4]. EEG signals spread in different frequency bands: delta (δ) (1-4 Hz), theta (θ) (4-8 Hz), alpha (α) (8-12 Hz), beta (β) (12-30 Hz) and gamma (γ) (30-40 Hz). These frequency bands provide information of brain activation, e.g., high activation in theta is related to high demand and task difficulty. Similarly activation in alpha narrates calmness of the brain. Moreover, scalp locations under the EEG electrodes can provide very important information. Frontal midline (Fz) performs function of motor planning and parietal midline (Pz) is involved in perceptions [5]. A growing task load is associated with enhancement in the theta activity in Fz and reduced alpha activity in Pz [6].

Previous research studies have shown changes in cardiac activities such as heart rate (HR), heart rate variability (HRV) and blood pressure in situations such as mental workload, task performance, and exercises [7-9]. Similar situation are also reported to highlight brain activation [6, 10-12]. In [7], mental stress of car drivers was found and HRV was measured to analyze stress. The results showed a discrete difference between stressed and non-stress conditions. HRV was also analyzed in [8] to measure cognitive load and mental stress. Moreover, study [9] analyzed HRV to evaluate mental stress among positive responders, negative responders and non-responders. Similarly HRV was analyzed as a quantitative marker in study [13], to depict ANS activity to represent mental stress. This study evaluated short term time required for the analysis of several HRV features to represent mental stress.

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The authors [14] studied HRV along with other physiological variables to assess cognitive load.

Scalp potential, HR and HRV were measured in [10] to show correlation between laterality ratio at parietal region (P3 vs. P4) and HR changes. In EEG studies, increasing demands in terms of working memory as well as high workload, can cause an increased frontal theta power and decreased parietal alpha power [15-17]. Frontoparietal association was found as a measure of workload index [6, 11], which showed significant relationship with increased task difficulty. EEG and HRV were analyzed in [18-20] where participants were playing video games. Results showed an increment in SNS activity during game playing.

This paper investigates how information from EEG a scalp potential, in terms of theta Fz/alpha Pz, is related to the changes in HR and HRV. The arrangement of this paper follows: section II introduces relevant factors for the research; methodology of the work is discussed in section III, section IV presents results; result discussion was given in section V followed by conclusion in section VI.

II. INTRODUCTION ON TERMINOLOGY

A. HR and HRV

Heart rate (HR) was derived from the R-R intervals of ECG as the number of R peaks/minute. Power spectral analysis on R-R interval using autoregressive model (filter order 16) was performed to estimate HRV. The power spectrum of HRV was distributed into VLF, LF and HF. It is reported that the HF and LF components of HRV are influenced by parasympathetic activity and sympathetic mediations, respectively [3]. However, LFnu, i.e. the normalized power of LF is attributed to sympathetic activity [2]. The ratio LF/HF was calculated as a representation of sympathetic to parasympathetic distribution or a reflection of sympathetic attribution.

B. EEG Workload Index

EEG data was filtered from artifacts and integrated in theta (4-8 Hz) and alpha (8-12 Hz) in Neuroguide software. Workload index was calculated from theta in the midline frontal and alpha in the midline parietal as shown in (1) [6]:

$$index = \frac{theta(Fz)}{alpha(Pz)} \tag{1}$$

III. METHODOLOGY

A. Experiment

Complete flow of the experiment is shown in fig.1. The experiment on each participant was conducted at the same time of day starting from 6 p.m. The experiment designed was based on video game playing (Grand Turismo5), in PlayStation3. A 40 inch screen was used and the distance between the participant and the screen was kept 1.8m. The duration of playing game was twenty minutes. The video game consists of six levels of racing circuits, i.e., from easiest (level 1) to most difficult levels (level 6). Out of six levels of game, levels 2, 4 and 5 were selected for analysis because of sufficient duration. Other three levels were not chosen due to inconsistency. Five minutes of rest periods before and after playing video game were included (pre-game rest, post-game rest). The rest period in the start was regarded as a baseline (reference) to compare results at other levels. Rest period in the end was to observe if participants were coming towards the relaxed state.

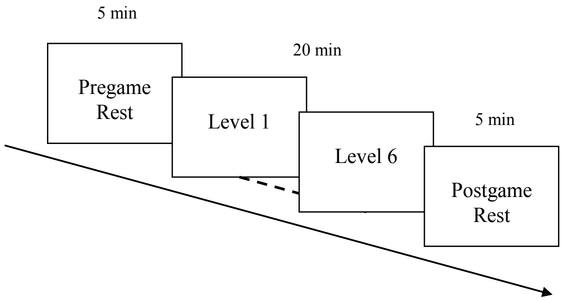

Figure 1. Experiment flow

B. Participants

Ten healthy participants including two females (age: 19-25 years) were included in this study. They were selected based on criteria: previous medical record, i.e., only those were chosen who had no head injury and not using any medication that might increase cardiac activation. Participants were asked to perform fasting for at least two hours before starting the experiment. Each participant signed an informed consent after agreeing to participate, and was given an honorarium of RM 50 to compensate his/her time.

C. Data Acquisition and Analysis

EEG and ECG data were simultaneously measured during the experiment. The data were then acquired using BrainMaster 24E system with Discovery acquisition software at the rate of 256 samples/sec. EEG electrodes were mounted on nineteen cites according to the international 10-20 system. as shown in fig. 2.

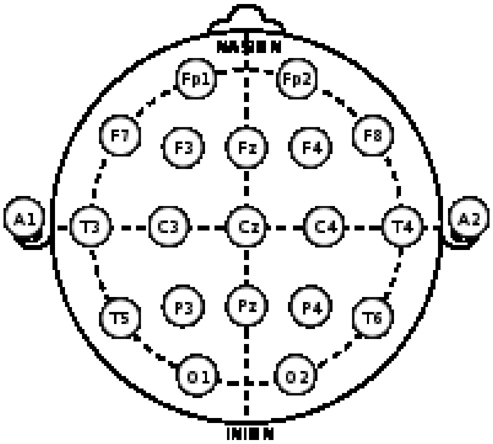

Figure 2. Cites of EEG channels

The reference to these electrodes was average values of linked ear electrodes. Impedance of all the electrodes was kept below 5 kΩ. Two Ag/AgCl surface electrodes were patched onto the second rib below the right and left shoulder blades to measure ECG. HRV analysis was performed in MATLAB 7.1. HRV and EEG data were exported to Microsoft Excel to observe images and perform statistical calculations.

HR and HRV analysis were performed during first 3.29 minutes (50,600 samples) based on data obtained from pregame rest, levels 2, 4 and 5 of game and postgame rest. At the time the analysis window remains same for all conditions. Analysis on EEG data was performed on one minute duration from each condition. This selection of the duration was accumulated by Neuroguide from artifact free cleaned data according to the instruction of Neuroguide.

IV. RESULTS

A. EEG Results

The values of the ratio $Fz(\theta)/Pz(\alpha)$ are presented in Fig. 3 for all the participants during rest time prior (pregame), after the game (postgame), level 2 (L2), level 4 (L4) and level 5 (L5) of the games. The ratios showed significant difference in values of game playing as compared to the rest conditions ($p < 0.001$).

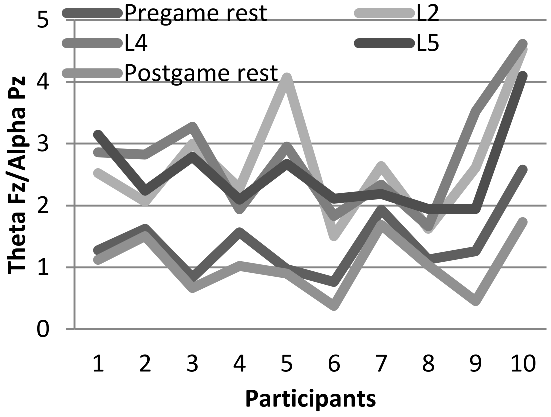

Figure 3. $Fz(\theta)/Pz(\alpha)$ values

B. HR and HRV Results

The values of HR are illustrated in Fig. 4 for all the participants during five conditions. HR showed a significant rise during all the levels of game as compared to the rest periods ($p < 0.005$).

Table I highlights the changes in HR and HRV. The results show a significant mount in HR during video game playing (71.6, 71.1 and 72.26 beats/minute (bpm)) as compared to pregame rest condition (66.21 bpm). Under the same condition the increment also occurs for LFnu (0.489, 0.506, 0.465 vs. 0.434) and LF/HF (1.812, 1.921, 2.217 vs. 1.6). These values decrease during the postgame rest condition (0.436 and 1.366, respectively). HFnu significantly decreases ($p<0.05$ and 0.1) while playing video game (0.336, 0.328, 0.3509 vs. 0.418) and again increases during postgame rest condition (0.4177) as compared to pregame rest condition.

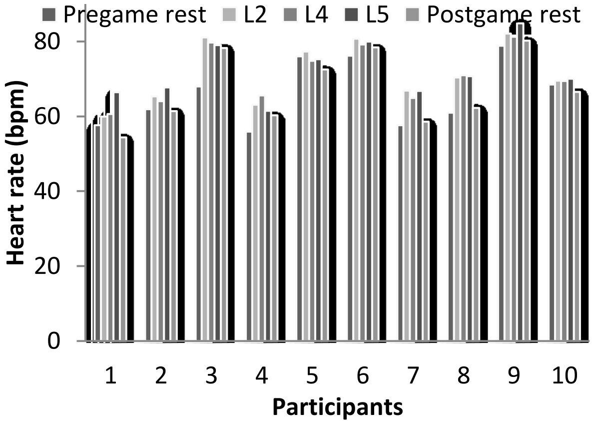

Figure 4. Heart rate

TABLE I. HR AND HRV IN REST AND PLAYING VIDEO GAME

	HR (bpm)	LFnu	HFnu	LF/HF
Pregame rest	66.21 ± 8.14	0.434 ± 0.2	0.418 ± 0.2	1.6 ± 1.3
Level 2	71.67 $\pm 7.68^{*}$	0.489 ± 0.12	0.336 $\pm 0.12^{***}$	1.812 ± 1.06
Level 4	71.10 $\pm 6.98^{*}$	0.506 $\pm 0.15^{**}$	0.328 $\pm 0.13^{***}$	1.931 ± 1.1
Level 5	72.26 $\pm 6.93^{**}$	0.465 ± 0.19	0.3509 $\pm 0.17^{****}$	2.217 ± 1.8
Postgame rest	67.31 ± 8.89	0.436 ± 0.16	0.4177 ± 0.16	1.366 ± 0.9

Information is written as: average ± standard deviation. *, **, *** and **** represent $p<0.005$, $p<0.001$, $p<0.05$ and $p<0.1$ respectively. HR, heart rate; LFnu, normalized low frequency; HFnu, normalized high frequency; LF/HF, low frequency to high frequency ratio.

V. DISCUSSION

The results showed significant changes in HR ($p<0.005$) and HRV accompanied by variation EEG scalp potentials ($p<0.001$) while playing video game. HR, LFnu, LF/HF and $Fz(\theta)/Pz(\alpha)$ were raised and HFnu was sunk while playing video games as compared to pregame rest condition and inverted during the postgame rest condition. These findings showed the sympathetic innervations of the heart while playing video game and parasympathetic innervations of the heart during pre and postgame rest conditions.

As discussed early sympathetic and parasympathetic activities have excitatory and inhibitory behavior to the heart, respectively. HRV can distinguish between sympathetic and parasympathetic activations. In this case HR, LFnu, and LF/HF rose higher during game playing than pregame rest condition, which represented sympathetic activation. These features were again dropped down in postgame rest condition, which indicated parasympathetic activation. In addition, the reduced value of HFnu during game playing showed reduced parasympathetic activity as compared to rest conditions.

Cardiac excitation during game playing was accompanied with cortical activation. The ratio of Fz/Pz was significantly higher during playing time than rest conditions. This indicated a remarkable workload during game playing compared to rest condition.

VI. CONCLUSION

We observe that scalp potential prominently increases while playing video game in accordance to sympathetic activation and parasympathetic deactivation. Higher ratio of Fz/Pz in game indicates a considerable workload. At the same time, higher HR, LFnu and LF/HF values in game show sympathetic activation. The results can support the idea to observe cerebral activation and autonomic innervations to measure mental stress.

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