# QEEG Index for Early Detection of Imbalanced Conditions During Aerobatics

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*Abstract*—**In this paper, the brain activity was studied and observed while person was in the loss of balance state due to vestibular system disorder. Brain activity was recorded as QEEG data which was analyzed by the Z-scored FFT method. The experimental results showed brain activities in the positions $O_1$, $O_2$, $P_3$, $P_4$, $P_Z$, $T_5$, and $T_6$ in the forms of topographic map (Absolute Power) and brain connectivity (Amplitude Asymmetry). It was represented in the topographic map that, during the loss of balance state, brain areas at occipital and parietal lobes have high intensity level of brain processing. For brain connectivity, the results clearly showed the brain connections while subjects were trying to maintain their balances. These strong connections were represented by red lines between $O_1$, $O_2$ positions (occipital lobe) and $P_z$ (parietal lobe), $F_z$ (frontal lobe) and $C_z$ (central lobe). Similarly, there were strong connections between $T_5$ and $F_z$ positions and $T_5$ and $T_6$ positions. On the other hand, the connection between $T_6$ and $F_z$ was found to be a weak connection. The analysis of results can be employed in the alarm system of pilot during aerobatics.**

## I. INTRODUCTION

In human body, there are many pathways that connect between the balance and postural control to other parts of the body. Normally, postural control of human integrates inputs from multimodal sensory sources such as (1) the visual system, (2) the vestibular system, (3) the proprioceptive system, (4) the nervous system, and (5) the exteroceptive system. These sensory sources receive the information from specific parts of the body and process the information in the brain. The cortical network is distributed in the brain at positions of parietal and central lobes. Therefore, EEG signal pattern can be detected when human is in the loss of balance state [1].

There are many previous researches that have been studied related to the electroencephalography (EEG) signal that occur when human is in the loss of balance state. One of the important factors that affect the recovery of human balance is the age. The delay in sensory systems of young, ole, and ole-frail people has main effect to their responses to stance perturbation. EEG signal over the vertex (Cz) shows maximum of stance perturbation-evoked potential. The EEG signal patterns (stance perturbation-evoke potential) among young, ole, and ole-frail were different. There were delays in some portions of pattern for ole and ole-frail people [2].

Human balance to upright stance was associated with later cortical potentials that could reflect sensory and later motor processing of later phases of the postural reaction which is called perturbation-evoked cortical responses (N1). When N1 responded, the postural reaction to whole-body in stability maximally occurred over Cz [3]. The effects of postural stability which came from unpredictable and predictable postural perturbation were related to the brain cortical potential. Unpredictable perturbation generated a large negative potential (N1) while predictable perturbation generated a small N1 potential [4]. Characteristic of the N1 response was associated with balance reaction of upright stability in human. While subject is in balance recovery process, the N1 response was widely distributed on the brain cortical which maximal responded at fronto-central electrode sites (FCz, Cz) [5]. In addition, the phenomenon called contingent negative variation (CNV) was occurred in cerebral cortex. CNV was evident before a perturbation which was associated between activity of the cerebral cortex and postural response modification when warned of a perturbation (cue condition). Significantly, negative shifts in the EEG signal (CNV potentials) were evident at the Cz and Pz positions on the brain but maximum over Cz. These CNV potentials were evident at the Cz position onset to the postural perturbation in the cue condition which was not in the no cue condition [6]. In addition, cerebral cortex activities that show peak activity (N1) which is located at the Cz electrode can anticipate postural muscle activation (EMG) [7].

Besides, there are also an increasing number of patients who are unable to control their balance which may have caused from nervous abnormality and vestibular system disorder. Nervous abnormality is the abnormality of nervous system that normally sends the command to muscle to maintain balance of the body through nerve. When nerve is abnormal and unable to transfer the command, the body will not be able to maintain the balance. The causes of nervous abnormality may come from the effects of alcohol consumption and the symptoms of spinal cord injury and stroke patients. Vestibular system disorder is the abnormality of human balance system which consists of two parts; peripheral and central vestibular systems. The causes of vestibular system disorder are from car sickness, sea sickness of normal people and loss of balance state of pilot due the vertigo and fatigue. These symptoms show the phenomenon in the brain which is called vestibular evoke potential (VESTEPs). VESTEPs occur when human body

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sways from the normal balance position which can be observed in Cz position of the brain. VESTEPs are studied in human subjects during flight training simulation which consists of rolling up, down and changing gravity [8]. EEG signal activity of fighter pilot (FP) and novice pilot (NP) is different in high alpha band which can be observed in various situations of imagery flight training (IFT) [9]. The review of published papers related to neurophysiological measurements of EEG, electrooculography (EOG) and heart rate (HR) in pilots/drivers during their driving tasks. The aim is to summarize the relationship between aircraft pilots and vehicle drivers' brain activity during driving performances which develop mental workload, mental fatigue, and drowsiness. The results show an increase in EEG power in theta band and a decrease in alpha band which occur in high mental workload. There is an increase in EEG power in theta as well as delta and alpha bands characterize the transition between mental workload and mental fatigue. In addition, drowsiness is characterized by increased blink rate and decreased HR values [10].

The functional and effective connectivity must be operationally defined by each investigator who evaluates EEG quantities [11]. In another meaning, brain connectivity refers to a pattern of anatomical links of interactions between units within a nervous system which occur as a result of changing body and thought movement such as vestibular system disorder. Different body and thought movement leads to different brain connectivity. Normally, brain connectivity is analyzed by the measurement of multi-channel brain activity namely quantitative electroencephalography (QEEG). The EEG signal is digitally recorded and mathematically processed to be defined as QEEG in order to highlight waveform components and transform the EEG signal into a format that illustrates relevant information. QEEG is often used as the analysis tool [12-13]. In this study, the QEEG signal was analyzed by the Z-scored FFT method. The results were represented in two forms; topographic map (Absolute Power) and brain connectivity (Amplitude Asymmetry). In addition, the effects of vestibular system disorder such as vertigo, dazzled eyes and the delay of sensory perception and response will be intensively studied.

## II. MATERIALS AND METHODS

### *A. Participants*

Five healthy volunteers took part in this study (age:$25.2 \pm 3$ years; height: $166 \pm 10.2$ meters; weight: $62.2 \pm 11.2$kg; M±SD). They had no history of neurological and mental disorders. All participants were right leg and arm dominant.

### *B. Instrumentation and data collection*

The instrumentation used in this paper is the Brain Master Discovery 24E which recorded 19 channels EEG at positions $Fp_1$, $F_3$, $C_3$, $P_3$, O1, $F_7$, $T_3$, $T_5$, $F_z$, $Fp_2$, $F_4$, $C_4$, $P_4$, $O_2$, $F_8$, $T_4$, $T_6$, $C_z$, and $P_z$. The data were analyzed via NeuroGuide software. The sampling rate is set to 256 Hz. The measurement was taken when the subjects are in the open-eye condition. The reliability percentages of data are done using the split half and test retest methods which the values should be greater than 90%. The analysis is displayed in the forms of the topographic map (Absolute Power) and the brain connectivity (Amplitude Asymmetry).

### *C. Procedure*

Participants wore EEG caps and stood in the relax position with no movement. The EEG signal was recorded for 2 minutes. The signal was used for an analysis for only 1 minute which was selected only the part that contains no artifacts such as eye blink, eye movement and head movement. This signal was used as a normal baseline to compare with the signal obtained from the experimental procedure. Then, participants stood on two feet and bended downwards to the feet. Next, cross one hand to touch another side of their ear while the other hand touched the floor and used as a rotation axis which is called Head-down spinning as shown in Fig. 1. Each participant rotated around themselves for 10-15 times. After performing the rotation, the subjects lost their balance ability. The QEEG signal was, then, recorded for 2 minutes while the patients tried to stand and recover their balance. Each participant repeated the rotation and was recorded the QEEG signal after the rotation for one more time.

Figue1. Head-down spinning.

### *D. Analysis method*

Data were analyzed by using the Z-scored FFT method. The results were represented in two forms; topographic map (Absolute Power), and brain connectivity (Amplitude Asymmetry). The application of the mathematical Gaussian curve (Bell Shaped curve) by the estimation of probabilities using the auto and cross-spectrum of the EEG is defined as Z-scored FFT method [14]. This method is used to identify brain regions that are de-regulated and depart from expected values as described in Eq. (1),

$$Z_{FFT} = \frac{X_i - \bar{X}}{SD_s}, \quad (1)$$

where $SD_s$= standard deviation among subjects, $X_i$ = EEG feature, $\bar{X}$ = mean value of $X_i$.

This Z-scored FFT information will be further analyzed via the topographical map and brain connectivity as follows:

- Topographic Map: Topographic EEG presents a spatial representation of raw EEG data such as voltage amplitude or a derived parameter such as power in a given frequency band, or peak latency.

Normally, the parameter of interest is mapped onto a formalized picture of the head or the brain and maybe mapped onto an anatomically accurate rendering of the brain [12]. In this paper, the results were displayed as topographic maps by calculating the absolute power. The absolute power involves an activation of the brain which reflects the amount of a specified frequency within the EEG [15].

- Brain Connectivity: The objective of Brain connectivity is to gather the knowledge of computational neuroscience, neuroscience methodology and experimental neuroscience with a special interest in understanding the tripartite relationship between anatomical connectivity, brain dynamics and cognitive function. In this paper, the results were displayed as brain connectivity by calculating from amplitude asymmetry. The level of asymmetry can be quantified by a simple ratio of band values between the corresponding channels of the left and right hemispheres [16]. The formula for the left/right symmetry is described as follows:

$$R = \log\left(\frac{\text{Average band value in left hemi.}}{\text{Average band value in right hemi.}}\right) \quad (3)$$

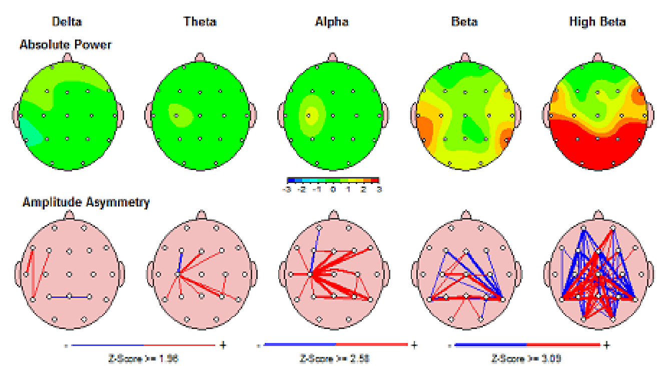
For front/back differentiation, the ratio of the band value of the posterior channel to that of the anterior channel of the same hemisphere reflects the extent of their differentiation. Two measurements are extracted which consist of one measurement for each hemisphere [16]. The parameter is derived as follows:

$$R = \log\left(\frac{\text{Average band value in posterior}}{\text{Average band value in anterior}}\right) \quad (4)$$

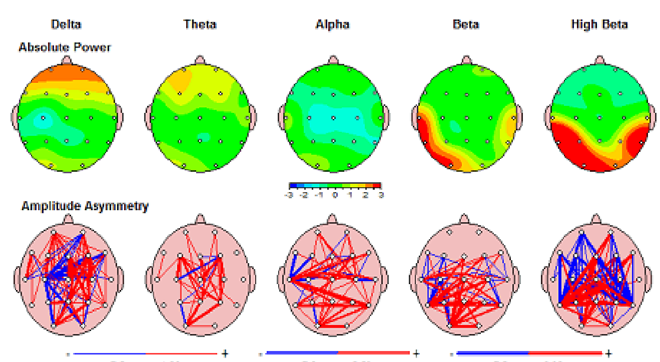
## III. RESULTS

The experimental results were represented in the forms of topographic maps (absolute power) and brain connectivity (amplitude asymmetry) as shown in Fig. 2. The results were recorded and interpreted from the subjects having vertigo from vestibular system disorder. From Fig. 2, the effects from vestibular system disorder were clearly observed in topographic map in high beta band (25-40 Hz) of the occipital and parietal lobes. Red color represents the higher intensity level of brain processing than normal people at the same age as the subject (blue color represents the lower intensity level of brain processing than normal people at the same age as the subject). High intensities in the area of occipital and parietal lobes mean that the subject needs more visual processing and exteroceptive perception, respectively, in order to maintain the balance.

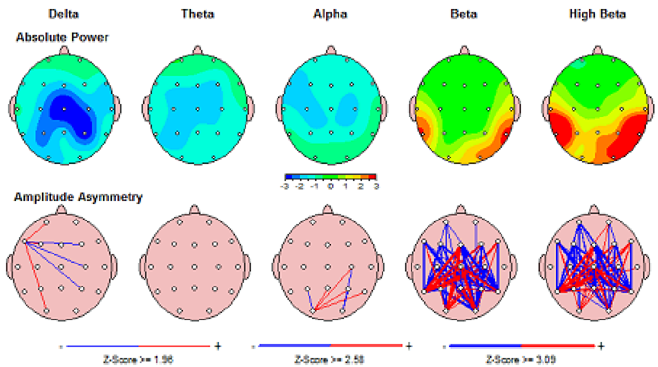
In more detail, brain connectivity describes the activity of brain to maintain the balance. According to amplitude asymmetry in high beta band in Fig. 2, there were strong connections (represented by red lines) between $O_1$, $O_2$ positions (occipital lobe) and $P_z$ (parietal lobe), $F_z$ (frontal lobe) and $C_z$ (central lobe). The connection between $O_1$, $O_2$ and $P_z$ showed the relationship between the visual processing in right and left halves of space and perception. This means that there was demand from the subjects having vestibular system disorder to increase visual perception in order to maintain their balance. The connection between $O_1$, $O_2$ and $F_z$ showed the relationship between the visual processing in right and left halves of space and motor planning of both lower extremities. This means that there was strong connection between visual perception and movement planning of legs to maintain the balance. The connection between $O_1$, $O_2$ and $C_z$ showed the relationship between the visual processing in right and left halves of space and sensorimotor integration of lower extremities. This means that there was strong connection between visual perception and sensorimotor integration of lower extremities to maintain balance. Similarly, there were strong connections between $T_5$ and $F_z$ positions and $T_5$ and $T_6$ positions. On the other hand, the connection between $T_6$ and $F_z$ was found to be a weak connection. The brain areas at positions $T_5$ and $T_6$ are responsible for complex visual processing.




(a)




(b)




(c)

Figure 2 Results of Z-Scored FFT for topographic map (Absolute Power) and brain connectivity (Amplitude Asymmetry) of (a) subject 1, (b) subject 2 (c) subject 3.

## IV. DISCUSSION

The analysis of results in this paper consists of two parts which are topographic map and brain connectivity which can be used in many applications. One of the interesting applications is an alarm system of pilot in flight simulator. According to the analysis of results, when the human starts to lose their balance, the demands for visual processing and perception which are represented by brain activity in occipital and parietal lobes will be increased. This observed brain activity for result can be employed in the alarm system of pilot in aerobatics. If the brain activities in occipital and parietal lobes start to be detected, the warning sound will be alarmed to indicate that the pilot is in the loss of balance state.

## V. CONCLUSION

In this paper, the brain activity was studied and observed while person was in the loss of balance state and tried to recover their normal balance. The cause of balance losing was from vestibular system disorder. Brain activity was recorded as QEEG data which was analyzed by the Z-scored FFT method. The experimental results showed brain activities in the positions $O_1$, $O_2$, $P_3$, $P_4$, $P_Z$, $T_5$, and $T_6$ in the forms of topographic map (Absolute Power) and brain connectivity (Amplitude Asymmetry). These positions are parts of the brain related to visual processing, perception and complex visual processing. Therefore, the person having loss of balance due to the vestibular system disorder will have more brain activities in the mentioned positions than those of the normal person.

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