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Electrocortical brain oscillations and social anxiety disorder: a pilot study of frontal alpha asymmetry and delta-beta correlation

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Abstract. The main objective of the present study is to investigate whether socially anxious individuals and healthy control show recognizable electroencephalographic (EEG) patterns in the frontal brain during baseline and recovery states. Towards this goal, this study recruited eight participants to examine the severity of social anxiety disorder (SAD) on EEG oscillations through the study of electrocortical frontal alpha asymmetry (FAA) and delta–beta correlation. A group of healthy male participants was chosen (consisting of 4 SAD and 4 HC individuals), and they were assessed by using Social Interaction Anxiety Scale (SIAS) to determine the level of social anxiety. Frontal EEG oscillations were measured to investigate the delta-beta correlation and frontal alpha asymmetry in baseline tasks (eyes opened and eyes closed) and recovery from social tasks (speaking in front of camera). As an outcome, Delta-beta coupling in SAD has shown greater correlation in baseline condition (eyes closed, and eyes open) than the recovery task, unlike HC individuals who exhibited greater correlation in recovery state more than baseline state. For frontal alpha asymmetry, SDA participant have shown greater left frontal cortical activity, whereas HC participants have demonstrated greater right frontal cortical activity. Taking all together, the reported findings indicate that delta-beta correlation and alpha asymmetry are presumptive EEG biomarkers of social anxiety.

1. Introduction

The diagnosis of social anxiety disorder (SAD) was first introduced in the Third Edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-III) in 1980 [1]. SAD is a common internalization disorder characterized by excessive fear of certain specific objects or impediment of social situations, especially those that may be subjected to judgment, evaluation or potential for scrutiny [2]. SAD is defined as a distinct and persistent fear of one or more social situations in which a person is exposed to unfamiliar people or possible scrutiny by others. Anxious people suffer from the potential risk of embarrassment or humiliation due to inadequate performance or signs of nervousness and tension. Therefore, they often avoid social situations, and when the situation is unavoidable, they experience severe anxiety and stress. SAD is associated with an increased risk of developing comorbid conditions, especially major depression, acute grief, and substance abuse disorders [3], [4]. SAD can cause serious damage to the lives of those who suffer from it. It is assumed that SAD occurs along with a severe and continuous sequence of mental illnesses [3]. SAD Symptoms may be so extreme that they disrupt everyday life and can interfere significantly. SAD typically starts between early and late adolescence [5] and may then follow a highly stable, persistent epidemiology across the lifespan if went without treatment [6]. The Patron of the Malaysian Psychiatric Association (MPA), reported according to the 2017 National Health and Morbidity Survey, 29% of Malaysians suffer from depression and anxiety, compared with 12% in 2011 [7]. A cross-sectional research study underwent to study the prevalence and related factors of stress, anxiety, and depression among emergency medical staff in Malaysian hospitals. The highest prevalence is anxiety in 2018 (28.6%), followed by depression and stress [8].

2. Electrophysiological correlation of social anxiety disorder

Various studies have been conducted to determine the electroencephalographic and electrophysiological correlations of anticipatory anxiety induced in social phobia patients. There are many modalities to capture information about the structure and function of the brain. The most three commonly and frequently used imaging modalities are functional Magnetic Resonance Imaging (fMRI), magnetoencephalography modality (MEG) and electroencephalography modality (EEG). Among these modalities, EEG is the most multilateral and cost-effective method for studying brain activity and an effective model to study the neural correlates of social anxiety, which take an important role in the comprehensive connectivity of brain functions. Over the last decade, the analysis of electrophysiological signals has been constantly popularized by using blind source separation (BSS) approaches to identify the possible linear mixtures into multivariate recorded data channels so as to prepare multivariate data sets for more general data mining and extracting the biomarkers of social anxiety at different conditions in particular for (EEG) data. Among these biomarkers as follows:

2.1. Delta-beta cross-frequency correlation in social anxiety

Delta-Beta cross-frequency correlation is a widely used measure for the investigation of social anxiety. This measure represents the cross-frequency correlation between the amplitudes of delta band and beta band oscillations and known as delta-beta correlation. The spectral coupling between the delta and beta oscillations has been proven to be related to social anxiety [9]–[11]. Generally speaking, the EEG bands are associated with different functional and behavioral correlations. For instance, a slow wave brain oscillation like delta is associated with the subcortical regions responsible for motivation, mood, and reward processing [12]. On the other hand, a fast brain wave, reflect intercortical connections and will be activated when attentional control, cognitive processing, and regulation is required [13]. In general, Beta waves exist when we are vigilant, attentive, involved in problem-solving, judgment, decision making, or mentally focused.

2.1.1. Delta-beta correlation at resting state (baseline)

EEG signals were recorded from preschool children at rest and used to test whether the correlation level in delta-beta coupling are related to the harsh parental behaviors of mothers and fathers [14], [15]. Shreds of evidence were found of higher correlation at prefrontal electrodes for children whose fathers' exhibit extreme degree of severe parental harsh in compression to those who exhibit less degree of harsh parents. Remembering that cross frequency between delta-beta provides a real-time indicator of electro-cortical neural network down-regulation of mood-based responsiveness in subcortical networks [15]. Children with dysregulated fear or high fear in low- threat episodes showed greater levels of baseline coupling comparing to children who showed low levels of fear in low-threat environments [16]. An attempt was made to examine the relationship between correlation of EEG delta-beta and testosterone concentrations measurement in male participants at rest state. The salivary testosterone and EEG signal were collected in resting regional brain activity from thirty four healthy adult participants. Men with elevated percentage of testosterone exhibited non-significant coupling between delta-beta, while men with low testosterone showed significant delta-beta coupling. These relationships are only constructed in the frontal lobe [17]. The level of delta-beta coupling can be influenced and controlled experimentally. For instance, the use of synthetical cortisol [18] and stimulated anxiety [19] will affect the coupling between delta-beta in frontal lobe. In contrast, subcutaneous administration of testosterone resulted in a significant decrease in delta-beta cross-frequency, which is in line with the anxiolytic attributes of the steroid hormone [20]. Several findings regarding delta-beta correlation at baseline condition are obtained. The study in [21] proved that the cross frequency between delta-beta before cognitive behavioral therapy was greater than after therapy for SAD patients. Nonetheless, the pre-treatment delta-beta correlation in SAD patients was post-event test, compared with the control group, and there was no significant difference [11] and the delta- beta coupling was higher compared with the low behaviorally inhibited. Conversely, two studies did not find any difference between trait and state social anxiety [9], [21]. It was hypothesized that the magnitude of the power between delta and beta oscillation in spontaneous EEG is related the level of hormones as cortisol and testosterone so that the study of social anxiety during resting state is a good idea to be investigated.

2.1.2. Delta-beta correlation at recovery state

Despite the fact that post-processing is a very crucial aspect of social anxiety, few studies only studied slow waves and fast waves (SW-FW) coupling after predicting social stress conditions (recovery). This study [9] shows that individuals with higher social anxiety have an increased negative correlation with SW-FW compared with individuals with lower social anxiety [21], [22] after delivering self-presentation. The results have proven that delta-beta coupling distinguishes between low social anxiety and high social anxiety in the expectations time of social performance tasks and was more significant under all conditions of participants in low socially anxious participants, suggesting that delta-beta is extreme sensitive to trait anxiety and reflects an adaption of stressed neural regulation mechanism [23]. Therefore, it seems worthy to increase the number of studies in the recovery state in the social performance paradigm and future research should verify whether the SW-FW correlation during recovery can be a hypothetical EEG measurement of SAD so that the recovery phase can help to understand the state and trait characteristics of these putative EEG patterns.

2.2. Frontal alpha asymmetry in social anxiety

The theory of hemispheric asymmetry and emotion is an influential theory and it indicates that individual differences in positive and negative outcomes can be quantified by asymmetric patterns of FAA power [24]. More specifically, relatively larger left frontal cortical activity is associated with approach behaviors, while relatively larger right frontal cortical activity is associated with withdrawal behaviors [25]. Nonetheless, it should be noted that there is no straightforward consistency between positive/negative effects and approach/inhibition behaviors. For instance, anger is a negative sensation associated with approach behaviors and was also found to be associated with greater left frontal cortical activity [25]. FAA is typically quantified by calculating the difference between the right logarithmic-transformed lateralized frontal alpha power and left logarithmic-transformed right-lateralized FAA power [26]. For the reason that, alpha power amplitude is inversely proportional correlated to cortical activation, positive FAA scores are reflecting relatively higher left frontal cortical activity, and negative FAA scores are reflecting relatively higher right frontal cortical activity [26]. FAA has been investigated in relation to behavioral approaches and neuronal avoidance system. In addition, there are studies showed that FAA is involved in behavioral avoidance and inhibition [27], while other studies have shown that this relationship is a more complex and uncorrelated behavior inhibition [28].

2.2.1. Frontal alpha asymmetry in the resting state

FAA has been investigated during the baseline states where participants are asked to sit, blink or close their eyes for a period of time. The literature on the asymmetry of FAA in baseline states in social anxiety appears to be mixed and inconsistent. For instance, individuals with SAD show an increase in left frontal alpha activity after cognitive behavioral therapy [29]. However, the study didn't compare its results with control subjects. FAA during rest states has also been studied with traits associated with social anxiety, such as shyness. The study shows greater right frontal lobe activity in adults with high scores of shyness in comparison to those of low scores [30]. Conversely, other studies found no significant differences between patients with SAD and control as well as between patients with high and low social anxiety in resting FAA [10]. It was also found that the drawn relationship between shyness and right frontal EEG asymmetry at rest state occurs only after controlling for synchronous and concurrent depressive mood. After controlling for concomitant depression, high self-reported shyness and high socially withdrawn individuals have shown greater relative right frontal EEG activity at rest comparing to low socially withdrawn individuals [21], [31], [32]. High social anxiety and low social anxiety participants differ significantly in FAA in resting state. HSA participants show differences in the asymmetry of the FAA in all anxious states as well, which means FAA can be used as an indicator of SAD.

2.2.2. Frontal alpha asymmetry in the recovery state

Recovering from social stress situations, such as performing a public speech, may lead to an increased anxiety induction in post-processing of socially anxious individuals. As stated by various cognitive behavioral studies [33], [23] post-processing of SAD is characterized by reflection and continuous thinking (for example, destructive thoughts about past performance in social situations). Enhancing the painful memory retrieval and attention to negative assumptions are thought to preserve symptoms of SAD [33]. Probably, post rumination during the recovery state of a social performance task can be investigated by FAA. However, only two detailed investigation measured the FAA during recovery from a self-presentation. Unfortunately, these investigation could not track the differences in FAA between SAD patients and control subjects [10] and those with high social anxiety and low social anxiety individuals [21]. Although significant research deficiency should be considered, the post rumination processing of SAD is not reflected or can be explained in the pattern of FAA by the previous studies. This may indicate that the FAA is not a possible trait biomarker of SAD, but may be related to SAD under some certain highly stressful conditions. This study [34] showed that mixed findings in the FAA literature may be associated with comorbidity with other mental disorders such as depression. In fact, only a few studies on SAD have elucidated the mechanism of depression.

3. Methodology

In this introductory investigation, an experimental research was conducted to quantify the delta- beta correlation and FAA for SAD and HC during a resting state and a recovery from social event. This part of work will further delineate related information about the subjects, the experimental design and the scheme elaborated in spectral analysis of EEG signals.

3.1. Subjects

The participants admitted were eight healthy male subjects (4 SAD subject and 4 HC subjects), aged 19–22 years old (20.60 ± 0.73). The severity of SAD was assessed by using Social Interaction Anxiety Scale (SIAS), to appraise subject's propensity of fear or anxiety about one or more social situations where the individual is subject to possible scrutiny. According to their self- assessment, participants with high score of SIAS were recognized as SAD individuals, while individuals with low score of SIAS were identified as HC subjects. All participants were healthy, free from psychoactive therapy and right-handed. All participants gave voluntary informed consent and were compensated for their time and participation. Participants were recruited from or within the proximity of Universiti Technology Petronas. This work has been accepted and approved by the Ethical Clinical Research Committee of the Universiti Teknologi PETRONAS, and by the standardization of Medical Research Ethics Committee of University of Kuala Lumpur Royal College of Medicine Perak, Malaysia.

3.2. Experimental design

As a central protection, selected participants are provided with a detailed explanation about the EEG proceeding and signed the informed-consent form. The participants were requested to be seated in a pleasant position in a relatively noise-isolated room. The experimental protocol started posterior to the attachment of the electrodes by collecting EEG baseline state for 4 minutes (eyes closed, eyes open).

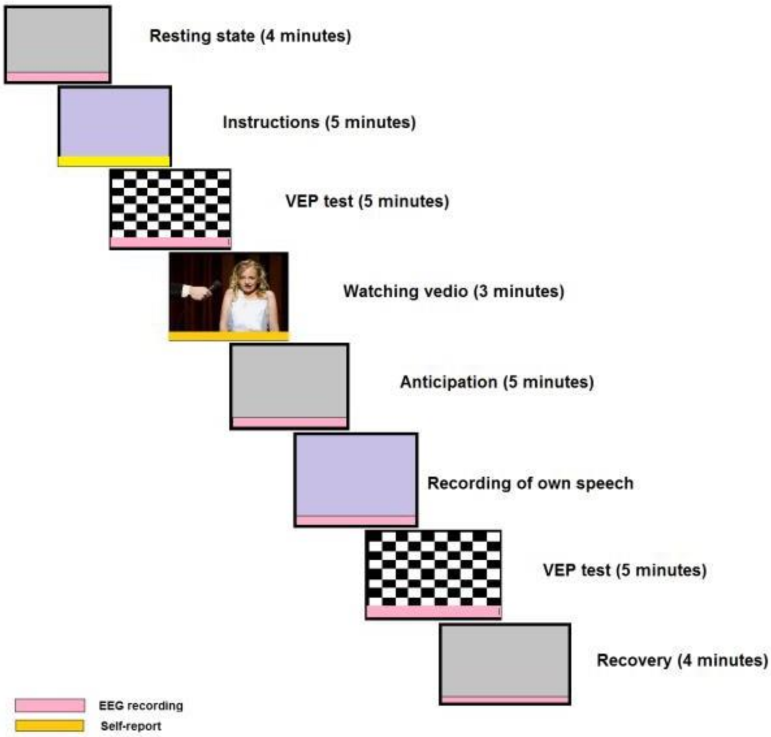

Figure 1. Overview of the experiment setup.

Thereafter, participants performed a social performance task (self-presentation in front of audience and camera), where all participants have to speak about their negative social traits for 3 minutes in front camera. After all subjects had delivered their presentation for 3 min, they had 4 minutes to relax after the self-presentation (recovery). The social performance task include five stages (instructions, watching video, anticipation of speech, speech, and recovery from social event), which were shown in a constant procedure as shown in Fig. 1. For this preliminary study we will only investigate on the resting and recovery states and the rest of the tasks will be reported in somewhere else. Overall, the experiment took 2.4 h.

3.3. EEG recording and signal processing

The EEG signals was continuously detected using Ag/AgCl scalp at 32-channel sites using eegoTM sports system (ANT Neuro, Netherlands) based on the International 10–20 System. EEG recordings were collected at a sampling rate frequency of 2048 Hz and then down-sampled to 512 Hz and recorded with a common reference CPz and the impedance was kept below 5 kΩ. First, the electrical brain EEG data were band-pass filtered with a cut-off frequency of 0.53–40 Hz with a 50 Hz notch filter and decomposed into the four different sub-bands, namely, delta (0–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (12–30 Hz). Eye artifacts (movements and blinks) and muscle movements were manually inspected and corrected using the BESA software. The cleaned EEG data were then exported to MATLAB for EEG features extraction for further frequency analysis. The power values for electrodes F3, Fz, Fpz, F1, F2, F6, F7, F8, F5, and F4 were averaged into composite frontal delta and beta power values and we calculated the final alpha scores by averaging the alpha power in a frontal left hemisphere (F3, F5) and frontal right hemispheres (F4, F6).

4. Result and discussion

This part of work is comprised of three different segments. In the first sections, we have discussed the main findings of delta-beta correlation for SAD and HC individuals during baseline measurements (i.e. eyes closed and eyes open) and during the recovery from social event. In the second section, we compared the results of FAA for SAD and HC.

4.1. Delta-beta correlation in SAD and HC groups.
Delta–beta correlation has been proven to be very sensitive to any external influences since it can discriminate between SAD and HC groups in all performance conditions. As shown in table 1, delta-beta correlation in SAD group was decreased after the self-presentation task (recovery). Delta-beta coupling have shown higher correlation in baseline condition (eyes closed, and eyes open) than the recovery from social task in SAD group only as shown in figure 2. During baseline measurement, delta beta correlation was significant in eyes closed in SAD participants but not in HC.

Table 1. Delta–beta correlations in SAD and HC groups.

Group	Task	Correlation value	p-value
SAD	Eyes open	0.670	0.229
	Eyes close	0.998	0.001
	Recovery	0.374	0.625
HC	Eyes open	0.553	0.446
	Eyes close	0.363	0.677
	Recovery	0.704	0.002

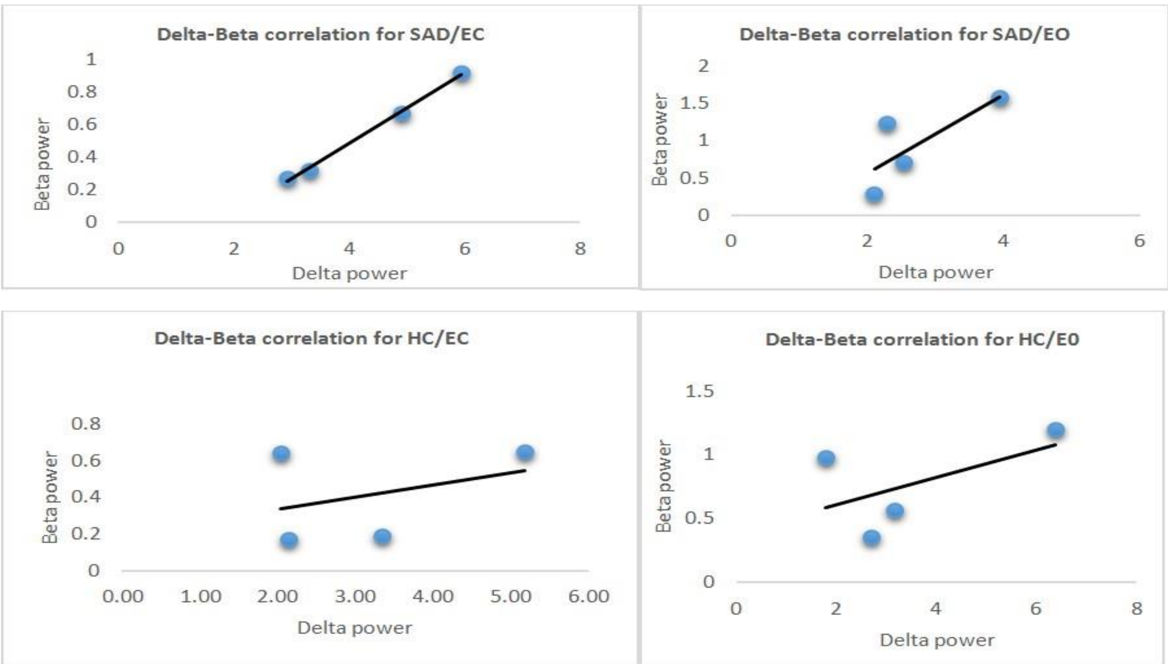

Figure 2. Scatter plots of the delta- beta correlation in SAD and HC in EO and EC.

It is believed that positive significant correlation between delta–beta waves is indicating to the presence of dynamical communication and cross-talk between cortical and subcortical neural areas [17]. In line with previous studies [9], [10], HC group have shown a significant positive delta–beta correlations after the recovery from social task which possibly means that delta–beta correlation could be more sensitive to state anxiety individuals more than trait anxiety individuals as shown in figure 3.

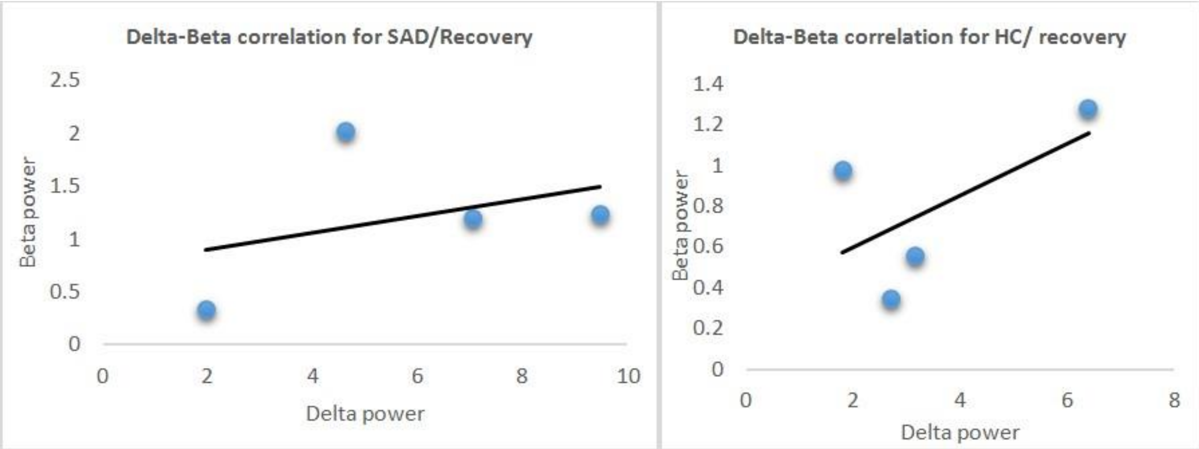

Figure 3. Scatter plots of the delta- beta correlation in SAD and HC in recovery.

4.2. Frontal alpha asymmetry in SAD and HC.

FAA is typically measured by quantifiing the difference between the averaged left alpha power and the right alpha power [83]. We have calculated the average alpha power in a left hemisphere (F3, F5, F7) and right hemisphere (F4, F6, F8) at frontal regions. SDA participant have shown higher alpha asymmetry scores in right frontal cortical lobe , which reflects relatively greater left frontal cortical activity, wherase HC partcipants have demonstrated higher alpha asymmetry scores in left frontal cortical lobe, which reflects relatively greater right frontal cortical activity as shoen in table 2. The findings presented here came with line with the previous works [35], [36].

Table 2. Frontal alpha Asymmetry in SAD and HC groups.

Group	Task	Alpha Asymmetry scores
SAD	Eyes open	-0.085
	Eyes close	-1.36
	Recovery	-0.09
HC	Eyes open	0.018
	Eyes close	0.51
	Recovery	0.31

Since alpha power is inversely linked to cortical activity, positive alpha asymmetry scores reflects relatively greater left frontal cortical activity, and negative alpha asymmetry scores reflecta relatively greater right frontal cortical activity. Generally, the increament of alpha activity is associated with decreased of alpha power due to alpha desynchronization as a typical reaction to activation, which means alpha synchronization is a marker of a neural deactivation.

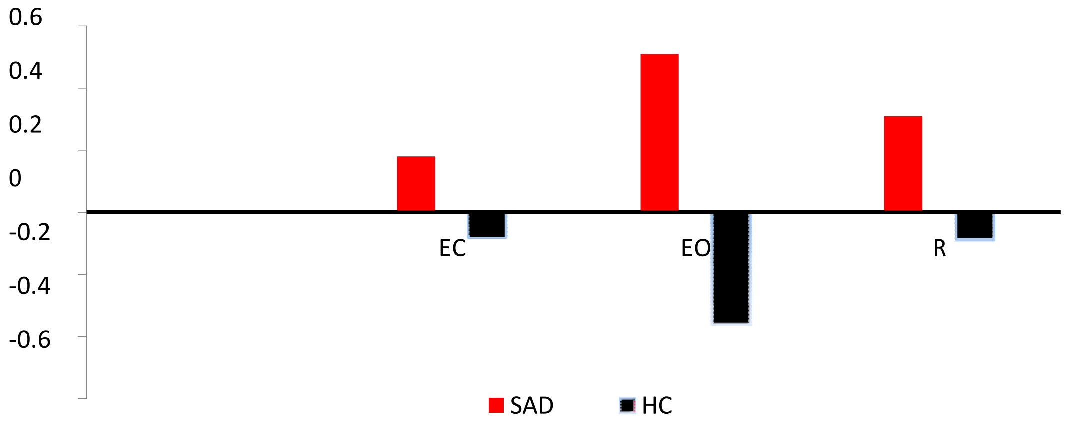

Figure 4. FAA scores for HSA and HC participants during eyes closed (EC), eyes opened (EO) and Recovery from social task (R).

5. Conclusion

Patterns of frontal EEG asymmetry may serve as an index of the severity for a variety of emotion-related disorders, including depression and social anxiety. Overall, Frontal alpha asymmetry and frequency coupling between the activity of the delta frequency band and the activity of the beta frequency band may be a presumptive biomarker for social anxiety. The reported results suggest that concurrent social anxiety levels can be segregated and quantified by studying the cross- frequency coupling between slow and fast wave oscillations and alpha asymmetry in resting state or any social tasks (i.e. giving a speech in front of An audience or camera).

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