Development of a Wearable Electroencephalographic Device for Anxiety Monitoring

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1 Background

Anxiety disorders are the most common mental illness in the U.S. affecting nearly $40 \times 10^6$ adults (18% of the U.S. Population). It has been shown that patients with recurring anxiety tend to be more suicidal and prone to depression [1,2]. Anxiety has also been proven to be an impeding factor in the rehabilitation time of subjects suffering from various diseases ranging from pulmonary afflictions [3] to cancer [4]. Detection of anxiety is commonly done through various tests conducted by psychologists [5], which are time consuming and not necessarily accurate. Recently, electroencephalographic (EEG) data have been shown to be useful in the case of most anxiety patients to detect the levels of anxiety [6–8]. Two of the key areas of the brain that are known to be affected by patients suffering from social anxiety are the occipital and frontal lobes [9,10]. EEG data are best explained through rhythms in the frequency domain: delta (1–4 Hz), theta (4–7 Hz), alpha (7–12 Hz), beta (12–30 Hz), and gamma (>30 Hz).

Research in the field has shown that changes in the alpha feedback are commonly seen in high anxiety and neurotic patients [11,12] and alpha EEG biofeedback is commonly used in the management of anxiety [13,14]. It has also been suggested that anxiety can be detected through analysis of alpha-theta and theta waves of the EEG signals [15,16] while theta waves are most commonly seen in the case of animal experimentation of anxiety and fear [17].

Considering the importance of real-time observation and management of anxiety states in patients, we developed a wearable EEG device for anxiety monitoring and investigated the influence of induced anxiety on the responses of the brainwaves obtained from the occipital lobes.

2 Methods

The wearable EEG system (Fig. 1) has four dry pin electrodes (G.Tec Medical Engineering, Austria) consisting of eight pins made of gold alloy. The electrodes are connected to an amplifier board which amplifies and digitizes the analog raw data. The raw data are then transmitted over a secure Bluetooth connection and filtered by a digital band-pass filter with a lower cutoff at 1 Hz and a higher cutoff at 30 Hz. A Fast Fourier Transform (FFT) was performed on the raw data acquired in time domain by the use of the PWELCH functionality in MATLAB, which generates the power spectral density estimate against the frequency of the signals. These power spectral values were then differentiated in order to facilitate peak detection.

Seven young healthy subjects aged between 19 and 24 yr of age with no prior history of mental illness were chosen for the purpose of the anxiety monitoring study. All subjects gave informed consent prior to participation. The wearable EEG device was then placed onto the scalp of the subjects to enable capture of the anxiety EEG data from the occipital lobe.

For the purpose of inducing anxiety, the subjects were requested to play four different games (Temple Run, Flappy Bird, 2048, and SlenderMan) and complete certain goals in a fixed duration of time. If the subjects were unfamiliar with the game, they were given a short duration of time to familiarize themselves with the basic controls. After playing each game, the subjects were asked to indicate the level of anxiety they experienced during the game with the use of a questionnaire and an anxiety scale, based on the Covi anxiety scale [18], ranging from 0 to 5. The subjects were videotaped while playing each game and were asked to identify instances (anxiety events) during the game when they felt the highest anxiety after each game. The subjects played all the games on an iPad to ensure consistency.

The reported anxiety events were then compared against the signal peaks observed in the EEG responses. Moreover, the normalized EEG power difference values for the individual channels were compared against the normalized anxiety scores provided by the subjects (Fig. 2). The normalized anxiety scores were further grouped into two categories to enable classification of the EEG responses: low anxiety (<50%) and high anxiety (100%; normalized over maximum anxiety score attained for each subject).

In addition, three representative points (before, during, and after anxiety event) were chosen from the O1 and O2 (left and right lobes, respectively) delta and theta signals and compared to investigate the statistical significance of the signal peak during anxiety event, in relation to its neighboring power densities (before and after anxiety event).

3 Results

3.1 Questionnaire Results. We found that subjects experienced the highest level of anxiety while playing SlenderMan, but the lowest level of anxiety while playing Flappy Bird (Table 1). We also found that the time deviation noticed between the EEG signal peaks and the reported anxiety events were quite small (Table 2).

3.2 Distinguishing Between Different States of Anxiety. To illustrate the differences between low and high anxiety levels, two different games where the average of anxiety scores were low (Flappy Bird) and high (SlenderMan) were chosen. A distinct relationship between the normalized power value difference from the signals in the delta waves of the occipital lobe and the normalized

![Wearable EEG device used for anxiety data collection](image-url)
anxiety score was noted, wherein higher anxiety leads to a higher normalized power difference and lower anxiety causes a significantly lower normalized power difference.

3.3 Occipital Peaks. In cases of low anxiety, there were no statistically significant differences in the delta and theta waves for both left (O1) and right (O2) occipital lobes (Table 3). For high anxiety cases, the power densities of the delta and theta peaks during anxiety at the right occipital regions (p = 0.025 and p = 0.012, respectively) were significantly higher than its neighboring power densities (before and after anxiety event), though no substantial difference was noted for the left lobe (Table 4).

4 Interpretation

The purpose of this study was to develop a wearable EEG device for anxiety monitoring and to identify differences in the EEG responses of the occipital lobe. Our results indicated that high and low anxiety cases can be distinguished through the power spectrum of the delta waves from the occipital lobe. However, it is difficult to distinguish medium anxiety cases as no distinct relationship can be inferred from the limited sample size adopted in this study. Moreover, we found a notable asymmetry in the left and right occipital lobes, when the subject experienced high amounts of anxiety, suggesting that the activity in the right occipital lobe may be dominant during high anxiety, which is in line with a prior report on cognitive biases [19].

Our preliminary study demonstrated that through the use of EEG signals, low and high anxiety levels may be detected and distinguished in its early stages, whereby patients can get the necessary care before their mental condition worsens. One of the key constraints of the study was the popularity and familiarity of some of the subjects with the games that were played which may have affected the basal anxiety levels of the subjects. Future work will involve analysis of a larger sample size and also include a greater range of anxiety-inducing activities so as to help distinguish the differences between different sublevels of anxiety, and to establish the potential similarities and differences between clinical and gaming anxiety.

References
