Brain Activity Analysis of Stressed and Control Groups in Response to High Arousal Images

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Abstract. Stress is known as a state in which an individual tussles with psychological or social demands. It can be detected in response to high arousal images, but the existing dataset of such images might not be effective to induce stress for the population of financially and politically unstable countries. This study examines the effects of stress-inducing high arousal images selected from the Geneva Affective Picture Database (GAPED) on the brain activity of stressed and control groups. Twenty-seven healthy participants of the same educational background and ethnicity took part in this study voluntarily. The electroencephalography (EEG) data signals are recorded using a single-channel headset and all participants are advised to close their eyes for one minute and avoid thinking about anything. Negative images with high arousal values are presented to the participants for one minute. EEG data signals are recorded again with closed eye condition for one minute. The t-test is applied to check the effects of high arousal images on brain activities of all participants, stressed participants, and participants in the control condition. The results of this study reveal that there are no statistically significant changes observed in all EEG bands after the presentation of the high arousal images. This study is the first step that points to the need for a new image dataset for high arousal images to induce stress for the population of developing countries.

Keywords: Electroencephalography · Brain activity · Statistical analysis · Human stress · High arousal images

1 Introduction

Stress is a condition in which a particular individual feels overwhelmed due to mental or psychological demands. These demands can be tied to work, family matters, and financial affairs [1]. Stress can overcome the immune system and could be a reason for functional disability while performing routine tasks [2]. It is a cause of various physical and mental diseases, for example, it enhances the chances of cardiac arrest, depression, coronary artery disease, and gastroesophageal reflux disease [3]. Therefore, it is important to measure and manage stress effectively.

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Stress can be assessed using psychological, physical, and physiological measures. Psychological questionnaires are based on an individual's rating of items on different scales [4–6]. Physical features like blink rate, facial expressions [7], pupil dilation, voice, and eye gaze are sensitive to stress. Physiologically, hormones are released relatively in a greater amount when a person is feeling stressed. The effect of these stress hormones can be measured through invasive (e.g., acquisition of blood, saliva, and urine samples) and non-invasive methods [8]. The stressful situations often lead to changes in the autonomous nervous system (ANS) [9]. ANS and the physical response of humans in stress are directly connected [10, 11]. ANS is organized into the sympathetic and parasympathetic nervous systems [12]. They both help in controlling heart rate variability (HRV), skin conductance, blood pressure, respiration, and brain waves [8–13].

Stress has a significant effect on the brain activity of an individual [14]. Electroencephalography (EEG), functional magnetic resonance imaging (fMRI), and positron emission tomography (PET) are used to analyze functional changes in the brain's activity [15]. EEG helps to measure brain disorders, which are associated with the electrical activity of the brain [16]. Therefore, EEG is regarded as an effective and non-invasive form of neuroimaging to obtain the cortical response to stress [17]. Moreover, EEG has been correlated directly with other stress response measures such as HRV [18].

EEG can be used to classify stress levels as it reflects the electrical activity of the brain [19]. Four rhythms of EEG tend to change with the changing level of stress [20]. For stress measurement, EEG recordings have been conventionally performed using 128, 64 and, 32 channel headsets but these headsets are not easy to wear [21]. Fourteen channel headsets are relatively easy to wear but it becomes difficult to wear in circumstances where frequent data acquisition is required. Therefore, we use a single-channel dry-sensor EEG headset to measure mental stress, which has an electrode at the frontal side of the head. Neuro-chemical changes due to stress response have a significant impact on the frontal part of the brain [22]. Therefore, this headset is preferred to be used in the experiment.

Several methods exist for stimulating subjects such as images can be displayed to the participant, they can watch movies, hear sounds, and can play games [23]. Stress can be assessed by measuring physiological signals in response to high arousal images and interviews [12]. Multimedia stimuli can induce emotions and these emotions are translated from the body response [24]. Geneva Affective PicturE Database (GAPED) is a relatively large, and effective dataset used to invoke specific emotions [25, 26]. The images of the dataset were rated based on valence and arousal scores [25]. Valence illustrates positive or negative affectivity; arousal deals with the extent of the calming or relaxing ability of the material. Negative images with high arousal values such as violence against humans and animals induce stress, which is indicated by heart rate variability, physiological stress parameters, EEG, and subjective rating [27, 28].

In this study, we intend to analyze the brain activity of stressed and control groups in response to high arousal images using a single-channel dry sensor headset. To evaluate the stress of 27 participants, PSS is used as a stress questionnairere. The reliability and validity of PSS-10 for perceived stress is found in many researches such as [29, 30]. Based on the PSS score, participants are divided into stressed and control groups. Immediately after filling the questionnaire by the participants, EEG signals are recorded using a single-channel NeuroSky's headset. After this, GAPED dataset is used to induce psychological stress in the participants. Participants are presented with twenty selected high arousal images of the first four categories such as snakes, spiders, emotion concerning, and animal mistreatment. The reason behind this is that they physiologically awake the humans and capture their attention [31]. Each picture was presented to the participants on a screen. After displaying selected GAPED images to participants, EEG signals of participants are recorded again. For statistical analysis, a paired t-test is applied on frequency bands of EEG signals. These EEG signals are acquired before and after the presentation of images to the participants.

The rest of the paper is organized as follows. The detailed methodology is explained in Sect. 2. Section 3 explains the results of the experiment such as data labeling and statistical results. This section also includes a discussion of brain activity analysis when high arousal images are presented as a stimulus. The conclusion is presented in Sect. 4.

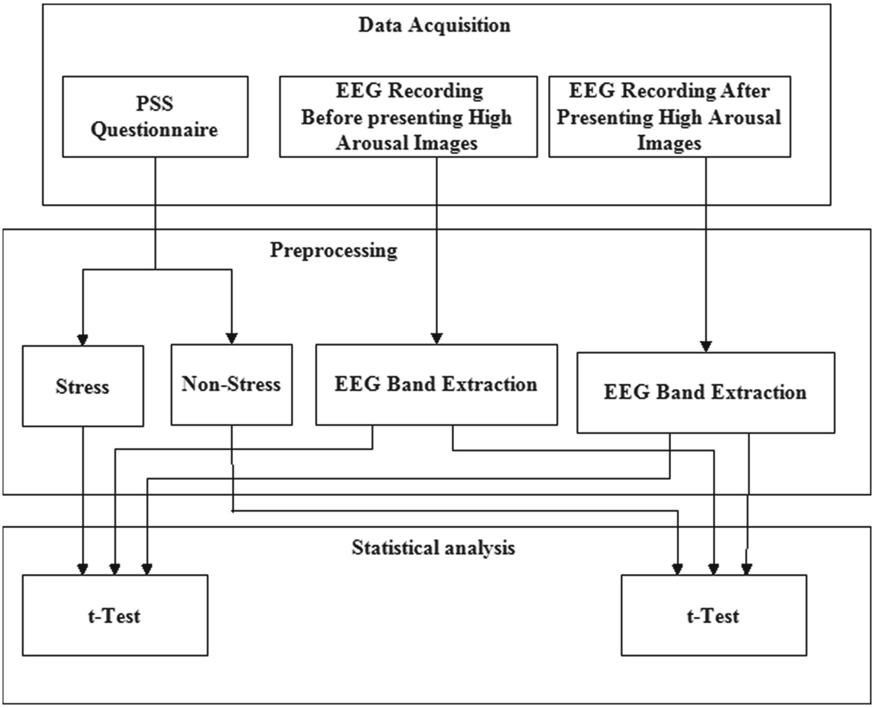

Fig. 1. Block diagram of the methodology employed for the brain activity analysis of the stressed and control groups.

2 Methodology

A block diagram to show the methodology adopted in this study is presented in Fig. 1. Initially, participants are asked to fill the PSS-10 questionnaire. The scores of the PSS questionnaire are recorded. After this, EEG data is recorded using NeuroSky's Mindwave headset. Recorded EEG data is then transformed into the frequency domain to extract various EEG bands such as theta, low gamma, mid gamma, low alpha, high alpha, low beta, high beta, and delta. These frequency bands are categorized based on their frequency ranges as shown in Table 1.

Table 1. Frequency ranges of EEG bands used in the study.

Sr. No	Band	Frequency Range (Hz)
1	Delta	1–3
2	Theta	4–7
3	Low-alpha	8–9
4	High-alpha	10–12
5	Low-beta	13–17
6	High-beta	18–30
7	Low-gamma	31–40
8	Mid-gamma	41–50

2.1 Participants

In this study, 27 healthy participants (67% male and 33% female) participated within the age range of 22–33 years, with a mean value of 27.5 years. Participants of this study belong to the same ethnicity i.e., Asia Pacific, and with almost the same educational background. Participants involved in this study belong to the field of education i.e., faculty, and students.

The PSS questionnaire is designed to be used by participants with at least a junior high school education, whereby the questions are easy to comprehend and make the responses simpler. The participants selected for this study fulfill all the basic requirements for PSS. The study is approved by the Board of Post Graduate Studies of the. Computer Engineering Department, UET Taxila.

PSS-10 questionnaire is used in this study to divide the participants into two groups i.e., stressed, and control group. PSS-10 comprises 10 questions that ask about the frequency of stressful incidents. These stressful incidents may have occurred in the span of last month or earlier. The participants are asked to rate each question on a scale of 0 to 4. PSS score is then used to categorize participants as stressed or control. EEG data was recorded using NeuroSky's Mindwave headset, which was easy to wear EEG device with a single electrode positioned at FP1. It was configured as a single channel with a sampling frequency of 512 Hz. EEG signals for each participant were recorded in the same environment. The experiment was conducted in a quiet environment to avoid acoustic noise. Every participant was asked to sign an informed consent and could leave the experiment of his/her will. To avoid any disturbance during the experiment lights were adjusted according to the comfort level of the participants. It was also ensured that no syncing error occurred during EEG signal recording.

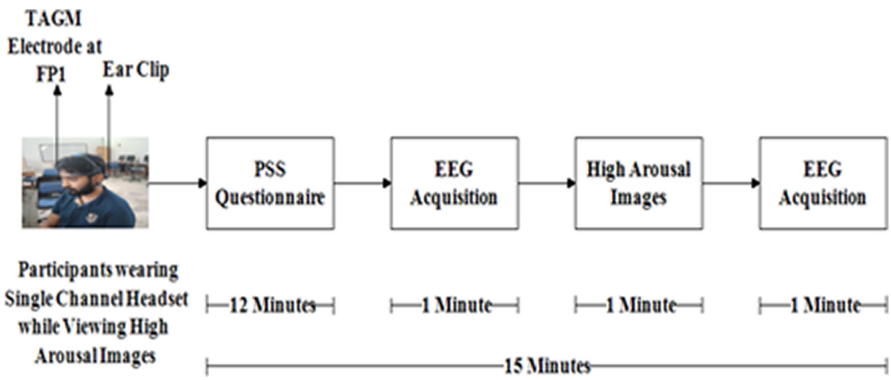

Fig. 2. Time flow diagram of the experiment.

All participants were advised to wear the EEG device. They were instructed to close their eyes for one minute and empty their minds from all thoughts. EEG of each participant was recorded for 1 min in an eye-closed condition. Images with high arousal values were presented to the participants for 1 min and after displaying of images participants were advised to close their eyes for 1 min and EEG data was recorded again. The t-test is then applied to frequency bands of the EEG data, recorded before the presentation of GAPED images to the participants and after displaying high arousal images. The time flow diagram of the experiment is shown in Fig. 2.

2.2 Stimuli

For this study, twenty GAPED dataset images are selected as a stimulus and are presented to the participants to induce mental stress. The images having a mean rating value for arousal, ranging from 51.829 to 91.290 points are selected. The mean rating value for arousal is in the range of 0.779 to 45.437. These images are projected on a full screen of 55 inches display, at three meters away from the participant. Twenty high arousal images are displayed for 1 min. Each image was displayed for a duration of five seconds. Figure 3 shows a grid of selected images from GAPED dataset based on high arousal values.

2.3 T-test

Statistical tests have great importance in the field of biomedical research. Various factors play an important role in the selection of appropriate t-Test as their inaccurate use may lead the research in the wrong direction and hence provide inaccurate results.

Fig. 3. 20 selected high arousal images from GAPED image dataset used as stimulus in this study.

The student's t-test is mostly used for statistical analysis; the William Gossett test that is known as the t-Test. The t-test determines the significant difference between the means of two groups, which are related to each other. The selection is dependent on data and the type of analysis required under specific criteria. The results obtained are termed as statistically significant if the p-value is less than 0.05. Unpaired t-test is used to determine the significant difference between the means of two independent variables. Paired t-test determines the significant difference between the means of two dependent variables**.** It is also appropriate for the data in which pair consists of before and after the measurements on a single group of subjects or two measurements on the same subjects are paired. In our case, paired t-test is applied over the frequency bands of the participants before and after the stimulus to check the difference between their means**.**

3 Experimental Analysis

The statistical analysis for overall (all participants), control, and stressed groups is presented in this section. Data labeling for stressed and control groups is described in the following subsection.

3.1 Data Labeling

The participants involved in the study are grouped into a stressed or control group using their PSS score. Figure 4 shows the PSS score of each participant. The overall mean (μ) and standard deviation (σ) of the total responses of PSS scores collected from participants were 17 and 4, respectively. For the stressed participants, the threshold value is calculated from the PSS scores using a formula such as [$\mu + \sigma/2$]. This value comes out to be 19 in our case. So, the participants having a value equal to or greater than threshold values are considered to be stressed. Similarly, for the control group, the threshold value is calculated from PSS scores using the formula [$\mu - \sigma/2$] which is 15. So, the participants having PSS scores below or equal to this threshold are considered the control group. The eight participants having PSS scores in the range (16 to 18) are ignored. Being ignored does not show a complete absence of one or other condition. 9 out of 27 participants were labeled as stressed while the rest of the participants are labeled as a member of control group.

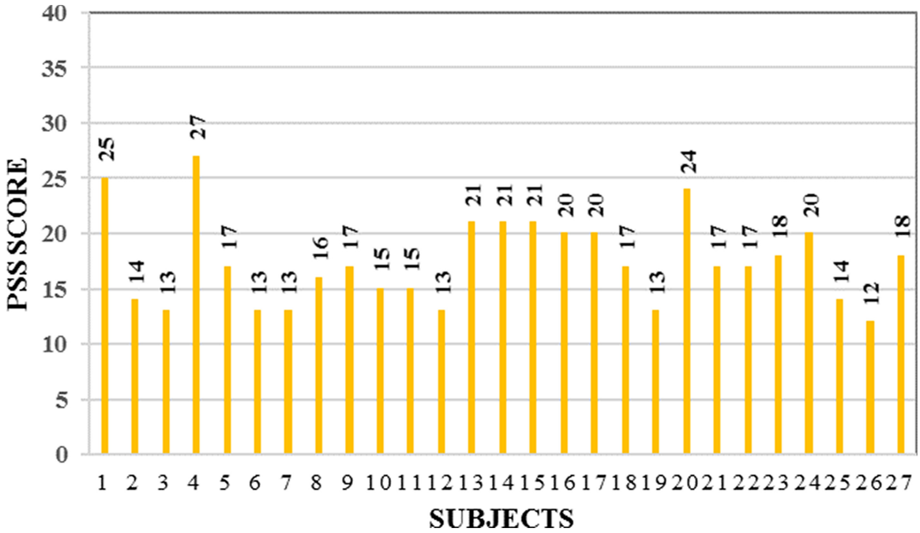

Fig. 4. Distribution of PSS Score of subjects participated in this study

3.2 Statistical Results

To analyze both groups two-sample (stressed and control group) paired t-test is applied to the frequency bands before displaying images (EC1) and after displaying images (EC2). The test decision is based on groups. The t-test results for EEG frequency bands before and after the presentation of the stimulus for overall, control, and stressed participants are shown in Table 2. It is evident from the results that none of the EEG frequency bands is significantly different before and after displaying high arousal images to all the participants except high alpha and high beta bands and participants belong to stressed and control groups.

The distributional characteristics of each band for all participants are presented using box plots, and these box plots represent an overall response of each frequency band. Whiskers represent 25% of the data values of the bottom and top, whereas interquartile ranges represent 50% of data values. A straight horizontal line marks the median of the data. Box plot of the EEG oscillations was captured using a single-channel headset before and after the presentation of GAPED images.

Here frequency band values before the presentation of images are denoted by EC1 and frequency band values after displaying images are denoted by EC2. Figure 5 shows the box plots of different EEG bands before and after displaying high arousal images for the overall group. It is evident from the presented results that no significant difference exists in any of the EEG frequency bands before and after displaying high arousal images. Figure 6 presents the box plots of different EEG bands before and after the presentation of GAPED high arousal images for the control group. A slight variation is observed in the means and standard deviation of EEG frequency bands. Thus, it shows that a minimal difference exists before and after displaying GAPED high arousal images Fig. 7 shows the Whisker box plot results for the stressed group.

Table 2. p-values of different EEG frequency bands before and after displaying high arousal images for overall, control, and stressed groups.

Sr. No	Frequency bands	p-value (p) (Overall)	p-value (p) (Control)	p-value (p) (Stressed)
1	Delta	0.33	0.88	0.81
2	Theta	0.79	0.34	0.17
3	Low alpha	0.22	0.36	0.79
4	High alpha	0.09	0.14	0.50
5	Low beta	0.16	0.24	0.58
6	High beta	0.09	0.46	0.66
7	Low gamma	0.29	0.68	0.33
8	Middle gamma	0.19	0.33	0.81

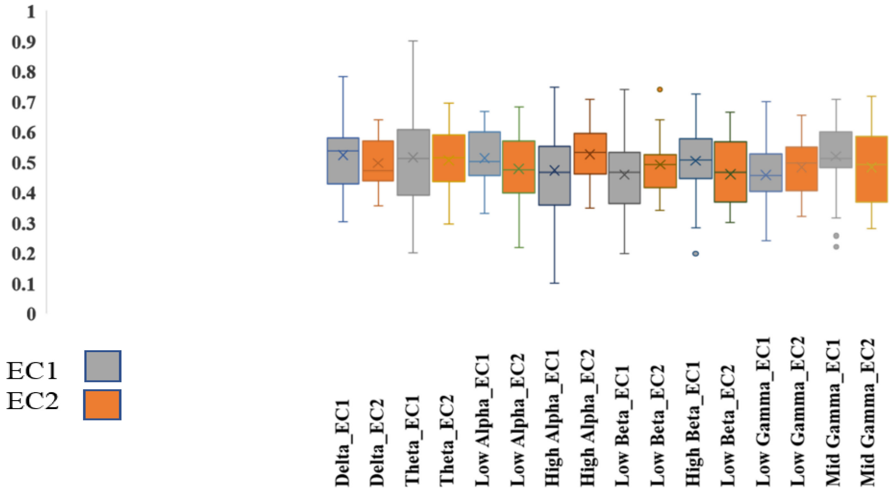

Fig. 5. Boxplot of different EEG bands of all the participants before and after presentation of high arousal images

From the results, it is noticed that no significant difference is present in any of the EEG frequency bands before and after displaying high arousal images i.e., EC1 and EC2. However, a slight variation is observed in the means and standard deviation of EEG frequency bands. Thus, it shows that there is a minimal difference before and after the presentation of GAPED high arousal images. The p-values obtained from paired T-test in EEG frequency bands show increased activity of high alpha and high beta bands as compared to other frequency bands. The p-value of high alpha in overall (Control and stressed group) show that there is only 91% confidence level that there is a significant difference. Also, the control and stressed group depicts 86% and 50% confidence level respectively that there is a significant difference, which indicates that the high alpha band was highly active during the presentation of high arousal images.

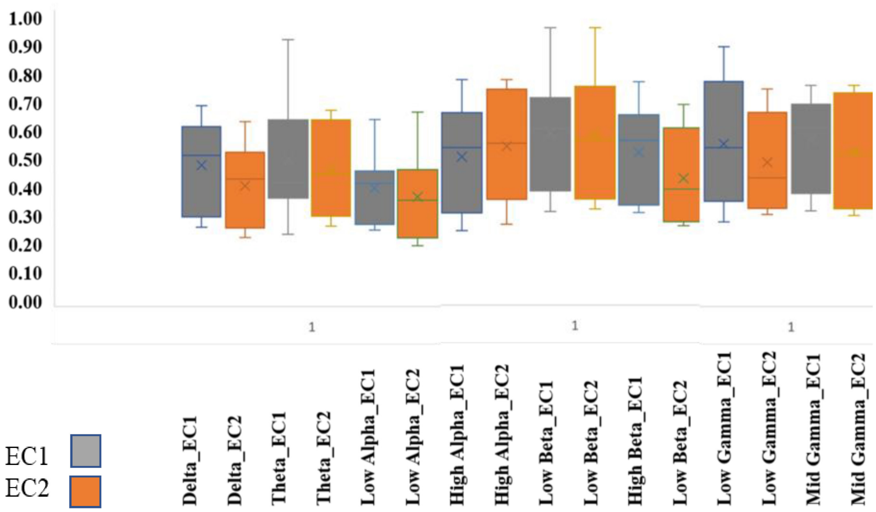

Fig. 6. Boxplot of different EEG bands of control group before and after presentation of high arousal images.

The p-value of the high beta band shows the confidence level of 91%, 54%, and 34% for overall (control and stressed group), control and stressed group respectively that there is a significant difference. Thus, from all the above discussion it is concluded that high alpha and high beta bands were relatively active to the high arousal images as available in the literature [32, 33]. But at a 95% confidence level, none of the frequency bands are significantly different. Table 2 shows the result of p-values of different EEG bands before and after of the high arousal images for the overall, control, and stressed groups. The limitation of the study is a smaller number of GAPED images presented to the participants. Thus, due to the lesser number of participants and data further investigation is required. If the number of GAPED images and the participants is increased, we may obtain a significant value for alpha and beta bands.

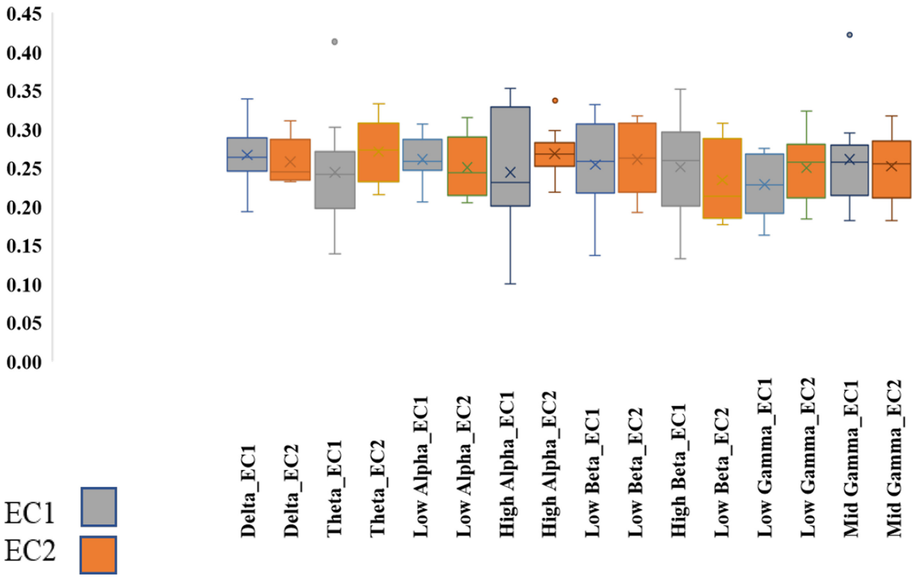

Fig. 7. Boxplot of different EEG bands of Stressed group before and after presentation of high arousal images.

4 Conclusion

The T-test is applied on frequency bands of all the participants, stressed, and control groups, before and after displaying high arousal images. It has been observed that there is no statistically significant difference in the frequency bands before and after the stimulus of high arousal images except the high alpha and high beta bands which show the relatively increased activity. These high arousal images were taken from GAPED dataset, which was made considering the population of developed countries. We can say from this preliminary study that there is a need to develop a new image dataset keeping in view the population of financially and politically unstable countries as these images might not affect their brain activities. A limited number of images are selected in this preliminary study for experiment according to mentioned criteria. In the future, we intend to acquire more data to validate these findings.

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