Detection of stress/anxiety state from EEG features during video watching

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Abstract— **This paper studies the effect of stress/anxiety states on EEG signals during video sessions. The levels of arousal and valence that are induced to each subject while watching each video are self rated. These levels are mapped in stress and relaxed states and subjects that fufill criteria of adequate anxiety/stress scale were chosen leading to a subset of 18 subjects. Then, temporal, spectral and non linear EEG features are evaluated for being able to represent accurately states under investigation. Feature selection schemes choose the most significant of them in order to provide increased discrimination ability between relaxed and anxiety/stress states.**

I. Introduction

Stress and anxiety are states of emotional strain that are experienced from many people especially over the last years as a result of the modern way of living. The effects of this situation can be observed in physiological, neurobiological and psychological levels [1]. Stress refers to the body response to demands for changes [2]. It influences major aspects of everyday activity deteriorating the quality of life. Measures to reduce stress are of great concern either for individual health and the society welfare.

Electroencephalography (EEG) is a reliable tool reflecting upper cognitive functions and mental or psychological states. It is generally adopted that higher spectral activity is correlated with arousal, cognitive processing or emotional activity. There is a specific frequency band (β3, 18–22 Hz) that it is considered to be correlated with emotional "intensity" that may, in some cases, comes from anxiety [3]. It is reported that a shift from greater left frontal activity during low stress to greater right frontal activity during high stress [4]. Frontal and prefrontal cortex appears to play a significant role in emotional processing, presenting increased prefrontal θ activity in reduced anxiety state [5].

There is the notion that alpha asymmetry is related to the valence while the beta/alpha ratio is related to the arousal dimension [6]. The alpha asymmetry has been implicated to stress in various studies [4, 7] or to discriminating among psychological states [8]. Frontal alpha asymmetry differences have been reported in stressed condition, with right exceeding relatively left hemisphere power [4, 9]. Moreover studies refer of higher right prefrontal activity on stressor moods, compared to left prefrontal activity [10]. Also, trait emotional intelligence is significantly positive correlated with left frontal asymmetry.

Further researches study coherence described as an EEG network, allure low stress values instead of relaxed for both inter- and intra-hemispheric theta, alpha and beta rhythms. Also coherence demonstrates greater values in function of distance between the channels involved [11, 12].

This paper aims to investigate EEG features implicated in anxiety/stress state and their significance of affect.

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II. MATERIALS AND METHODS

A. Data description and procedure

Data used in this study is the public available DEAP dataset [13]. It consists of various biosignals recordings, including EEG, while participants (aged 27.7±4.4 years old) were watching 1min videos. Experiment involved 40 sessions of recordings while watching 1min videos. After each trial, they were noted a self-assessment video rating in terms of valence and arousal. Valence scale extends from unhappy or sad to happy or joyful while arousal scale extends from calm or bored to stimulated or excited.

EEG data were preprocessed using band pass filter 4-45Hz and downsampled to 128Hz. Locations of 32 channels were used according to the international 10-20 system (Fp1, AF3, F3, F7, FC5, FC1, C3, T7, CP5, CP1, P3, P7, PO3, O1, Oz, Pz, Fp2, AF4, Fz, F4, F8, FC6, FC2, Cz, C4, T8, Cp6, Cp2, P4, P8, PO4, O2). EEG rhythms were determined as frequency intervals of θ (4-8Hz), α (8-13Hz), α1 (8-10Hz), α2 (10-13Hz), β (13-30Hz), β1 (13-15Hz), β2 (15-18Hz), β3 (18-22Hz), β4 (25-30Hz), γ (30-45Hz), low γ(30-35Hz) and high γ(35-45Hz).

B. Anxiety/stress data selection

Stress is an emotion that is characterized by negative valence and a positive arousal. According to circumplex model of affect [14], stress is mapped within upper left corner while relaxed state is mapped within lower right corner of the circle.

For each subject two trials were selected according to their self rating of the videos. Using a 9-scale rating of valence and arousal the stressed and relaxed states were determined as

$$S_{stress} = valence < 3 \cap \max\{arousal > 7\}$$
$$S_{relaxed} = \max\{valence > 7\} \cap arousal < 3 \quad (1)$$

In case a state preposition could not be satisfied, the subject was removed from analysis. Using this procedure, EEG recording sessions of 18 subjects were collected presenting two states, one relaxed and one stressed.

C. EEG features in this study

In order to detect stress/anxiety states from EEG signals, the features described in this section were used under literature review and visual inspection of the behavior of signals.

Frontal asymmetry within the alpha band can be inversely related to stress. Feature was calculated using power of alpha band. The natural logarithm of left side channels were subtracted from the right ones (L-R).

$$Asymmetry\ index = \ln(\alpha)\Big|_{L_{channel}} - \ln(\alpha)\Big|_{R_{channel}} \quad (3)$$

For the frontal asymmetry the F3-F4 pair was considered more appropriate as Fp1-Fp2 could be contaminated with eye related artifacts. In this study, besides frontal asymmetry, asymmetry was also calculated for symmetric pairs of electrodes between left and right hemisphere also in central, parietal and occipital lobes.

Coherence, can be calculated among two signals *x*, *y* and it is the fraction of square cross-spectral density between x and y, divided by the product between spectral density of signal *x* over spectral density of signal *y*.

$$C_{xy}(f) = \frac{G_{xy}^2(f)}{G_{xx}(f) \cdot G_{yy}(f)} \quad (4)$$

Brain load index defines the overall external or internal load. It can be calculated from parietal and frontal lobe using θ and α bands. It is also known that brain load index increases in frontal theta and decreases in parietal alpha [7].

$$BLI = \frac{\theta(Fz)}{a(Pz)} \quad (5)$$

Spectral centroid frequency was estimated using time-frequency representation of signal and calculating spectral information within overlapping sliding windows with length of 0.5sec and step of 0.25sec followed by the spectral centroid calculation. The session mean value of spectral centroid was used representing subject's frequency activity.

Hjorth parameters, namely activity, mobility and complexity, are time domain parameters useful for the quantitative evaluation of EEG [15]. The parameter of activity represents the variance of signal's amplitude, the mobility represents the square root of the ratio between the variances of the first derivative and the amplitude and the complexity is derived as the ratio between the mobility of the first derivative of the EEG and the mobility of the EEG itself.

Correlation Dimension is a non linear measure based on the correlation integral defined by Grassberger and Procaccia [16], which has been used as a feature for stress detection [17].

III. RESULTS

A. Features evaluation

Features were calculated and formulated the feature set. Although brain activity patterns and power presents great inter-subject variability, however power in the vast majority of bands and electrodes are highly correlated (r>0.7, p<0.01) between the two states (relaxed, stressed) across subjects. These findings suggest that a paired approach between two states should be followed.

An initial statistical evaluation (Wilcoxon Signed Rank test) was performed and the results of selected features are presented in table I.

TABLE I. FEATURES EXTRACTED FOR STRESS/ANXIETY DETECTION AND THEIR STATISTICAL EVALUATION (MEAN±STD), ASTERISKS DENOTE STATISTICAL SIGNIFICANCE AT 0.05 AND 0.01 LEVEL

Feature	State	
	Relaxed	*Stress*
Absolute power θ (ch. Cz)	**1273.6 ± 705.2**	**767.5 ± 635.75 ***
Absolute power α (ch. F3)	**345.3 ± 223.9**	**227.5 ± 214.3 ***
Absolute power β (ch. F3)	**402.0 ± 272.7**	**314.4 ± 112.6 ***
Absolute power β3 (ch. F3)	**79.6 ± 38.6**	**61.6 ± 29.8 ***
Absolute power α1 (ch. P4)	**610.1 ± 234.6**	**321.6 ± 259.2 ***
Relative power β1 (ch O1)	0.03 ± 0.02	0.034 ± 0.02
β/α band ratio (ch P3)	0.92 ± 0.77	0.89 ± 0.54
Brain Load Index	1.22 ± 0.86	1.71 ± 1.55
Frontal Asymmetry (ch F3-F4)	**0.017 ± 1.58**	**-0.161 ± 1.51 ****
Frontal Asymmetry (ch O1-O2)	**0.753 ± 1.04**	**0.624 ± 1.05 ***
Coherence α (ch. P3-P4)	**0.238 ± 0.161**	**0.342 ± 0.152 ***
Coherence β3 (ch. O1-O2)	**0.285 ± 0.054**	**0.158 ± 0.048 ***
Spectral centroid frequency (ch P3)	13.19 ± 3.67	14.55 ± 4.60

**P*<0.05, ***P*<0.01

It can be conducted that there are power differences in few electrodes for bands θ,α,β. Band γ does not appear to have effect in the discrimination of two states, but it should be kept in mind that signals were preprocessed with a cut off frequency at 45Hz so γ band was calculated until this frequency point. Also β/α band ratio which could be considered as an arousal index did not yield any notable result.

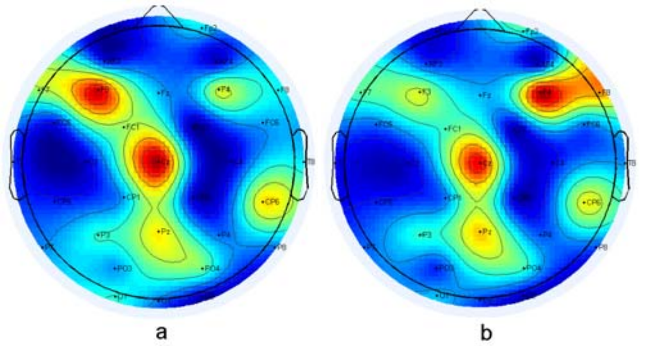

Figure 1. An example of Z-scores of spatial spectral distribution for (a) relaxed and (b) stressed state in the α band rhythm showing the asymmetry effect.

The z-scores of spatial spectral distribution of a characteristic subject is presented in Figure 1. As it can be seen there is an inversion on frontal activity between stress and relaxed state. Specifically pair F3-F4 shows a large amount of energy being reverted from left to right, for two states of emotions.

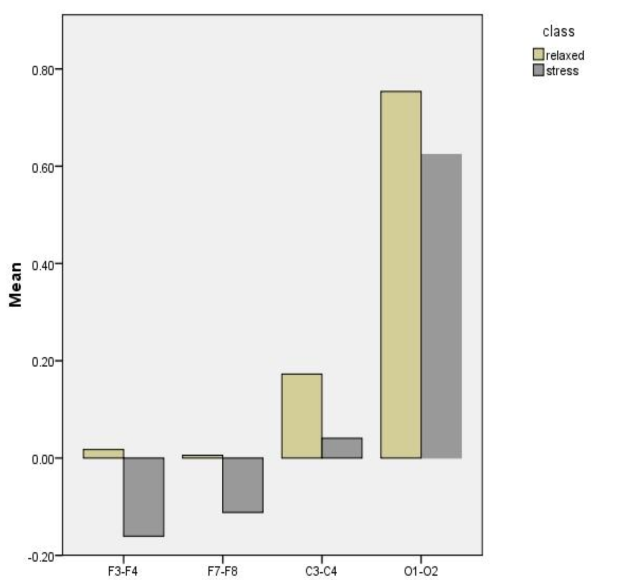

Figure 2. Mean asymmetry scores (left-sided) for electrodes pairs F3-F4, F7-F8, C3-C4 and O1-O2.

From Figure 2 it can observed that asymmetry is lower during stress state compared with the relaxed one. A statistically significant change is elicited between two states in electrodes pairs F3-F4 ($t(17)=3.282$, $p=0.004$) and O1-O2 ($t(17)=2.267$, $p=0.037$). It is also notable that in frontal area mean values of asymmetry has low values and in parietal and occipital areas are higher but preserving the pattern of difference.

The Brain Load Index (BLI) appears to be higher in stress state but it doesn't have a significant effect ($p=0.058$). Regarding spectral centroids, it is remarkable that a vast majority of channels (30 out of 32 electrodes) showed increased centroid frequency during stress but without significant effect.

B. Feature Selection

One problem arises in discrimination problems is that the usage of a feature set can be more effective than univariate approach. However, if too many features are used, this can deteriorate system's discrimination ability. Feature selection was performed using sequential forward selection (SFS) and sequential backward selection (SBS) methods [18]. The objective function evaluating feature subsets was the probability above the F-statistic of a repeated measures ANOVA test [19]. Feature set extracted in this study consists of 273 features (there are features that were calculated for all 32 channels). Comparing SFS and SBS, it was conducted that SFS is able to minimize objective function comparing with SBS, thus it was selected for this analysis. The number of features that should kept in the features subset was determined to 20. The selected feature subset according to this procedure is presented in table II

TABLE II. FEATURE SUBSET USING FEATURE SELECTION PROCEDURE

Feature
Asymmetry (pair F3-F4)
Asymmetry (pair F7-F8)
Asymmetry (pair O1-O2)
Coherence θ band (pair C3-P3)
Coherence θ band (pair F3-O1)
Coherence α band (pair F7-F8)
Coherence α band (pair F3-F4)
Coherence α band (pair O1-O2)
Coherence α band (pair Fp2-F4)
Coherence α band (pair C3-P3)
Coherence α band (pair F3-O1)
Coherence β band (pair F7-F8)
Coherence β band (pair O1-O2)
Coherence β band (pair C3-P3)
Coherence β band (pair F3-O1)
Hjorth Mobility (ch AF3)
Hjorth Mobility (ch FC5)
Hjorth Mobility (ch FC1)
Hjorth Mobility (ch CP5)
Hjorth Mobility (ch F4)

Using this procedure the features of table II were identified as being more representative for the data under investigation.

IV. DISCUSSION

EEG has been widely used for investigation of upper cognitive functions, mental states and models of affect. For stress/anxiety states detection through EEG there is not much literature as they are considered complex emotions [20, 21]. In addition, it is not yet clear the underlying mechanisms these states apply to EEG signals. Our pursuit is to present consistent features towards this problem.

The results of our study indicate that asymmetry is reduced during anxiety/stress state compared with relaxed state. It is asserted that EEG response to positive valence stimuli is left frontal activity while negative valence stimuli cause an increase to right activity. It would be interesting the interaction to handedness to be studied but there was only one left handed subject. Although, other studies have investigated only frontal asymmetry, giving to it characteristics of valence, this study shows a similar significant pattern in occipital pairs. This could be attributed to the fact that subjects had visual stimuli (video watching) during the experiment.

Coherence analysis showed that is able to discriminate between states mainly between inter-hemispheric locations than intra-hemispheric. Hjorth parameters did not show differences during univariate statistical analysis but mobility was selected by feature selection procedure as a robust feature in combined data subset. Band powers did not yield any unambiguous pattern, although there were some differences in few channels. Combination or clustering of channels or blind source separation methods could lead to a more specific pattern.

Limitations that can be referred are firstly the way stress/anxiety states were defined. There is not an accurate mapping of stress and anxiety to the circumplex model of affect, however there are insights of their position. Besides, the effect of videos stimuli to each subject was not the same something that was depicted in their self reports. The setup of the experiment and the rules for states determination led to the small number of subjects to be analyzed. A larger dataset should be investigated to validate results.

This study proposes features and a procedure for dataset reduction that can be used for efficient stress/anxiety detection through EEG.

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