

Scalp Level Connectivity for Representative Channels in Emotional Status

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Abstract

Emotion can be regarded as a special brain status and it can be captured by Electroencephalography (EEG) via deploying number of channels all over the scalp. To find out the characteristics of emotional responses, the scalp level connectivity is one of the interests that considered. Nevertheless, to distinguish the significant EEG channels, which can imply the special regions at scalp level, has not yet been studied well. Therefore, in this work, we aim to identify the representative channels towards different emotional status by considering the connectivity derived from the values of coherence and correlation. In this purpose, DEAP, an online database has been investigated. Certainly, the emotional status can be evaluated on the valence-arousal (V-A) space and here, four groups contain HVHA, HVLA, LVHA, and LVLA have been studied. The results from 16 subjects show that the EEG channels AF3, F7, P7 and O1 have higher percentages in term of the connectivity and they could be considered as the representative channels in this case. Such findings could be useful to understand the scalp responses in emotional status.

Keywords

Emotion • EEG • Scalp level connectivity
Representative channels

1 Introduction

Emotion is an affective reaction to an event or stimulation, which can be observed by facial expression, voice, body movement, and so on. As usual, emotion is regulated by the brain and certainly, it can be recognized by electroencephalography (EEG), a non-invasive electrophysiological monitoring technique to record the electrical signals of the brain. Furthermore, because the EEG technique can detect the changes within millisecond timeframe and has the best time resolution than other approaches such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI), it has been widely used to analyze the emotional status of brain [1–5]. Based on EEG signals analysis, the emotion recognition can be realized so that to identify individual emotions in various areas like artificial intelligence and disease treatment can be accomplished. Such applications reflect the significances of emotional studies by using EEG signals in biomedical engineering field.

In literatures, EEG-based emotional studies mainly concentrate on the extractions of distinct features for distinguishing the emotions by using various algorithms, such as relative power values by fast Fourier transform (FFT) [6], prominent frequency wave by time-frequency analysis [7], and event-related potentials (ERPs) by signal-to-noise ratio maximizer (SIM) algorithm [8], etc. Nonetheless, the studies related to the scalp responses in the emotional status, especially the representative channels, have not yet been investigated well. Thereby, this work aims the representative channels based on the analysis of connectivity at scalp level. In

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this purpose, two methods containing coherence in frequency domain and correlation in time domain have been employed. Then, with the values of coherence and correlation among all pairs of the channels, the representative channels can be selected. For experimental validation, DEAP, an online EEG emotional database has been considered [9]. Sixteen subjects from this database including female and male with different emotional status have been investigated. The representative channels are obtained from the statistical results of the values in term of the connectivity. The paper has been organized as follows. Section 2 introduces the usage of DEAP database in this work. Section 3 concentrates on how to find the representative channels by considering the connectivity based on coherence and correlation values. Section 4 discusses the statistical results from the subjects. Finally, conclusions have been drawn in Sect. 5.

2 DEAP Database

To study the responses in emotional status at scalp level through the EEG signals, it is required an EEG database that contains different emotional status and provides the technical parameters such as the number and locations of the scalp electrodes, sampling rate, time epoch, and so on. Then, DEAP database [9] is appropriate in this case. In DEAP, the EEG signals of 32 subjects have been denoted as each watched 40 different one-minute long music videos, i.e., there are 40 trails for one subject. After watching these videos, the subjects rated each video in terms of the levels of valence (V) and arousal (A). Based on the V-A scores, the emotions can be classified into four groups, high valence high arousal (HVHA), high valence low arousal (HVLA), low valence high arousal (LVHA), and low valence low arousal (LVLA). In this work, the chosen scores for classifications are: HVHA ($V \geq 5$, $A \geq 5$), HVLA ($V \geq 5$, $A < 5$), LVHA ($V < 5$, $A \geq 5$), and LVLA ($V < 5$, $A < 5$) respectively, where the thresholds of V and A scores are 5 [10]. Additionally, the EEG signals presented in the database have been recorded by 10–20 system consisting of 32 scalp channels (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, and O2). The sampling rate is 128 Hz and the analog pass band of 0.01–100 Hz had been applied for preprocessing the EEG signals. For each group of emotion, 6 subjects have been studied. Due to the amount of trials is limited for some subjects, especially in HVLA and LVLA group, we made adjustments of the number and finally, 96 trials from 16 subjects have been selected. The details have been summarized into Table 1 in which the first column specifies the types of

emotion groups, and the rest displays the selection of corresponding subjects and the number of trails.

3 Connectivity for Representative Channels

Normally, the reaction of brain in term of the electrical activities can be expressed by the EEG signals recorded from the scalp. Based on the analysis of EEG signals, several connections between the channels can be considered and via the connectivity, the channels with prominent responses in the emotional status can be presented. Therefore, based on the values of connectivity, the representative channels can be selected for denoting the special regions that correlates with the emotional status. To map the connectivity from the EEG signals, several approaches have been applied to quantify the communication between the EEG channels, such as coherence method in frequency domain and correlation method in time domain. Because EEG represents a set of continuous voltage and time values, hence, it can be considered as a multivariate time series that belongs to the stochastic processes and this stochastic nature of EEG allows the use of correlation and coherence to indicate the scalp level connectivity [11]. In this light, to attain the representative channels from the connectivity, the methods of coherence and correlation have been applied in this work.

On one hand, the correlation metric is a conventional connectivity technique derived in time domain and it can be used to reveal the signal similarity including EEG [12]. The correlation is mathematically expressed as:

$$\text{correlation}_{xy} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2}} \quad (1)$$

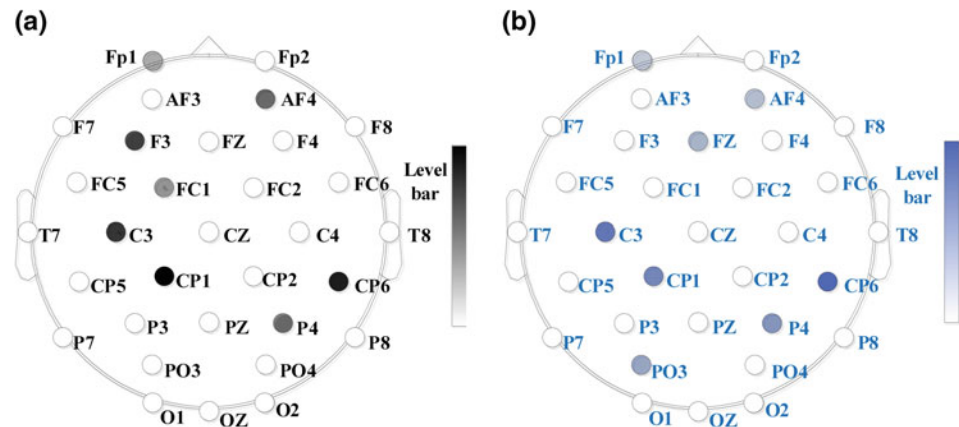
where x and y are two sets of signals for the correlation calculation, and n is the amount of each set elements. Certainly, the higher correlation means the higher connection existing between the two signals. On other hand, the coherence is another typical metric that quantifying the phase synchrony between a pair of signals in the frequency domain [13] and it is a normalized coefficient which is mathematically expressed as:

$$\text{coh}_{xy}(\omega) = \frac{|S_{xy}(\omega)|}{\sqrt{S_{xx}(\omega)S_{yy}(\omega)}} \quad (2)$$

In (2), the numerator and denominator represent the averaged cross-spectral densities and the averaged power estimations between signals x and y at frequency ω respectively. Again, the higher coherence indicates the higher

Table 1 Subjects and trials studied in this work

Group	Subject id in DEAP	No. of trials	Total trials
HVHA	2; 7; 21; 26; 27; 28	5 for each subject	30
HVLA	3; 5; 7; 11; 15; 28	3 for each subject	18
LVHA	2; 11; 13; 22; 24; 31	5 for each subject	30
LVLA	2; 4; 26; 27; 28; 29	3 for each subject	18

Fig. 1 Representative channels by the connectivity methods. **a** Coherence; **b** correlation

connection existing between the two signals. Additionally, from [14], for the EEG-based studies, the connection between a pair of signals can be regarded as strong when the value of correlation and coherence exceed 0.7 and 0.6 respectively. Thereby, in this work, the strong connections have been considered when the values exceed these thresholds (correlation ≥ 0.7 ; coherence ≥ 0.6). Based on the connectivity, the channels with larger summation of the connectivity values (correlation or coherence) among all pairs of the EEG channels have been regarded as the representatives. As a preliminary study, we consider the top 4 EEG channels which have larger summation of both coherence and correlation among all the channels as the representative channels for implying the special regions that have relationships with the emotional status. Therefore, by using the connectivity methods of coherence and correlation, the representative channels can be figured out.

4 Results and Discussion

Figure 1 is a sample result of the representative channels from trial 17 (HVHA) of Subject 2 and Fig. 1a is by coherence method, while Fig. 1b is by correlation method. In these two scalp maps, the channels enclosed with deeper color mean they have stronger responses in term of the connectivity, which decentralized in the central, frontal, and parietal lobes of both right and left hemispheres. Besides, the results of representative channels are similar (C3, CP1, CP6

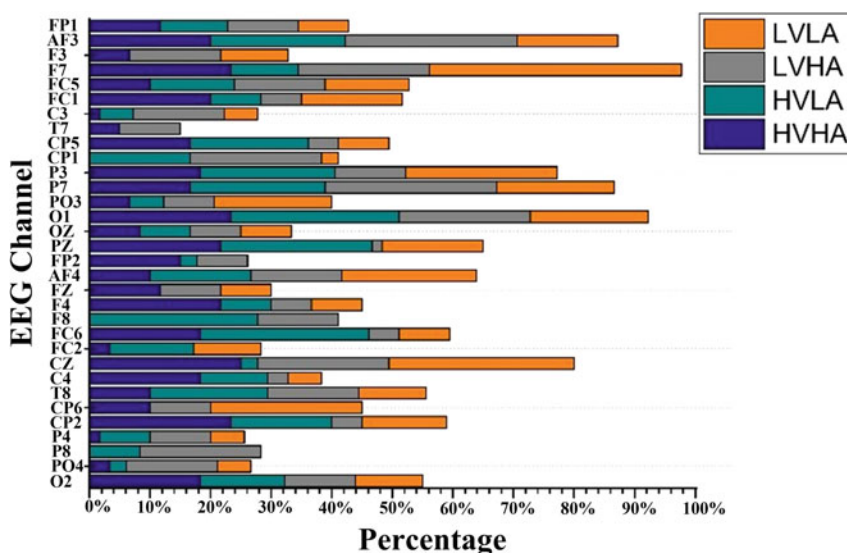
and P4) by the two applied methods. As seen, both of coherence and correlation are available to construct the scalp level connectivity via the EEG signals and to select the representative channels with prominent responses.

Figure 2 presents the statistical results of the representative channels from 16 subjects by using the mentioned methods. In Fig. 2, for LVLA, LVHA, HVLA, and HVHA groups, the representative channels with higher percentages are F7, CZ, CP6 and P3; AF3, F7, P7 and O1; F8, FC6, PZ and O1; F7, CZ, CP2 and O1, respectively. Additionally, to sum up the results of all 16 subjects in four kinds of emotions, the channels AF3, F7, P7 and O1 have relatively higher percentages. Thus, these EEG channels seem to have more connections in the emotional status. However, considering the individual results, the representative channels are not always very consistent and hence, it can be said that the emotional reaction seems subjective. Although there are common EEG channels can be found among different subjects, in our future study, the individual characteristics will be taken into as one of the significant considerations for the analysis of emotional status via EEG.

5 Conclusion

To investigate the scalp responses of the emotional status through the EEG signals, the data from DEAP database has been considered in this work. Then, the representative channels have been selected based on the two connectivity

Fig. 2 Statistical results of the representative channels in different groups of emotional status



methods including coherence and correlation. According to the mapping results of connectivity, both the coherence and correlation approaches are available to find the representative channels. Furthermore, from the statistical results of 16 subjects in four groups of emotions, the representative channels are found as: LVLA (F7, CZ, CP6 and P3); LVHA (AF3, F7, P7 and O1); HVLA (F8, FC6, PZ and O1); HVHA (F7, CZ, CP2 and O1). Moreover, the overall results with higher percentages of the connectivity are AF3, F7, P7 and O1. Therefore, these EEG channels can be regarded as significant with the emotional status. Although several channels can be found based on the statistical results, the individual characteristics can be observed so that it can be said that the emotional reactions are quite subjective. In short, the coherence and correlation methods can be used to obtain the scalp level connectivity and to select the channels presenting the special regions of scalp responses. Based on the connectivity, we can also study the relevant channels at scalp level in various neurological conditions, such as autism, sleep apnea, Alzheimer's disease, and so on.

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Conflict of Interest The authors declare that they have no conflict of interest.

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