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Spectral Perturbation of Theta and Alpha Wave for the Affective Auditory Stimuli

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ABSTRACT

The correlations between electroencephalographic (EEG) spectral power and emotional responses during affective sound clip listening are important parameters. Hemispheric asymmetry in prefrontal activation have been proposed in two decades ago, as measured by power value, is related to reactivity to affectively pleasure audio stimuli. In this study, we designed an emotional audio stimulus experiment in order to verify frontal EEG asymmetry by analyzing Event-related Spectral Perturbation (ERSP) results. Thirty healthy college male students volunteered the stimulus experiment with the standard IADS(International Affective Digital Sounds) clips. These affective sound clips are classified in three emotion states, high pleasure-high arousal (happy), middle pleasure-low arousal (neutral) and low pleasure-high arousal (fear). The analysis of the data was performed in both theta (4-8Hz) and alpha (8-13Hz) bands. ERSP maps in the alpha band revealed that there are the stronger power responses of high pleasure (happy) in the right frontal lobe, while the stronger power responses of middle-low pleasure (neutral and fear) in the left frontal lobe. Moreover, ERSP maps in the theta band revealed that there are the stronger power responses of high arousal (fear and happy) in the left pre-frontal lobe, while the stronger responses of low arousal (neutral) in the right pre-frontal lobe. However, the high pleasure emotions (happy) can elicit greater relative right EEG activity, while the low and middle pleasure emotions (fear and neutral) can elicit the greater relative left EEG activity. Additionally, the most differences of theta band have been found out in the medial frontal lobe, which is proved as the frontal midline theta. And there are the strongest responses of happy sounds in the alpha band around the whole frontal regions. These results are well suited for emotion recognition, and provide the evidences that theta and alpha powers may have the more important role in the emotion processing than previously believed.

Keywords : Emotion, EEG Power, Frontal Hemispheric Asymmetry, ERSP, IADS

청각자극에 따른 세타파와 알파파의 스펙트럼적 반응

Ruoyu Du† · 이 효 종††

요 약

감정을 유발하는 청각자극에 따라 발생되는 EEG(Electroencephalographic) 스펙트럼 강도와 감정 반응 간의 상관관계는 중요한 변수이다. 약 20여 년 전 쾌감을 주는 청각자극에 대하여 측정된 신호의 강도가 전전두엽에서 비대칭적으로 반응을 보였다는 연구 결과가 발표되었다. 본 연구에서는 자극관련 스펙트럼적 반응(Event-related Spectral Perturbation: ERSP)이 전두엽에서 비대칭적으로 발생되는지 고찰하기 위하여 청각자극 실험을 수행하였다. 30명의 건강한 대학생 지원자들이 IADS(International Affective Digital Sounds) 실험에 참여하였다. 이 청각자극은 행복, 공포, 그리고 중립의 3단계로 분류되었으며, 데이터의 분석은 세타파(4-8Hz)와 알파파(8-13Hz)에서 이루어졌다. 알파대역의 ERSP 지도는 오른쪽 전두엽에서 행복감과 공포감의 자극에서 높은 신호의 강도를 보여주는 반면 중립성 자극에서는 왼쪽 전두엽에서 높은 신호가 발생되었다. 그러나 세타파는 행복감과 공포감의 자극에 따라 좌측 전두엽에서 높은 신호가 나타나는 반면, 중립적 자극에 따라 우측 전두엽에서 높은 신호를 보여주었다. 높은 쾌감성 자극(행복)은 상대적으로 우측 전두엽에서 높은 EEG 신호가 측정되었으며, 낮은 쾌감성 자극(중립과 공포)은 왼쪽 전두엽에서 측정되었다. 또한 가장 큰 세타파의 변화가 전두엽의 중앙에서 발생되었다. 알파파에서 행복한 청각자극에 가장 강한 신호가 전두엽 전체에서 관찰되었다. 이 결과들은 기존의 감정들과 일치되며, 세타파와 알파파가 감정처리에서 중요한 역할을 하고 있음을 시사한다.

키워드 : 감정, EEG, 전두엽 비대칭, ERSP, IADS

1. Introduction

Emotion is highly susceptible to sound. Emotional analysis under the audio stimuli therefore becomes an important index for assessing different emotion models with valence and arousal level [1-4]. During the last two

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decade, a lot of research focused on the emotional processing based on EEG. One of these studies is hemispheric asymmetry for different emotions. Especially, pre-frontal hemispheric asymmetries have become widely accepted as a correlate of approach and feedback related motivation in basic emotion research [5-7], with more and more studies extending the frontal asymmetry methodology to diverse fields in related applied psychology. Recent researches on a differentiation of valence and approach-withdrawal motivation suggests that only the latter is lateralized in frontal and pre-frontal brain regions [8, 9]. Theta waves (4-8 Hz) have been associated with drowsiness, daydreaming, creative inspiration and meditation, arousal [10], sensorimotor processing and mechanisms of learning and memory [11]. One type of theta waves is named frontal midline theta. The theta waves exist during the various tasks which need the correlation of the increased mental effort and sustained concentration. Alpha waves (8-13 Hz) are broadly linked with perceptual processing and memory tasks, and have been largely implicated in the processing of emotions [12]. The theta and alpha waves are widely used in the auditory emotion research [13-15]. Event Related Spectral Perturbation (ERSP) was investigated firstly by S Makeig [13] in 1993. His study focused on the broad event-related auditory research. Some EEG studies on musically induced emotions provided evidence in favor of the frontal asymmetry. Sammler et al. [14] found an increase of frontal midline theta power for pleasant music in contrast to unpleasant music. Flores Guiterrez et al. [15] found also a lateralized frontal alpha suppression during listening of unpleasant and unpredictable music. These previous studies only focused on the different emotion based on the valence domain, but our study took care both of valence and arousal domains in the different emotion states. The ERSP reflects the influence of the stimulation on the power spectrum, and can prove the evoked response theory [16]. These ERSP features exhibit certain patterns in the time-frequency domain and contain relevant and complementary information, and might have the potential to provide new or extra features to increase the performance. In this paper, we aim to find out the EEG response features of frontal theta and alpha bands during the emotional audio stimulation using ERSP maps.

2. Data Collection

2.1 Subjects

Thirty males in the age group of 20-26 years were employed as subjects. They are all right-handed and have correct visions. All the subjects were healthy and none of them had prior history of neurological or psychiatric disorders. All of them gave informed consent. Written informed consent was obtained from each subject in accordance with the Helsinki Declaration, and the study was approved by the local ethical committee. Once the consent forms were filled-up, the subjects were given a simple introduction about the research work and stages of experiment. The subjects were still instructed to wear the headphone and seat in the semi-upright position, and were instructed to remain still and to blink or move their eyes and body as little as possible.

2.2 Stimuli and Procedure

The International Affective Digitized Sound system (IADS) provides a set of acoustic emotional stimuli for experimental investigations of emotion and attention. There are 42 sound clips from IADS in this experiment, which were shown in the Fig. 1. They were characterized by both levels of arousal and valence namely: high valence-high arousal, low valence-high arousal and middle valence-low arousal. These affective states are commonly defined as happy, fear and neutral separately.

During the experiment, the selected sounds were classified two equal runs, each of which have 21 sound clips from three states. Specially, Run1 have more excessive affective sounds. These sounds were selected from uniformly distributed clusters along the valence and arousal axes. Audio stimuli were 42 affective sounds with different emotional valence, presented randomly for 6s following another 4s for resetting emotion with no sound. It is also necessary to reset emotional status before the projection of the first sounds. Thus, fixation mark (cross)

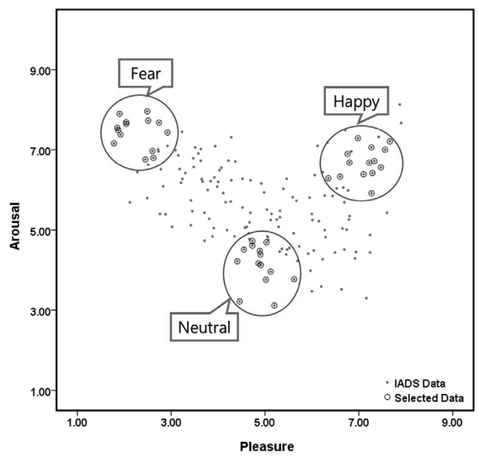


Fig. 1. The Scatter plot of valence and arousal ratings (1-9 scales) for all available IADS sound clips. The circles denote the sound clips select-ed in this study

was projected for eight seconds in the middle of the screen to attract the attention of the subject. The EEG signals from each subject were recorded during the whole projection phase. Fig. 2 shows the timing diagram used in this audio experiment.

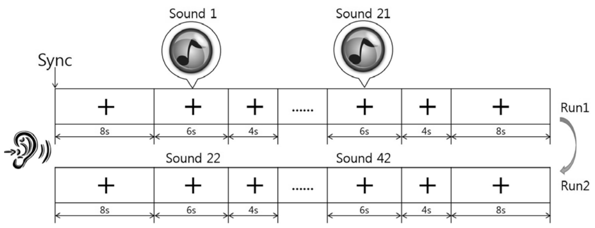


Fig. 2. Timing diagram for three different emotions. Each category has fourteen sound clips totalling 42 sound clips

2.3 EEG Recording

The EEG was recorded using a Brain Vision amplifier system. Silver-silver-chloride-electrodes (Ag/Gal) were used in association with the "Easy Cap System". In this research, eighteen electrodes (Fp1, Fp2, F3, F4, Fz, F7, F8, C3, C4, Cz, T7, T8, P3, P4, P7, P8, O1, and O2) were inserted to record EEG signals using the Easy Cap which refers to Fig. 3. The circles shows the selected channel in this study. These selected channels (Fp1, Fp2, F3, F4, F7 and F8) are located at the frontal lobe region and they were distributed equally in the left and right hemisphere.

3. Event-related Spectral Perturbation Analysis

Analysis of event-related changes in spectral power across single trials time locked to experimental events can characterize event-related perturbations in the brain oscillatory dynamics. We use the event-related spectral perturbation (ERSP) to measure event-locked changes in spectral power. This analysis method of power represents an average spectral changes in response to a stimulus.

Calculating an ERSP requires computing the power spectrum over a sliding latency window then averaging across data trials. To compute spectral density, EEGLAB uses a sinusoidal wavelet (short-time DFT) transform that provides a specified time and frequency resolution [16, 17]. Equation (1) indicates the mean event-related spectrum for frequency f and time t is defined as

$$ERSP(f,t) = \frac{1}{n}\sum_{k=1}^{n}\left|F_k(f,t)\right|^2 \tag{1}$$

where n is the number of trials, if, $F_k(f, t)$ is the spectral estimate of trial k at frequency f and time t. The color at each image pixel then indicates power (in dB) at a given frequency and latency relative to the time locking event.

4. Results

ERSP simply means a change in the frequency of spontaneous EEG related to an event. The ERSP results of this experiment demonstrated that the three different valence-arousal emotional states performance related changes on brain activities in the frontal lobe. Fig. 4 shows the theta ERSP map in the pre-frontal lobe. More ERSP maps of theta band around frontal lobes are thumb nailed in the Fig. 5 for three emotions: happy, fear and neutral. In addition, Fig. 6 shows the ERSP maps of alpha band in the whole frontal lobe. In the Fig. 4 and Fig. 5, the range of power (dB) was quantified from 2.0 to -2.0. However, in order to display the good response effects, the ERSP maps in the Fig. 6 showed the range

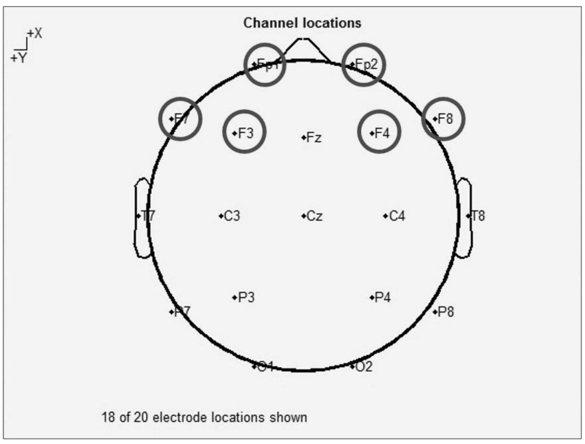


Fig. 3. The montage used in this research based on 10-20 system of electrode placement; the circles show the selected channels in this study

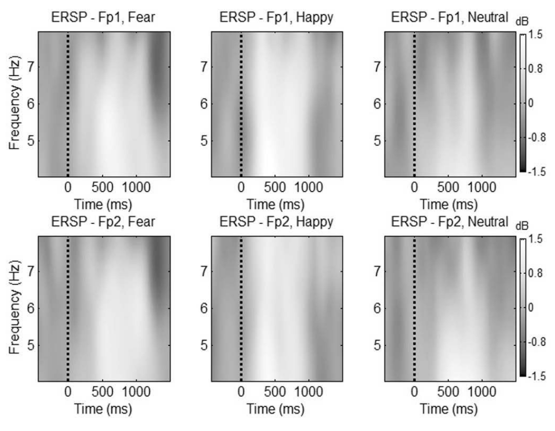
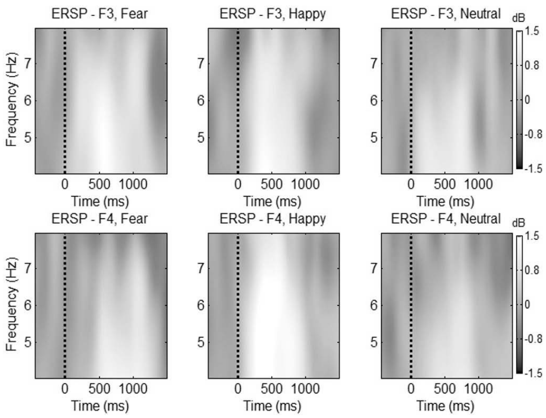


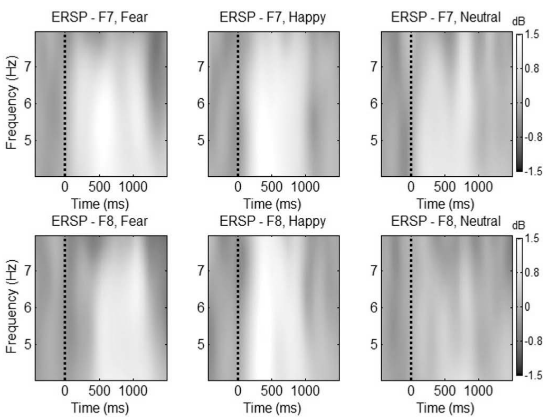
Fig. 4. ERSP maps of three emotion states in channels of pre-frontal region based on the theta band

of power (dB) in the more narrow scale calibration from 1.5 to －1.5. We chose the first 1500ms to analyze the first response of different emotion when the subject received the sound stimuli.

For the theta band, there were obvious differences in the responses between high arousal emotional stimuli and low arousal emotional stimuli in the pre-frontal regions, which were indicated in the Fig. 4. In the left pre-frontal lobe, there were the stronger response in the high arousal (fear and happy) stimulus than in the low arousal (neutral) stimulus. Moreover, the different emotion responses result of ERSP maps in the channels of frontal lobes were shown in the Fig. 5. The ERSP result windows have the same scale calibration as the Fig. 4. Fig. 5(a) show the result maps in the medial frontal region. Fig. 5(b) show the result maps in the lateral frontal region. The F3 and F7 belong to the left hemisphere of frontal lobe. There is a stronger response of theta band in the left frontal hemisphere than the right hemisphere in the fear and neutral. However, the greater responses in the happy stimuli were elicited in the right frontal hemisphere than that in the fear and neutral, which shown in the F4 and F8 electrodes of Fig. 5. In addition, the most obvious

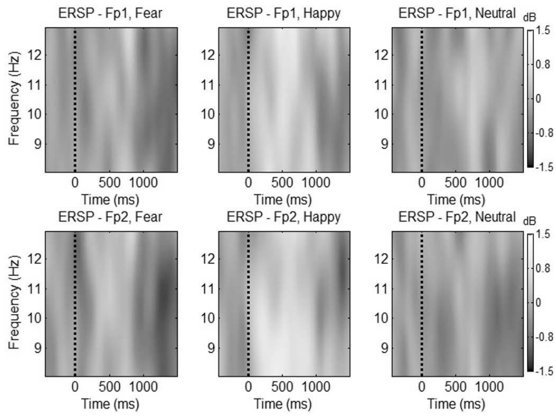


(a)

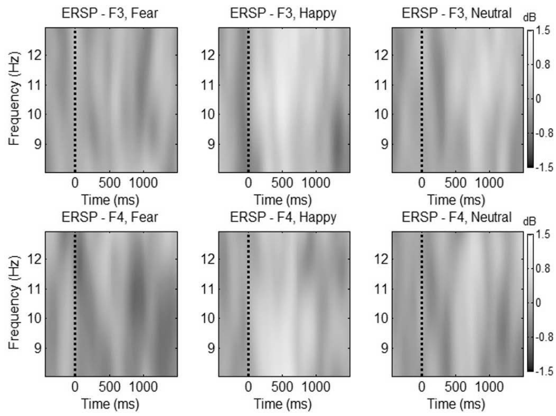


(b)

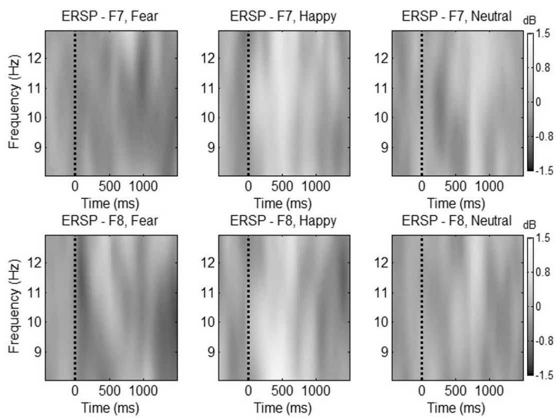
Fig. 5. ERSP maps of three emotion states in channels of (a) medial frontal and (b) lateral frontal regions based on the theta band



(a)



(b)



(c)

Fig. 6. ERSP maps of three emotion states in channels of (a) pre-frontal, (b) medial frontal and (c) lateral frontal regions based on the alpha band

power difference was elicited in the medial frontal region.

For the alpha band, there were obvious differences in the responses between high valence emotional stimuli and middle-low valence emotional stimuli in the whole frontal lobe, which were indicated in the Fig. 6. There were two rows in the Fig. 6(a), (b) and (c). The first row belonged to the left frontal hemisphere, while the second row belonged to the right frontal hemisphere.

In the left pre-frontal (Fp1) region, which is shown in the first row of Fig. 6(a), there was the stronger response of the middle and low valence (neutral, fear) stimuli. On the contrary, there were the stronger response of the high valence (happy) stimuli in the right pre-frontal (Fp2) region, which shown in the second row of Fig. 6(a). Fig. 6(b) and (c) show the ERSP maps of different audio emotional states in the medial (F3, F4) and lateral (F7, F8) frontal brain regions. In the Fig. 6(b), there had same performance of response as the pre-frontal region, which is the stronger response of the middle and low valence (neutral, fear) stimuli in the left medial frontal (F3) region, while the stronger response of the high valence (happy) stimuli in the right medial frontal (F4) region. However, there were the stronger responses of high arousal (happy, fear) stimuli in the right lateral frontal (F8) region, while the stronger responses of low arousal (neutral) stimuli in the left lateral frontal (F7) region, which shown in the Fig. 6(c). In the whole frontal regions, there existed the strongest responses of happy state, which were excited in the whole frontal region. A summary of ERSP performances in the difference frequency bands with the related channel location were shown in the Table 1.

Table 1. Summary of laterality in ERSP responses for the different frequency bands with the related channel location (LH: Left hemisphere, RH: Right hemisphere)

Frequency band / Channel location	Theta Wave	Alpha Wave
Prefrontal (Fp1, Fp2)	high arousal: LH > RH	middle-low valence: LH > RH
		high valence: RH > LH
Medial Frontal (F3, F4)	low-middle valence: LH > RH	middle-low valence: LH > RH
	high valence: RH > LH	high valence: RH > LH
Lateral Frontal (F7, F8)	low-middle valence: LH > RH	high arousal: RH > LH
	high valence: RH > LH	

5. Conclusion

In this paper we investigated how the brain activity changes in the frontal theta and alpha bands according to three classical audio emotional stimuli. IADS sound of 42 segments were selected as our stimuli. While those emotion statuses changed, the range of 4 to 8 Hz (theta band) and 8 to 13 Hz (alpha band) are extracted separately and the ERSP maps of three emotion states based on the two bands were calculated and revealed in the whole frontal lobe region. The intensity difference of power were found in the different frontal regions, where emotional changes were dominant. There have three findings are summarized in the theta band. First, there are stronger response for the high arousal stimuli in the left pre-frontal hemisphere. While the stronger response for the low arousal (neutral) stimuli were found out in the right hemisphere. Secondly, the high valence (happy) emotional states were elicited greater relative EEG activity in the right hemisphere. While the low (fear) and middle (neutral) valence emotions have the stronger responses in the left frontal region. Finally, the most obvious power response was elicited in the medial frontal region. In other words, the frontal midline theta was also found in this research. The greatest response in the happy stimuli proved the theta band have the correlation with the change of emotional states. In the alpha band, there also have three conclusions are found. First, we find out there exist the strongest response of happy emotional sounds in the whole frontal regions. Secondly, the middle-low valence emotional sounds were elicited greater relative left pre-frontal and medial frontal EEG activity, while the high valence emotional sounds were elicited greater relative right pre-frontal and medial frontal EEG activity. Finally, the high arousal emotional sounds (happy, fear) could elicit the stronger responses in the right lateral frontal region, while the low arousal emotional sounds could elicit the stronger responses in the left lateral frontal region.

In conclusion, the results of the present study provide evidences that theta and alpha powers activation may play the important roles in the emotion processing. Moreover, they indicate that during the affective sound clips listening the whole frontal regions in the theta and alpha bands are activated for the different emotional states and that different level of valence and arousal might be captured by different electrodes.

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