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EEG-based emotion perception during music listening

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ABSTRACT

In the present study correlations between electroencephalographic (EEG) activity and emotional responses during music listening were investigated. Carefully selected musical excerpts of classical music tested in previous studies were employed as stimuli. During the experiments EEG activity was recorded in different regions without a-priori defining regions of interest. The analysis of the data was performed in both alpha and theta bands. Consistent with existing findings, the results in alpha band confirm the hemispheric specialization hypothesis for emotional valence. Positively valenced emotions (happy and serene) elicited greater relative left EEG activity, whereas negatively valenced emotions (angry and sad) elicited greater relative right EEG activity. The results show interesting findings related to the affective dimension (arousal and valence) by electrodes in different brain regions that might be useful in extracting effective features for emotion recognition applications. Moreover, theta asymmetries observed between pleasant and unpleasant musical excerpts support the hypothesis that theta power may have a more important role in emotion processing than previously believed and should be more carefully considered in future studies.

I. INTRODUCTION

During the last decade, a considerable body of research focused on the neural basis of emotional processing of pleasant and unpleasant emotion. Some studies looked at the brain activation areas during music listening differing in emotional arousal. As a first step to examining musical emotion Blood et al. (1999) used PET imaging to identify regions whose activity correlated with changes in musical stimuli along the consonance-dissonance dimension. It was found that increasing unpleasantness activated the right gyrous, whereas increasing pleasantness correlated with activation in frontopolar region. In a second step, Blood and Zatorre (2001) examined the brain response of subjects listening to music known to trigger the pleasurable experience of “chills” using PET imaging. They found that as the intensity of chills increased, brain regions known to be involved in emotion and arousal exhibited cerebral blood flow changes. Brain structures known to be stimulated by pleasurable activity were activated during the process. Instead of using computerized sounds, as in the study of Blood et al., Koelsch et al. (2006) used dance music of commercial recordings in an fMRI study and pointed out that the same neural structures activated during dissonant music are also involved in the processing of pleasant stimuli. Koelsch (2005) studied the effect of the manipulation of the harmonic structure of chord sequences on brain responses and pointed out that they include areas of emotional processing, specifically the orbital frontolateral cortex. Few studies have investigated the influence of long-term individual differences such as musical training on brain responses to musical emotion (Koelsch et al. 2005).

A different approach taken to examine emotional processing are EEG experiments during music listening. Some 20 years ago Davidson et al. (1988) suggested that the left frontal area is involved in the experience of positive emotions such as joy and happiness. In contrast, the right frontal region is involved in the experience of negative emotions such as fear, angry and sadness. Using EEG measurements Davidson et al. (1990) found substantial evidence for the asymmetric frontal brain activation. Since then, several EEG studies using various sets of musical stimuli provided support for the hemispheric specialization hypothesis for emotional valence. That is, musical stimuli which are considered positive or negative in valence, elicited asymmetric frontal EEG activity. Schmidt and Trainor (2001), for example, investigated patterns of EEG activity induced by musical excerpts in a group of undergraduates. They found greater left-and right-frontal activity during music listening to pleasant and unpleasant music. Sammler et al. (2007) investigated electrophysiological correlates during the processing of pleasant (consonant) and unpleasant (dissonant) music using both heart rate and EEG measurements. In the EEG they found an increase of frontal midline theta power for pleasant music in contrast to unpleasant music. Altenmueller et al. (2002), presented musical excerpts from four different genres to students who provided judgments for each excerpt. Positively valenced stimuli elicited bilateral fronto-temporal activations predominantly of the left hemisphere, whereas negatively valenced stimuli elicited bilateral activations predominantly of the right hemisphere.

In the present paper brain correlates of emotional reactions during music listening of non-musicians are investigated. For the experiments carefully selected excerpts of classical music were employed. The specific emotions induced by each piece were known because they have been used in previous experiments (Bigand et al., 2005).

During the experiments electroencephalographic (EEG) signals were recorded. Coherent EEG activity was explored without a-priori defining regions of interest. The analysis of the data was performed separately for alpha and theta bands. Consistent with existing findings, the results in alpha band show that positively valenced emotions (happy, serene) elicited greater relative left EEG activity in frontal and central regions, whereas negatively valenced emotions (anger, sadness) elicited greater relative right EEG activity. The new finding is that theta band asymmetries in the central region are observed. The results confirm the hemispheric specialization hypothesis for emotional valence and provide evidence that theta power activation may play a more important role in emotion processing

II. METHOD

A. Participants

Sixteen non-musicians (M = 26 years of age) were recruited as participants (8 males and 8 females). They had no formal musical training and had never learned to play a musical instrument. All participants reported normal hearing and no medical history of neurological disease.

B. Stimuli

A sample of 40 musical excerpts of serious non-vocal music was selected by music theorists and psychologists according to several constraints based on a previous study (Bigand et al. 2005). They were chosen to elicit a large variety of emotions, and to be representative of key musical periods of Western classical music (baroque, classic, romantic, and modern) as well as of the most important instrumental groups (solo, chamber music, orchestra). This final constraint is of methodological importance since it helps to neutralize any confound effect between the structural surface similarity and the emotional similarity of excerpts. The musical excerpts reflected different affective valence (pleasant vs. unpleasant) and arousal (intense vs. calm), namely happiness, anger, sadness and serenity. An average duration of 20s duration sounded appropriate for the purpose of the experiment. EEG measurements were recorded continuously during each of the 20 second musical excerpts.

C. Procedure

The participants were presented with the stimuli and they stated that none of the pieces sounded familiar to them. During the experiment each stimulus presented once and with alternating and random order. At the end of each trial participants had to rate each musical excerpt according to four emotions namely happy, angry, sad and serene using a 7-point scale which was visually represented (with 7 corresponding to very happy, angry, sad or serene and vice versa). Participants were asked to judge their experience with music and not the emotion expressed by the music. Behavioural ratings were then averaged for each condition and participant. The EEGs were collected using a Lycra stretch cap (Electro-Cap, Inc.) with electrodes positioned according to the International 10/20 Electrode placement position. During the experiments participants sat comfortably in an acoustically isolated and electrically shielded room. Music excerpts were presented via loudspeakers using presentation software. Participants were instructed to relax and listen carefully to the music with eyes open during the whole experiment. To control the attention of the participants, the subjects were instructed to look at a cross in the screen while listening to the music.

III. EEG RECORDINGS AND DATA ANALYSIS

The EEGs were recorded with a Biosemi instrumentation from 64 scalp locations according to the international 10-20 system. After the measurements all electrodes were referenced to the central vertex (Cz) during recording. The data were bandpass filtered between 1 Hz and 100 Hz and digitized at 512 Hz. Muscular and eye blinking artifacts were rejected off-line. Power spectrum analysis was computed using Welch's method of spectral averaging for 30 scalp electrodes including Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, and O2. Artifact-free EEG epochs, lasting 20 s each, were selected. For each condition, single segment power spectra were computed via Fast Fourier Transform (FFT) and then averaged to yield the mean power spectrum. Before FFT calculation, data segments were windowed using a Hamming function in order to reduce spectral leakage and zero padded to obtain a spectral resolution of 0.448 Hz. Mean band power values were calculated for each condition by averaging power values across frequency bins. Power (micro-volts-squared) was derived in the theta (4-8 Hz), alpha (8–12 Hz), beta (12-30 Hz) and gamma (30-40 Hz) bands. On average, 40 epochs per participant entered the grand average for each condition.

IV. RESULTS

Analyses of variance (ANOVA) with condition (emotion) and hemisphere (left-right) as within subjects factors were performed on log (EEG) power. The ANOVAS were performed separately for theta (4-8Hz) and alpha (8-12 Hz) bands. The results show significant emotion by hemisphere interaction for different emotional conditions and brain regions. The results for alpha band will be presented first in Fig.1 and Fig. 2.

Throughout the whole brain, there were 12 asymmetry indexes. Only 5 pairs of electrodes showed significant power asymmetries. The negative numbers are a result of the log power transform. More negative values indicate less alpha power and consequently more activation. The pair F7-F8, for example, shows significant asymmetry ($p < 0.02$) for the sad-serene condition. The condition by hemisphere interaction for the frontal region (F3, F4) was also significant, $p < 0.05$. It can be seen that the angry and sad conditions are associated with less alpha power (i.e. more activation) in the right frontal region compared to the happy and serene conditions. The same holds for the pair FC3-FC4, where significant asymmetry ($p < 0.05$) for the condition serene-sad is observed. Consistent with previous literature positively valenced (happy, serene) musical excerpts elicited greater relative left EEG activity, whereas negatively valenced musical excerpts (angry, sad) elicited greater relative right EEG activity.

In terms of alpha power, the condition by hemisphere interaction for the central region showed further significant asymmetries (see Fig.1 and Fig. 2). The pair C3-C4 showed asymmetries ($p < 0.048$) for the sad-serene condition. The same asymmetry ($p < 0.05$) is shown for the CP3-CP4 pair as well. It can be seen that sad condition is associated with less alpha power (i.e. more activation) in the right central region compared to the serene condition. In other words, alpha asymmetry is observed also in the central region.

Thus, based on alpha power, in both frontal and central regions positively valenced conditions (happy, serene) are associated with more left-sided activation, whereas negatively valenced conditions (anger, sad) are associated with increase in right-sided activation.

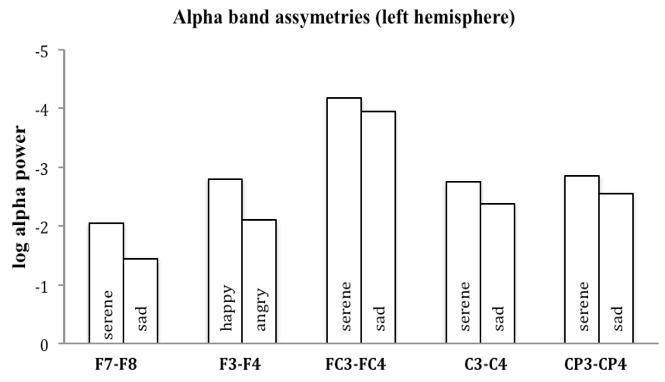

Figure 1. Alpha power for left frontal and central region for happy, angry serene and sad conditions

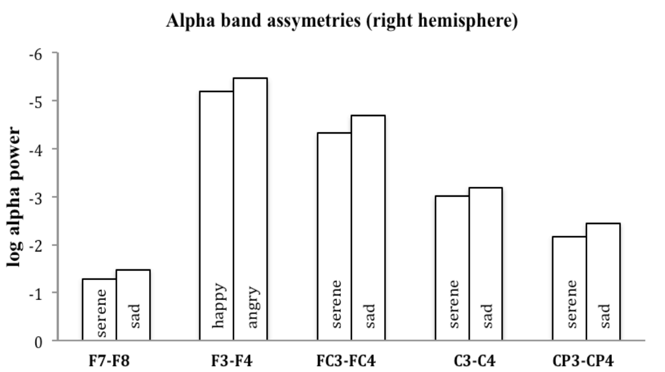

Figure 2. Alpha power for right frontal and central region for happy, angry serene and sad conditions

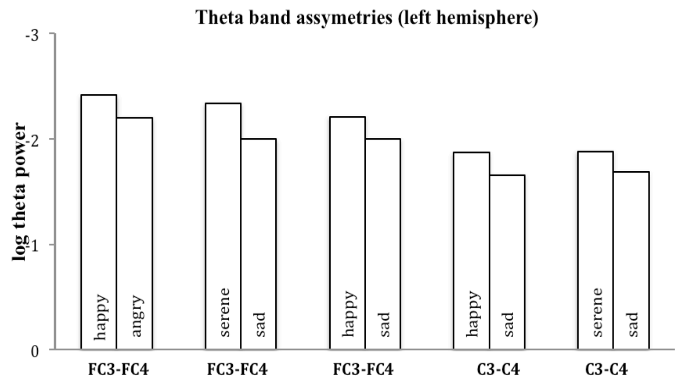

Figure 3. Theta power for the right central region for happy, angry sad, serene conditions

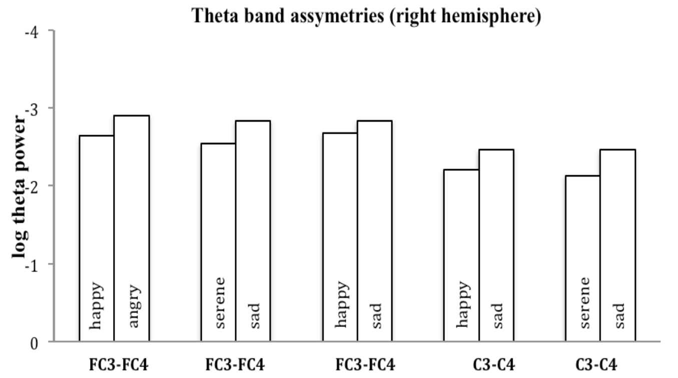

Figure 4. Theta power for the left central region for happy, angry sad and serene conditions.

The same analyses as described for the frontal and central alpha power were also performed in the theta band. The results are presented in Figure 3 and Figure 4. In theta band, some of the electrodes exhibit asymmetries for more than one emotional condition. The pair FC3-FC4, for example, shows significant asymmetries for three conditions, namely happy-angry ($p < 0.05$), happy-sad ($p < 0.05$) and sad- serene ($p < 0.05$). In terms of theta power, the condition by hemisphere interaction was also highly significant ($p < 0.009$) for the sad-serene and happy-sad ($p < 0.048$) condition in the central region (C3, C4). It can be seen that sad condition is associated with less theta power in the right hemisphere compared to the happy and serene condition.

V. DISCUSSION

In the present study coherent EEG activity correlates of pleasant and unpleasant emotional states evoked by musical excerpts of classical music were investigated in both theta and alpha bands. During the experiments, the subjective evaluations of the musical excerpts were similar to those previously obtained by Bigand et al. 2005. This justifies the selection of the musical collection based on this study where the distinction between emotional states was tested.

Consistent with previous literature (Davidson 1989, Schmidt and Trainor 2001, Aftanas and Golocheikine 2001) positively valenced (happy, serene) musical excerpts elicited greater relative left EEG activity, whereas negatively valenced musical excerpts (angry, sad) elicited greater relative right EEG activity. Alpha frontal and central asymmetry was also observed in the experiments of Flores-Gutierez et al. 2007. The coherent EEG activity was higher in the left central region (C3 and F3) for pleasant (Bach and Mahler excerpts) compared to unpleasant (Prodromides excerpts) feelings. In contrast, coherent EEG activity was higher in the right hemisphere (C4 and F4) for unpleasant compared to pleasant feelings. Thus, in terms of alpha power, the results confirm the hemispheric specialization hypothesis for emotional valence. In terms of theta power, asymmetries of the EEG activity were observed in both frontal (FC3-FC4) and central region (C3-C4) for more than one emotional conditions. There is higher left part activation for happy and serene compared to angry and sad condition.

The research of asymmetry of the EEG activity has been traditionally focused on the investigation of the alpha power. Relatively few studies have examined bands other than alpha including theta, beta and gamma bands (Pizzagalli 2001, 2002, Sammler et al. 2006). Sammler et al. 2006 reported an increase of midline (F_m) theta power during listening to pleasant (consonant) music. Aftanas and Golocheinike 2001 also reported an increase of midline theta power during 'blissful' states achieved during meditation.

The new finding in our results is the theta band asymmetries observed in frontal and central and brain region. Theta power is considered to be related to mental effort and attention (calculations, learning and meditation).Thus, the observed asymmetries in theta band support the hypothesis that emotional responses may be partly related to attentional processes (Sammler et al. 2006). It is possible that consonant, pleasant excerpts are listened more attentively and consequently cause increased theta power compared to dissonant, unpleasant excerpts. The results are in agreement with other EEG experiments during the observation of pictures from the international effective picture system I A P S. The results indicate an increase of EEG activity in central theta band of the left hemisphere for pleasant pictures (Alfanas et al. 2004).Our results are also similar to those reported recently by Vecchiato et al. 2011 who studied coherent EEG activity of subjects during observing commercial advertisement. The EEG analysis showed an asymmetrical increase of theta and alpha activities related to the observation of pleasant (unpleasant) advertisement in the left (right) hemisphere.

Moreover, the results show interesting findings related to the arousal and valence dimension during music listening. From the results in alpha band follows that the participants had the tendency to be affected more easily by music excerpts that elicit low arousal (sad, serene) regardless of the value of valence. In alpha band, only the pair F3-F4 reached significance for high arousal-high valence condition (happy-angry). On the other hand there are electrodes, which show significance for more than one affective dimension. The FC3-FC4 pair, for example, shows asymmetries for both angry-happy and serene-sad conditions in theta band. These electrodes might not be able to distinguish changes between valence and arousal separately. Thus, the obtained results may have implications when extracting EEG-based features for emotion recognition and classification applications.

In conclusion, the results of the present study confirm the hemispheric specialization hypothesis for emotional valence and provide evidence that theta power activation may play a more important role in emotion processing related to attentional processes that should be more carefully examined in future studies. Moreover, they indicate that during music listening different brain regions in different bands are activated for a variety of emotional conditions and that valence and arousal dimensions might be captured by different electrodes.

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