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RESEARCH ARTICLE

EEG spectral powers and source localization in depressing, sad, and fun music videos focusing on gender differences

Atefeh Goshvarpour[1] · **Ateke Goshvarpour**[2]

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Abstract

Previously, gender-specific affective responses have been shown using neurophysiological signals. The present study intended to compare the differences in electroencephalographic (EEG) power spectra and EEG brain sources between men and women during the exposure of affective music video stimuli. The multi-channel EEG signals of 15 males and 15 females available in the database for emotion analysis using physiological signals were studied, while subjects were watching sad, depressing, and fun music videos. Seven EEG frequency bands were computed using average Fourier cross-spectral matrices. Then, standardized low-resolution electromagnetic tomography (sLORETA) was used to localize regions involved specifically in these emotional responses. To evaluate gender differences, independent sample *t* test was calculated for the sLORETA source powers. Our results showed that (1) the mean EEG power for all frequency bands in the women's group was significantly higher than that of the men's group; (2) spatial distribution differentiation between men and women was detected in all EEG frequency bands. (3) This difference has been related to the emotional stimuli, which was more evident for negative emotions. Taken together, our results showed that men and women recruited dissimilar brain networks for processing sad, depressing, and fun audio–visual stimuli.

Keywords Gender differences · Electroencephalogram · Standard low resolution brain electromagnetic tomography (sLORETA) · Power spectral analysis · Emotion · Music video stimuli

Introduction

Nowadays, entertainment is an industry that attracts the attention of many countries economically. Entertainment involves several sub-industries, including gaming, music, mass media, and the like. Since music has a great impact on the audience, its application has been taken into consideration in different fields, including advertising, education, learning, and even for medicine/healthcare purposes. To enhance the music's impact on the audience, usually, it is combined with visual stimuli, known as "music video". It has been shown that the integration of music and the film increases the impact of emotional stimuli (Parke et al. 2007). However, depending on the application, music videos with different emotional contents have been used in previous studies (Soleymani et al. 2011; Zhang et al. 2008).

Several specialized brain regions collaborate tightly during various tasks comprised of learning, cognitive, emotional, behavioral, motor and sensory performances in normal and pathological states (Buiza et al. 2018; Dasdemir et al. 2017; Duru and Assem 2018; Hussain 2018; Khasnobish et al. 2017; Liu et al. 2016; Nimmy John et al. 2018; Yerlikaya et al. 2018; Yuvaraj and Murugappan 2016). Interestingly, for each task, the contributions of some particular brain networks are enhanced. Understanding the brain circuitry related to behavior is doubtlessly the greatest endeavor of all time. It is also a challenging issue for researchers in various disciplines

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✉ Ateke Goshvarpour
ateke.goshvarpour@gmail.com; ak_goshvarpour@sut.ac.ir

Atefeh Goshvarpour
af_goshvarpour@sut.ac.ir

1 Department of Biomedical Engineering, Faculty of Electrical Engineering, Sahand University of Technology, Tabriz, Iran

2 Department of Biomedical Engineering, Imam Reza International University, Mashhad, Razavi Khorasan, Iran

from neuroscience to computer science and mathematics. Concerning this issue, one of the most appealing topics of psychologists is to fully realize which brain regions are involved in emotion (Goshvarpour et al. 2016; Güntekin et al. 2017). Evidence advocates distinct anatomical circuits for some emotion categories such as fear, sadness, love, and anger (Barrett et al. 2007). To some extent, there has been some agreement about the role of some brain activation in a certain emotional stimulation. Accordingly, the role of the amygdala in fear has been endorsed by many scientists (LaBar et al. 1998). In addition, there is an evidence in literature on the role of nucleus accumbens for fun, joy, and reward processing; insula for avoidance, disgust, and pain; postcentral gyrus for pain or pain expectancy; and many more (Koelsch 2014; Schreuders et al. 2018; Yoshino et al. 2017). For most types of affective stimuli, a potential involvement of particular brain circuits has not been examined.

The contribution of some other important factors to the connectivity and circuit of the brain has confirmed in the literature during affective stimuli. The gender of volunteers is one of the chief effective factors. In addition, gender-related emotional brain activities have been reported in various investigations (Jaworska et al. 2012; Mahaldar and Aditya 2017; Stevens and Hamann 2012).

To address the emotional brain networks, most findings are derived from neuroimaging methods such as positron emission tomography (PET), magnetic resonance imaging (MRI), and functional MRI (fMRI) (Canli et al. 2001; Demaree et al. 2009; McRae et al. 2012; Lisiecka et al. 2013; Yoshino et al. 2017). Another procedure for tracking brain functions, at the time an event occurs is the electroencephalogram (EEG) signal. EEGs can be scrutinized in different frequency bands. In addition, EEG measurements not only have the very high temporal resolution, but they also have low costs. To localize the electrical activity gained from EEG and to identify the EEG sources, specific algorithms have been used to solve the EEG inverse problem (Pascual-Marqui et al. 1994, 2011).

For this study, we considered several hypotheses that can be summarized as follows.

1. A growing number of studies have inspected the gender-related differences in emotion processes in healthy and unhealthy participants (Jaworska et al. 2012; Mahaldar and Aditya 2017; Stevens and Hamann 2012). The role of socialization factors, genetical predispositions, and biological structures/processes has been highlighted by the researchers (Bradley et al. 2001). In this context, the contribution of a gender-specific role in the brain-emotion relationship has been addressed in several studies (Kesler-West et al. 2001; Williams et al. 2005; Stevens and Hamann 2012). For example, a meta-analysis study (Stevens and Hamann 2012) reported an augmented brain activation for negative valence stimuli in females (particularly in the subcortical and limbic areas); while an increased brain activation was found for positive valence inducements in males (especially in subcortical and cortical areas). However, it is noted that studies of sex differences in brain activation were to some extent inconsistent and inconclusive (Brody 1999). In this study, we hypothesized gender differences in the brain processing of the emotional music-video clips.
2. The hypothesis that dimensional or discrete emotion classes correspond to distinct brain activation has been introduced in previous studies (Colibazzi et al. 2010; Lindquist et al. 2012; Hamann 2012). Some studies discussed the role of an individual brain area for a particular emotion, whereas others claimed that one-to-one mappings between emotion classes and specific brain areas are insufficient and contribution of a network region is required (Scarantino 2012). Specifically, we aimed to evaluate if there is any difference between the brain processing of the fun, depressing, and sad emotional stimuli induced by music-video clips.
3. Previously, it was shown the role of the different frequency generators in different tasks. For instance, slow waves are associated with long-range distance communication; the alpha wave is dominant in relaxing effects; for the motor and/or empathic mirror neuron activations the beta wave and for local and higher order brain processing the gamma wave is dominant (Pfurtscheller and Lopes da Silva 1999; Marshall and Bentler 1976; Gros et al. 2015). The role of the specific EEG frequency band in emotion processing was highlighted by some researchers. A prominent alpha power activation was reported over the right posterior regions during the viewing of the disgusting scene (Sarlo et al. 2005). The activation of right parietal regions was shown to be dominant at theta (Aftanas et al. 2004) and gamma (Balconi and Lucchiari 2008) spectral bands. Sammler et al. (2007) highlighted the role of frontal midline theta power for pleasant stimuli. The results of Schutter et al. (2001) indicated an extremely significant association between the beta asymmetry at the parietal region and the angry faces. Müller et al. (1999) showed an augmented gamma power for the negative valence over the left temporal as compared to the right; however, for the positive valence, a laterality shifted towards the right hemisphere. They also showed that compared to processing neutral pictures, emotional processing boosted gamma power at right frontal regions irrespective of the specific valence. From this evidence, we can assume

that emotional stimuli are associated with several frequency bands of EEG activity depending on the function sub-served by the various cortical regions.

Briefly, until now, no studies have investigated brain source localization during the presentation of the fun, sad, and depressing music videos concerning gender differences. Therefore, the main goal of this study was to explore the effect of gender differences on EEG frequency bands and circuits, while participants are watching a music video with emotional contents of fun, sad, and depressing. To identify the brain topographic distribution, standard low-resolution brain electromagnetic tomography (sLORETA) was applied. Comparison of different localization approaches revealed that sLORETA is a suitable first-order tomographic localization approach (Pascual-Marqui 2007). The performance of the sLORETA approach is considerably better than the minimum norm [an inverse problem for defining primary current distributions from brain magnetic fields (Hämäläinen and Ilmoniemi 1994)] and Dale [it employs standardized current density estimation for localization inference (Dale et al. 2000)] approaches regarding localization errors and spatial spread even in noisy conditions (Pascual-Marqui 2002). This method has a high temporal resolution as a result of employing EEG signals. It also has a proper spatial resolution of five mm, which is very close to fMRI (Jatoi et al. 2014).

Materials and methods

EEG data

To localize the brain frequency fluctuations to different emotional music video clips in two genders, we analyzed the preprocessed EEG time-series, available in the database for emotion analysis using physiological signals (DEAP) database (Koelstra et al. 2012). The database is composed of 32 standard EEG channels located according to the international 10–20 system (EEG electrodes: Fp1, Fp2, AF3, AF4, Fz, F3, F4, F8, F7, FC5, FC6, FC1, FC2, T7, T8, C3, C4, Cz, CP5, CP6, CP1, CP2, P3, P4, P7, P8, Pz, PO3, PO4, O1, O2, and Oz). To acquire EEG, AgCl electrodes were used.

The sampling frequency of 512 Hz was chosen. Then, EEG data of all 32 standard scalp leads were down-sampled to 128 Hz and ocular artifacts, generated from electrooculogram (EOG) potentials, were removed using a blind source separation technique (Koelstra et al. 2012). In addition, a band-pass frequency filter was applied with the cutoff frequencies of 4.0 Hz and 45.0 Hz (Koelstra et al. 2012). Finally, the data recordings were averaged to the common reference (Koelstra et al. 2012). In this study, the 32 channel EEG signals of 30 healthy participants were examined. Table 1 shows the characteristics of the subjects.

Table 1 Subject characteristics

	Number of subjects	Age range	Mean age	SD
Female	15	19–33	25.4	3.76
Male	15	23–37	28.8	4.51

The DEAP database applied music-video clips to induce emotion. Before starting the emotional experiment, a 2-min baseline recording was acquired. For this period, the subject was requested to relax and a fixation cross was presented. Following the baseline recording, the 40 videos were presented in 40 trials. For each trial, the trial number was displayed for 2 s to enlighten the subject of the progress. Then, a fixation cross was presented for 5 s. Next, the music video was displayed for 1 min. Finally, the self-assessment was performed. There was a short break after the 20th trial. During this period, the volunteer was served with beverages (non-caffeinated and non-alcoholic) and some cookies. In addition, the signal quality and the electrode placement were checked by the examiner. Subsequently, the second half of the experiment was performed (Koelstra et al. 2012).

The measurements were performed in two controlled illumination laboratory rooms (Koelstra et al. 2012). The Biosemi ActiveTwo system (http://www.biosemi.com) was used for the signal recording with a Pentium 4, 3.2 GHz PC (committed recording PC). Also, Pentium 4, 3.2 GHz PC was dedicated as a stimulus PC for presenting stimuli. It directly sent synchronization markers to the recording PC. The "Presentation" software by Neurobehavioral systems was used for the music video presentation and for the users' ratings recording. A 17-inch screen was used to present the music videos (1280 × 1024, 60 Hz). However, to keep eye movements at a minimum, all video clips were displayed at 800 × 600 resolution, which covers about 2/3 of the monitor. The distance of the subjects to the screen was about 1 m. The music was presented via Stereo Philips speakers, while the volume was set at a quite loud level. However, before the experiment, the volunteer was asked to verify if the volume was comfortable, else it was adjusted (Koelstra et al. 2012).

Employing the self-assessment manikins (SAM) introduced in 1995 (Morris 1995), the volunteers rated each music video clip based on the levels of like/dislike, valence, arousal, dominance, and familiarity. In addition to the SAM assessment ratings, the database (Koelstra et al. 2012) includes the online subjective annotation via last.fm (http://www.last.fm) affective tags, which were carefully

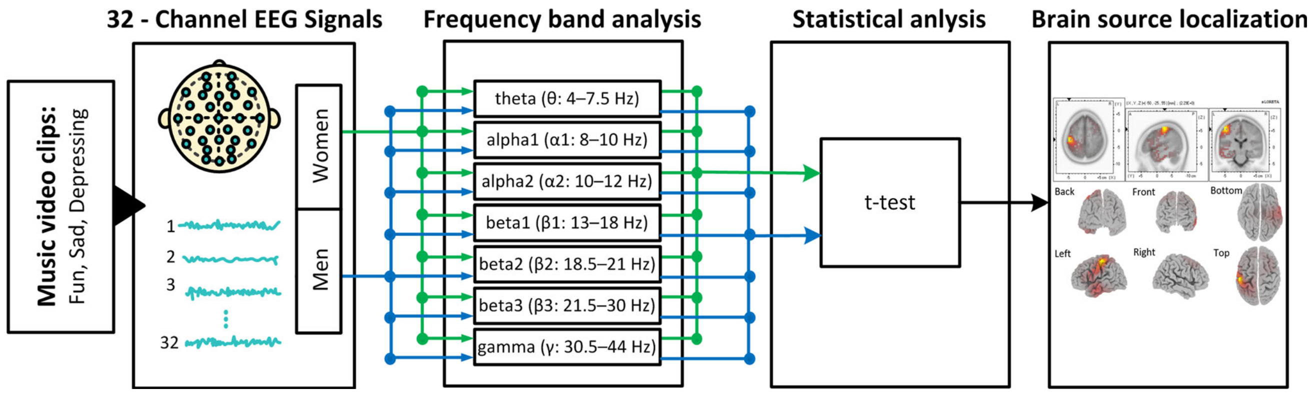

Fig. 1 Diagram of the proposed procedure

assessed to check if the tag accurately reflects the emotional content. In this article, fun, depressing, and sad music-video clips were selected for further analysis.

sLORETA analysis

In this study, we investigate seven EEG frequency bands while subjects watching sad, fun, and depressing music clips. EEG frequency bands, including theta (θ: 4–7.5 Hz), alpha1 (α1: 8–10 Hz), alpha2 (α2: 10–12 Hz), beta1 (β1: 13–18 Hz), beta2 (β2: 18.5–21 Hz), beta3 (β3: 21.5–30 Hz), and gamma (γ: 30.5–44 Hz) were computed using average Fourier cross-spectral matrices. The selection of EEG bands was performed based on the previous investigations on emotion (Aftanas et al. 2006).

To this end, the discrete Fourier transform (S_x) of the time-series $X(t)$ ($t = 0, \ldots, T - 1$) with length T is firstly computed

$$S_x(\omega) = \sum_{t=0}^{T-1} X(t)e^{-i2\pi\omega t/T}. \tag{1}$$

Then, the cross-spectral density (S_{xy}) between two signals $X(t)$ and $Y(t)$ is calculated as (2):

$$S_{xy}(\omega) = E\left[S_x(\omega)S_y(\omega)^*\right] \tag{2}$$

where $E[]$ is an expectation function and * is the complex conjugate. This procedure was performed in women's and men's groups for sad, fun, and depressing stimuli.

Then, sLORETA was used to obtain topographic maps of the localization of the EEG frequency bands and to compare the cortical distribution of electrical activity between women and men. More precisely, we aimed to answer what EEG oscillations (frequency bands) are significantly different between men and women. And if there are significantly different frequency bands, which brain activation is responsible for the difference.

The neuronal activity as current density was estimated by the sLORETA. To this end, it uses the Montreal Neurological Institute MRI template (Talairach and Tournoux 1988). The sLORETA solution space restricted to cortical gray matter sampled at five mm resolution (5 × 5 × 5 mm/voxel) with a total 6239 voxels. A linear, weighted sum of scalp potentials is applied to calculate the current source density (CSD). The current density power measure (A/m^2) is realized by computing the square of the CSD for each voxel. The sLORETA and its previous version (i.e., LORETA) has been cross-validated (Phillips et al. 2002; Pizzagalli et al. 2004; Mulert et al. 2005; Olbrich et al. 2009). In this article, the free academic software package for sLORETA (Pascual-Marqui 2002) was used.

To scrutinize the EEG frequency band differences between women and men, independent sample *t* test was calculated for a log of the ratio of averages (log of F-ratio) sLORETA power. Neither data normalization nor the baseline correction was performed. The statistical nonparametric mapping randomization was performed to compute a critical single-threshold and *P* values. The number of randomization was set to 5000.

Figure 1 summarizes the procedure schematically.

Results

EEG results

We used the following numbers to simplify the content of the EEG channels: 1: Fp1, 2: AF3, 3: F3, 4: F7, 5: FC5, 6: FC1, 7: C3, 8: T7, 9: CP5, 10: CP1, 11: P3, 12: P7, 13: PO3, 14: O1, 15: Oz, 16: Pz, 17: Fp2, 18: AF4, 19: Fz, 20: F4, 21: F8, 22: FC6, 23: FC2, 24: Cz, 25: C4, 26: T8, 27: CP6, 28: CP2, 29: P4, 30: P8, 31: PO4, and 32: O2.

The statistical test comparing the mean θ power of the men's and women's groups for depressing, fun, and sad stimuli found a significant difference between the means of the two groups in 22, 14, and 22 channels, respectively ($p < .05$). These channels are 5, 7, 10, 11, 12, 20, 21, 22, 25, 26, 27, 28, 29, and 31 for fun and 2, 3, 5, 7, 8, 10, 11, 12, 15, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 28, 29, and 31 for depressing and sad. The mean of the men's group (150.32 ± 127.26, 135.17 ± 110.56, and 156.62 ± 124.77, for depressing, fun, and sad, respectively) was significantly lower than the mean of the women's group (483.34 ± 463.13, 436.41 ± 447.62, and 469.55 ± 441.4, for depressing, fun, and sad, respectively).

The statistical test comparing the mean α1 power of the men's and women's groups for depressing, fun, and sad stimuli found a significant difference between the means of the two groups in 19, 6, and 18 channels, respectively ($p < .05$). These channels are 2, 3, 5, 7, 8, 10, 11, 15, 17, 18, 20, 21, 22, 23, 26, 27, 28, 29, and 31 for depressing, 10, 11, 20, 27, 28, and 31 for fun, and 2, 5, 7, 8, 10, 11, 15, 17, 18, 20, 21, 22, 23, 26, 27, 28, 29, and 31 for sad. The mean of the women's group (119.17 ± 102.81, 112.12 ± 97.16, and 122.32 ± 104.52, for depressing, fun, and sad, respectively) was significantly higher than the mean of the men's group (49.74 ± 28.24, 44.79 ± 21.4, and 53.02 ± 31.7, for depressing, fun, and sad, respectively).

The statistical test comparing the mean α2 power of the men's and women's groups for depressing, fun, and sad stimuli found a significant difference between the means of the two groups in 18, 7, and 17 channels, respectively ($p < .05$). These channels are 2, 3, 5, 8, 10, 11, 15, 17, 18, 20, 21, 22, 23, 26, 27, 28, 29, and 31 for depressing, 10, 11, 20, 27, 28, 29, and 31 for fun, and 2, 3, 5, 8, 10, 11, 15, 17, 18, 20, 22, 23, 26, 27, 28, 29, and 31 for sad. The mean of the women's group (81.33 ± 65.05, 76.3 ± 63.56, and 84.91 ± 69.14, for depressing, fun, and sad, respectively) was significantly higher than the mean of the men's group (38.15 ± 18.08, 35.65 ± 13.33, and 40.44 ± 20.6, for depressing, fun, and sad, respectively).

The statistical test comparing the mean β1 power of the men's and women's groups for depressing, fun, and sad stimuli found a significant difference between the means of the two groups in 12, 9, and 17 channels, respectively ($p < .05$). These channels are 2, 5, 10, 11, 15, 20, 21, 22, 23, 26, 28, 29, and 31 for depressing, 5, 10, 11, 20, 26, 27, 28, 29, and 31 for fun, and 1, 2, 5, 8, 10, 11, 15, 17, 18, 20, 22, 23, 26, 27, 28, 29, and 31 for sad. The mean of the women's group (114.93 ± 90.33, 111.58 ± 88.04, and 133.87 ± 113.02, for depressing, fun, and sad, respectively) was significantly higher than the mean of the men's group (55.88 ± 23.73, 55.68 ± 23.49, and 60.75 ± 30.33, for depressing, fun, and sad, respectively).

The statistical test comparing the mean β2 power of the men's and women's groups for depressing, fun, and sad stimuli found a significant difference between the means of the two groups in 6, 4, and 9 channels, respectively ($p < .05$). These channels are 10, 11, 20, 22, 28, and 31 for depressing, 11, 20, 29, and 31 for fun, and 1, 5, 10, 11, 20, 22, 27, 28, and 31 for sad. The mean of the women's group (43.8 ± 32.82, 43.2 ± 30.79, and 54.57 ± 48.19, for depressing, fun, and sad, respectively) was significantly higher than the mean of the men's group (23.69 ± 10.4, 23.94 ± 10.75, and 23.74 ± 10.5, for depressing, fun, and sad, respectively).

The statistical test comparing the mean β3 power of the men's and women's groups for depressing, fun, and sad stimuli found a significant difference between the means of the two groups in 4, 5, and 11 channels, respectively ($p < .05$). These channels are 10, 11, 22, and 31 for depressing, 10, 27, 28, 29, and 31 for fun, and 1, 10, 11, 12, 18, 20, 22, 24, 27, 28, and 30 for sad. The mean of the women's group (145.51 ± 126.93, 141.08 ± 115.13, and 180.47 ± 170.4, for depressing, fun, and sad, respectively) was significantly higher than the mean of the men's group (68.56 ± 32.87, 71.72 ± 39.93, and 71.74 ± 39.23, for depressing, fun, and sad, respectively).

The statistical test comparing the mean γ power of the men's and women's groups for depressing, fun, and sad stimuli found a significant difference between the means of the two groups in 4, 7, and 10 channels, respectively ($p < .05$). These channels are 10, 11, 22, and 31 for depressing, 10, 11, 22, 27, 28, 29, and 31 for fun, and 1, 10, 11, 18, 20, 22, 24, 27, 28, and 30 for sad. The mean of the women's group (209.72 ± 192.18, 203.19 ± 160.74, and 263.51 ± 264.77, for depressing, fun, and sad, respectively) was significantly higher than the mean of the men's group (92.23 ± 50.13, 104.46 ± 72.33, and 91.35 ± 57.92, for depressing, fun, and sad, respectively).

Table 2 provides the statistical results for each pair of stimulus categories.

There was a significant difference between sad and fun in β2, β3, and γ brain frequencies. Among the frequency bands, β3 showed the highest significant differences between each pair of stimulus categories in some brain regions.

Moreover, to postulate a specific effect of the video-clip category on gender differences, a two-factorial interaction GENDER × VIDEO-CLIP-CATEGORY was calculated. *P* values indicated a main effect of gender, but there was no evidence of the video clip nor an interaction effect of the two.

sLORETA results

The sLORETA differences between men's and women's EEG frequency bands for depressing, fun, and sad stimuli are shown in Table 3, Suppl. 1, Suppl. 2, and Suppl. 3.

Table 2 Statistical differences ($p < .05$) for each pair of stimulus categories (a) sad versus depressive, (b) depressive versus fun, and (c) sad versus fun

(a)								(b)							
Ch.	θ	$\alpha1$	$\alpha2$	$\beta1$	$\beta2$	$\beta3$	γ	*Ch.*	θ	$\alpha1$	$\alpha2$	$\beta1$	$\beta2$	$\beta3$	γ
1	–	–	–	–	.029	.016	.003	**1**	–	–	–	–	–	–	–
2	–	–	–	–	.019	.012	.005	**2**	–	–	–	–	–	.008	–
3	–	–	–	–	–	.044	.04	**3**	–	.026	.047	–	–	.024	–
4	–	–	–	–	–	–	–	**4**	–	–	–	–	–	–	–
5	–	–	–	–	.04	.021	.012	**5**	–	–	–	–	–	.031	–
6	–	–	–	–	–	–	–	**6**	–	–	–	–	–	–	–
7	–	–	–	–	–	–	.035	**7**	–	–	–	–	–	–	–
8	–	–	–	–	–	–	.002	**8**	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	**9**	–	–	–	–	–	.002	.007
10	–	–	–	–	–	–	–	**10**	–	–	–	–	–	–	–
11	–	–	–	–	–	–	–	**11**	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	**12**	–	–	–	–	–	–	–
13	–	–	–	–	.037	.028	.022	**13**	.047	.008	.006	–	–	.013	–
14	–	–	–	–	–	.036	.024	**14**	–	.046	–	–	–	.011	–
15	–	–	–	–	–	–	.043	**15**	–	–	–	–	–	.019	–
16	–	–	–	–	–	–	–	**16**	–	–	–	–	–	–	–
17	–	–	–	–	–	–	.037	**17**	–	–	–	–	–	.049	–
18	–	–	–	–	.017	.013	.006	**18**	–	–	–	–	–	.022	–
19	–	–	–	–	.042	.025	.018	**19**	–	.034	–	–	–	.006	.043
20	–	–	–	–	–	–	–	**20**	–	–	–	–	–	.048	–
21	–	–	–	–	–	–	–	**21**	–	–	–	–	–	.02	–
22	–	–	–	–	–	–	–	**22**	–	–	–	–	–	–	–
23	–	–	–	–	–	.033	.024	**23**	–	–	–	–	–	.032	–
24	–	–	–	–	–	–	–	**24**	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	**25**	–	–	–	–	–	–	–
26	–	–	–	–	.047	.035	.025	**26**	–	–	–	–	–	.009	–
27	–	–	–	–	–	–	–	**27**	–	–	–	–	–	–	–
28	–	–	–	–	.03	.019	.005	**28**	–	–	–	–	–	–	–
29	–	–	–	–	.048	.034	.026	**29**	–	–	–	–	–	.013	–
30	–	–	–	–	–	–	–	**30**	–	–	–	–	–	–	–
31	–	–	–	–	–	.044	.043	**31**	–	–	–	–	–	.014	–
32	–	–	–	–	–	–	.038	**32**	–	–	–	–	–	.006	.037

Table 2 (continued)

Ch.	θ	$\alpha1$	$\alpha2$	$\beta1$	$\beta2$	$\beta3$	γ	*Ch.*	θ	$\alpha1$	$\alpha2$	$\beta1$	$\beta2$	$\beta3$	γ
1	–	–	–	–	.002	3.6×10^{-5}	2.8×10^{-5}	**17**	–	–	–	–	.009	.0001	.0004
2	–	–	–	–	.0001	1×10^{-6}	8.4×10^{-6}	**18**	–	–	–	–	.001	5.2×10^{-6}	2.8×10^{-5}
3	.033	.035	.043	–	.002	3.8×10^{-5}	.0003	**19**	–	–	–	–	.0006	2.3×10^{-6}	2.6×10^{-5}
4	–	–	–	–	–	–	–	**20**	–	–	–	–	.022	.0003	.001
5	–	–	–	–	.003	1.8×10^{-5}	.0001	**21**	–	–	–	–	.013	.0001	.0003
6	–	–	–	–	–	–	–	**22**	–	–	–	–	–	–	–
7	–	–	–	–	.013	.0002	.001	**23**	–	–	–	–	.005	3.7×10^{-5}	.0003
8	–	–	–	–	–	–	.019	**24**	–	–	–	–	–	–	–
9	–	–	–	–	.024	6.8×10^{-5}	.0001	**25**	–	–	.043	.047	–	–	–
10	–	–	–	–	–	–	–	**26**	–	–	–	–	.001	7.2×10^{-6}	5.3×10^{-5}
11	–	–	–	–	.042	.004	.008	**27**	–	–	–	–	–	.023	.012
12	–	–	–	–	–	–	–	**28**	–	–	–	–	.007	.0002	.001
13	.008	.009	.006	–	.0009	7.9×10^{-6}	7.1×10^{-5}	**29**	–	–	–	–	.001	1.1×10^{-5}	.0001
14	–	–	–	–	.002	9.4×10^{-6}	7.7×10^{-5}	**30**	–	–	–	–	–	–	–
15	–	–	–	–	.006	4.7×10^{-5}	.0003	**31**	–	–	–	–	.003	1.8×10^{-5}	.0001
16	–	–	–	–	–	–	–	**32**	–	–	–	–	.002	8.3×10^{-6}	5.9×10^{-5}

Ch. EEG channel, – not significant

The results showed that significant gender-differences were mainly achieved for parietal lobe in depressing and sad music videos. While for fun music video, the significance was chiefly attained for the limbic lobe. If we analyze the frequency bands of the signal separately, different results are obtained for various emotional stimuli. Considering θ power, significant gender-specific differences for depressing, fun, and sad stimuli were achieved for Brodmann area 2 (BA2), BA32, and BA40. Significant sLORETA differences were observed for BA2/BA5, BA24/BA24, and BA42/BA40 with respect to α1/α2 bands.

For fun inducement (Table 3 and Suppl. 2), the main differences for β1, β2, β3, and γ were detected in BA23, BA13, BA8, and BA13, respectively. However, BA39, BA40, BA19, and BA40 showed the most corresponding differences between the men's and women's groups for the sad music video (Table 3 and Suppl. 3). For depressing stimuli, BA7 for β1, β3, and γ and BA23 for β2 EEG bands showed the gender differences (Table 3 and Suppl. 1).

In addition, the study of the region coordinates with the greatest difference between the two groups (Table 3) indicates the superiority of different hemispheres for different EEG frequency bands in different emotional music videos. The dominance of left hemisphere in θ and α1 bands during the presentation of depressing video, β1 and β3 in fun music video, and α2, β1, β2, β3, and γ in sad incentive is concluded.

For depressing stimuli, the thresholds for significance were T = 2.495 in $p < .05$ and T = 3.008 in $p < .01$. In this case, significant differences ($p < .05$) were observed between men and women in α2 ($p = .0382$), β2 ($p = .038$), and β3 ($p = .038$) EEG bands. These differences were localized in the activity of the right postcentral gyrus, right cingulate gyrus, and precuneus region.

For fun music video, the thresholds for significance were T = 2.634 in $p < .05$ and T = 3.259 in $p < .01$. In this case, significant differences ($p < .05$) were observed between men and women in α2 and β2 EEG bands ($p = .0482$). These differences were localized in the right cingulate gyrus and right insula.

For sad inducement, the thresholds for significance were T = 2.987 in $p < .05$ and T = 3.324 in $p < .01$. In this condition, significant differences were observed between men and women in all EEG bands for $p < .05$ and in α2, β3, and γ for $p < .01$. These differences ($p < .01$) were localized in the left supramarginal gyrus and left fusiform gyrus.

Comparing EEG electrodes with the sLORETA anatomical regions, the best matching electrodes were CP1 and CP6.

Discussion

We applied the sLORETA to the EEG recordings of men and women while watching depressing, fun, and sad music videos. The data were analyzed with the following objectives: (1) detection of brain activation differentiation between men and women while watching the depressing, sad, and fun music videos, (2) specifying these differences in all EEG frequency bands. It should be noted that a difference in brain areas between women and men is fundamentally different from brain activations. Differences in brain areas suggest potential structural differences, whereas activation differences can be both due to structural, but also to the recruitment of particular individual mental strategies (see Fuster 2009; Fehr 2013). The latter can fundamentally be modulated by learning history and socialization. In this study, we emphasized the brain activation.

Previous studies have shown different emotional responses of men and women and they claimed the roots of these differences lie in biological and sociocultural factors (Bradley et al. 2001). Although some scientists argue that women experience a different socialization than men—and this is not defined by genetical pre-dispositions, but by different social norms and rules defined by politics, culture, and religion (Fischer et al. 2004)—others emphasized the physiological differences between men and women (Kret and De Gelder 2012). Hormonal and genetic factors are known to influence the emotional responses of men and women. On the other hand, some studies have shown the correlation between changes in these factors and brain activity. For example, on the hormonal status, augmented amygdala activity and affective recall in females were associated with high progesterone levels (Sundström Poromaa and Gingnell 2014). In contrast, testosterone status in males was positively related to the ventromedial prefrontal cortex and negatively related to the amygdala in response to anger faces (Stanton et al. 2009). Regarding the genetic factor, the study of Raab et al. (2016) showed that serotonin transporter gene (5-HTTLPR) polymorphisms have been associated with different brain activation during the processing of facial emotions. Along with this theory, sex-related brain activation in the processing of emotions has been frequently documented (Kesler-West et al. 2001; Williams et al. 2005). In this paper, we considered the second hypothesis in response to specific emotions and for different brain frequency bands. The EEG results showed the mean power of all frequency bands in the women's group was significantly higher than that of the men's group. Evaluating gender-wise differences while participants were watching emotional films also indicated the more expressiveness of women compared to men (Kring and Gordon 1998). The activity of a wider quota of the limbic system in

Table 3 The sLORETA main localization activities for different EEG bands in depressing, fun, and sad music videos

	Max value	X, Y, Z coordinate	Close region
Depressing			
θ	2.46	X = − 50, Y = − 30, Z = 40	BA2; postcentral gyrus; parietal lobe
α1	2.32	X = − 50, Y = − 30, Z = 55	BA2; postcentral gyrus; parietal lobe
α2	2.53	X = 5, Y = − 45, Z = 65	BA5; postcentral gyrus; parietal lobe
β1	2.31	X = 35, Y = − 65, Z = 45	BA7; superior parietal lobule; parietal lobe
β2	2.65	X = 5, Y = − 20, Z = 30	BA23; cingulate gyrus; limbic lobe
β3	2.64	X = 0, Y = − 45, Z = 45	BA7; precuneus; parietal lobe
γ	2.29	X = 0, Y = − 45, Z = 45	BA7; precuneus; parietal lobe
Fun			
θ	2.28	X = 5, Y = 20, Z = 50	BA32; cingulate gyrus; limbic lobe
α1	2.57	X = 10, Y = 15, Z = 30	BA24; cingulate gyrus; limbic lobe
α2	2.64	X = 5, Y = 5, Z = 30	BA24; cingulate gyrus; limbic lobe
β1	2.62	X = − 5, Y = − 20, Z = 30	BA23; cingulate gyrus; limbic lobe
β2	2.65	X = 35, Y = − 10, Z = 15	BA13; insula; sub-lobar
β3	2.46	X = − 30, Y = 10, Z = 45	BA8; middle frontal gyrus; frontal lobe
γ	2.32	X = 30, Y = − 25, Z = 15	BA13; insula; sub-lobar
Sad			
θ	3.25	X = 55, Y = − 60, Z = 40	BA40; inferior parietal lobule; parietal lobe
α1	3.28	X = 65, Y = − 35, Z = 20	BA42; superior temporal gyrus; temporal lobe
α2	3.46	X = − 60, Y = − 50, Z = 35	BA40; supramarginal gyrus; parietal lobe
β1	3.04	X = − 50, Y = − 65, Z = 40	BA39; inferior parietal lobule; parietal lobe
β2	3.27	X = − 60, Y = − 55, Z = 35	BA40; supramarginal gyrus; parietal lobe
β3	3.93	X = − 20, Y = − 85, Z = − 20	BA19; fusiform gyrus; occipital lobe
γ	3.96	X = − 60, Y = − 55, Z = 35	BA40; supramarginal gyrus; parietal lobe

BA Brodmann area

women compared to the men during emotional stimuli was also reported (George et al. 1996).

Our sLORETA results also showed the significant gender differences for all emotion categories in α2 power. Exactly, for depressing stimuli, sLORETA localization was significant in the α2 in the right postcentral gyrus (BA5), β2 in the right cingulate gyrus (BA23), and β3 in the precuneus (BA7) region. For fun, in the α2 and β2 powers the significant differences were localized in the activity of the right cingulate gyrus (BA24) and right insula (BA13). For sad, sLORETA localization was significant in all EEG bands. Previously, Koelsch (2014) performed a review of functional neuroimaging studies on music and emotion and showed the crucial involvement of some brain structures in emotion, like the insula and the cingulate cortex. Although his article highlighted the role of some other areas of the brain in the processing of emotions, the limitation of emotional classes (fun, depressing, and sad) as well as the type of stimulation (the combination of music and film; i.e., music video) can lead to obtain different brain activities in this study.

Formerly, the incorporation of BA5 and BA7 in the emotion recognition has been reported (Pouladi et al. 2010; Royet et al. 2000). These areas may contribute to the processing of chaotic patterns and working memory during audio and visual emotions. The results of Kragel and LaBars (2016) demonstrated that happiness and surprise expressions were projected by the activity of the postcentral gyrus. Generally, they concluded the hemodynamic activity in the right somatosensory cortex (postcentral gyrus) as a result of perceiving vocal and facial emotions. Yoshino et al. (2017) evaluated the association between anger and dysfunctional somatosensory mechanism in patients with burning mouth syndrome using fMRI. The results showed that the postcentral gyrus is strongly affected by negative emotions. Our findings indicated the effect of a negative stimulus (depressing) on the activity of the postcentral gyrus, which is in accordance with Yoshino et al. (2017). The effect of gender differences in processing a negative emotional state was also shown exploiting the other affective physiological signals (Goshvarpour et al. 2017).

The recent study (Ferri et al. 2016) showed that compared to neutral images, there is a relation between the non-arousing unpleasant pictures and heightened amygdala-precuneus connectivity; which was positively related to the visual attention. If we compare these findings with our own results, it can be concluded that the depressing music video, which served as an unpleasant stimulus, attracted the attention of men and women in different ways. In addition, previous evidence (Brodt et al. 2016) indicated the involvement of similar brain circuits, including precuneus, in the formation of long-term memory. The difference in how memory is stored and retrieved in men and women may seem to be another reason for the difference between the brain circuits of two genders in confronting emotional stimuli. However, differences between men's and women's memory performances should be studied more deeply regarding different socialization-related kinds of learned emotional memory handling styles, as well as their expectations, physiological capabilities, and interest, or some composite interaction of these elements (Loftus et al. 1987).

Canli et al. (2001) have provided evidence about the right cingulate gyrus activation in the processing of positive stimuli. However, the fMRI study of McRae et al. (2012) revealed an age-related quadratic pattern of activation in some brain regions, including the right cingulate gyrus. The look negative condition considered the engagement of these regions more strongly in young adults compared to the adolescents. Our results did not show the superiority of the right cingulate gyrus for a positive or a negative emotion with gender. Significant differences were achieved in the right cingulate gyrus for both positive and negative stimuli.

It was claimed that subjective emotions are produced in the insula (Damasio 2003). This region implicates the processing of subjective awareness and higher level cognitive procedures (Craig 2009). The right insula activation during mental stress and arousal based emotions (Critchley et al. 2000) as well as sadness, happiness, anger, and disgust affective states (Critchley et al. 2005) has been reported. In most of these studies, the activity of insula has been under the influence of negative emotions. These findings contradict ours, in which the activity of this area during a positive emotion (fun) was highlighted. However, according to our findings, it may be concluded that the fun music video stimulates the cognitive system of women and men differently.

Enhanced activity in the left supramarginal gyrus was observed in negative emotion words (Compton et al. 2003). The fMRI study (Lisiecka et al. 2013) revealed significant differences between healthy and major depressive disorder patients in emotional processing in the left supramarginal gyrus. The results of our research coincide with these findings. Our results revealed the activity of the left supramarginal gyrus in the negative emotional music video (sad), while it highlighted the role of gender in this activation.

Earlier, the association of the left fusiform gyrus with perceptual processing efficiency was shown during affective face processing (Ho et al. 2016). An increased activity in fusiform gyri was reported in the presentation of fearful faces compared to neutral (Vuilleumier et al. 2001). Previous MRI study (Demaree et al. 2009) reported that participants with a disease, which has been associated with the anxiety and the depression etiology (Lesch et al. 1996), show decreased left fusiform gyrus activation while watching positive emotional stimuli. By summarizing these results, it might be possible to relate the performance of the fusiform gyrus to the recognition of negative emotions, which is in the line with our findings, in which for sadness, the gender differences were localized in the left fusiform gyrus.

From the perspective of EEG powers, our results emphasized the importance of $\alpha2$, $\beta2$, $\beta3$, and γ powers. It is believed that β power is associated with heightened alertness and cognitive processes (Steriade 1999). The emotion literature reported that by increasing the emotional arousal, an increase in β power is observed (Aftanas et al. 2006; Sebastiani et al. 2003). α power is thought to associate with perceptual, cognitive, and memory performances (Klimesch et al. 2005; Ward 2003), and emotion (Aftanas et al. 1996; Schmidt and Trainor 2001). Jaworska et al. (2012) showed an increased α power in parietal and frontal regions of depressed participants. The results of Klimesch et al. (2007) demonstrated that $\alpha2$ has been related to memory retrieval. Therefore, it may be concluded that depressing, sad, and fun music videos established cognitive and/or memory related processes in men and women.

γ power is linked with semantic functions, conscious attention, and perception. Sustained γ power was also associated with the semantic elaboration of emotional information in depression and schizophrenia (Siegle et al. 2010). Our results revealed significant γ power gender differences in the sad music video. Therefore, it can be concluded that sad stimuli involved perceptual and semantic processing in men and women.

This experiment achieved very interesting results; however, there are several limitations of this study as a small number of subjects and the lack of a broad range of emotion categories. (1) A division of the 30 participants in two groups of 15 individuals revealed the brain regional differences in the sLORETA analysis. Only permutation statistics or reliability testing in larger samples would really substantiate potential gender differences. Therefore, these worthwhile study results should be considered as an exploration that has to be substantiated by subsequent studies and not as a stand-alone study producing facts for the gender mainstream discussion. (2) We utilized a pre-processed version of the data, in which a user-blind algorithm for artifact correction of the data was implemented. The characteristic and specificity of these algorithms restrict their use to remove one or some kinds of artifacts. For removal of various types of unwanted EEG contaminations, additional visual inspection of the raw data is indispensable. (3) Our results showed the putative differences between gender groups are prominently located at isocortical brain sites, and in particular in heteromodal association cortices, which lead to conclude that differences are especially due to different gender-related learning histories, and therefore due to differently learned cognitive and/or emotional processing styles of the different music entities. A detailed evaluation of how the different study participants processed the different music-clips is an important pre-requisite for a valid discussion on the physiological data. Therefore, in the future, these techniques should be employed to a larger database with respect to gender-related learning histories. (4) It should be kept in mind that sLORETA provides good spatial resolution; however, only for more superficial brain sites. Important areas like the brainstem and other subcortical areas cannot be addressed. Therefore, our results provided an initial insight into the active regions of the brain in different sexes. To conclude a gender-linked neural basis of emotion processing, a more precise and powerful technique should be applied in the future. (5) With regard to the active brain regions for each gender, some algorithms for the treatment of emotion-related abnormalities and for emotion recognition systems should be designed in the future.

Conclusions

This study assessed the gender-related sLORETA main localization for different EEG powers in depressing, fun, and sad music videos. Our results showed evidence about significant gender-related differences in parietal lobe activation for depressing and sad music videos and limbic lobe activation for fun stimuli. For all emotion categories, sLORETA localization for $\alpha 2$ power was significantly different in men and women. Totally, spatial distribution differentiation between men and women were detected while watching the depressing, sad, and fun music videos. These differences were specified for each EEG frequency band. This evidently suggests that to generalize findings of the brain activation during different emotional stimuli, we undeniably should consider the participants' sex. However, as mentioned in the limitation section, the reported data should first be replicated before extrapolative action can really be justified by the results.

Compliance with ethical standards

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

Ethical approval This article examined the DEAP dataset (Koelstra et al. 2012) EEG signals which is freely available in the public domain. This article does not contain any studies with human participants performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study (Koelstra et al. 2012).

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