International Journal of Psychophysiology xxx (2008) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Differential alpha coherence hemispheric patterns in men and women during pleasant and unpleasant musical emotions

Enrique O. Flores-Gutiérrez [a], José-Luis Díaz [c], Fernando A. Barrios [b], Miguel Ángel Guevara [d], Yolanda del Río-Portilla [a], María Corsi-Cabrera [a,*], Enrique O. del Flores-Gutiérrez [a,e]

[a] Facultad de Psicología, Universidad Nacional Autónoma de México, Mexico
[b] Instituto de Neurobiología, Universidad Nacional Autónoma de México, Mexico
[c] Departamento de Historia y Filosofía de la Medicina, Facultad de Medicina, Universidad Nacional Autónoma de México, Mexico
[d] Instituto de Neurociencias, Universidad de Guadalajara, Mexico
[e] Instituto Nacional de Psiquiatría Ramón de la Fuente, Mexico

ARTICLE INFO

Available online xxxx

Keywords:
EEG coherence
Alpha band
Emotion
Music
Sex differences
Men
Women

ABSTRACT

Potential sex differences in EEG coherent activity during pleasant and unpleasant musical emotions were investigated. Musical excerpts by Mahler, Bach, and Prodromidès were played to seven men and seven women and their subjective emotions were evaluated in relation to alpha band intracortical coherence. Different brain links in specific frequencies were associated to pleasant and unpleasant emotions. Pleasant emotions (Mahler, Bach) increased upper alpha couplings linking left anterior and posterior regions. Unpleasant emotions (Prodromidès) were sustained by posterior midline coherence exclusively in the right hemisphere in men and bilateral in women. Combined music induced bilateral oscillations among posterior sensory and predominantly left association areas in women. Consistent with their greater positive attributions to music, the coherent network is larger in women, both for musical emotion and for unspecific musical effects. Musical emotion entails specific coupling among cortical regions and involves coherent upper alpha activity between posterior association areas and frontal regions probably mediating emotional and perceptual integration. Linked regions by combined music suggest more working memory contribution in women and attention in men.

1. Introduction

Dissimilar cognitive capacities and their neural foundations suggest that men and women diverge in their general emotional response. Women recognize facial expression of emotions faster than men (Mandal and Palchoudhury, 1985), they are better to identify non-verbal prosodic information (Hall, 1978), and manifest stronger interference when language and prosodic signs are incongruent (Schirmer and Kotz, 2003). Several neuroimaging studies have reported sex differences in brain locations involved both in the perception (Killgore and Yurgelun-Todd, 2001; Lee et al., 2002) and subjective experience of emotion (Canli et al., 2002). Specifically, more brain regions and wider activations are involved in the processing of emotion in women (Bremner et al., 2001; Canli et al., 2002). Consistent with their lower hemispheric specialization (McGlone, 1986), brain activation during emotion is less lateralized in women (Killgore and Yurgelun-Todd, 2001; Wager et al., 2003). Women have higher interhemispheric coherent activity, whereas men show higher intrahemispheric coherent activity (Rappelsberger and Petsche, 1988; Corsi-Cabrera et al., 1993; Azari et al., 1995). Men and women also differ in their emotional response to music. For example, females attribute more positive valence to soft music compared to males, while the converse occurs for heavy metal and hard rock (Christensen and Peterson, 1988). Similarly, females show greater positive attributions to music, left brain predominance, larger hemisphere portions involved in the task (Altenmüller et al., 2002) and bilateral event-related potentials (Koelsch et al., 2003).

Since men and women differ in brain functional organization, in their emotional response to music, and in their patterns of inter and intrahemispheric functional coupling during rest and cognitive processing, it is reasonable to predict that different gender coupling patterns may be implicated in music emotion. The aim of the present study was to detect and analyze the neural patterns or networks of coherent activity between cortical regions during the feeling of pleasant and unpleasant musical emotions in men and women.

We have recently reported that music-induced emotions are sustained not only by activation of specific brain sites, but also by changes in the pattern of coherent activity or simultaneously synchronized oscillations between cortical regions (Flores-Gutiérrez et al., 2007). Hence, pleasant emotions increased left metabolic activation and coherent activity among primary auditory, posterior

* Corresponding author. Facultad de Psicología, Posgrado, Universidad Nacional Autónoma de México, Av. Universidad 3004, México, D.F. 04510, Mexico. Tel.: +52 5 6 22 22 51; fax: +52 5 6 22 23 10.
E-mail address: Corsi@servidor.unam.mx (M. Corsi-Cabrera).

0167-8760/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpsycho.2008.07.007

temporal, inferior parietal, and prefrontal regions, whereas unpleasant emotions involved the activation of right frontopolar and paralimbic areas. In order to assess possible sex differences in the brain coupling patterns involved in pleasant and unpleasant music emotion, the data from this neuroimaging study were separately analyzed in the male and female subjects. The analysis was focused on alpha frequencies because such brain activity range has been related to the processing of auditory information over the temporal cortex (Lehtelä et al., 1997), and it is a general indicator both of cognitive performance (Klimesch, 1999) and emotional tone (Davidson and Irwin, 1999; Kemp et al., 2004).

2. Method

2.1. Subjects

The data were obtained from 14 students (7M and 7F, 22–32 years) selected for a previous brain image study of musical emotions (Flores-Guitiérrez et al., 2007). Structured interviews verified that the subjects had no formal or informal music training, no restricted musical preferences, were right-handed, in general good health, free from neurological symptoms or psychoactive drugs use, and that the women were recorded between the 5th and 10th day of the menstrual cycle.

2.2. Music and noise stimuli

In accord to the subjective emotions known to be elicited by them, three musical excerpts repeatedly proven to produce particular emotions (Ramos et al., 1996; Flores-Gutiérrez, 2001) and unfamiliar to the participants were chosen as stimuli. In order to produce happiness, two pieces of music were used: a soft section of piano *in tempo andante* (*Invention for three parts, BWV 789* by J.S. Bach performed by Glenn Gold. CD: Sony, SMK 52685, 1959), and an energetic and dramatic composition for symphony orchestra (the first part of the second movement *Stürmisch beweg, Symphony number 5* by Gustav Mahler. Berlin Philharmonic Orchestra, Bernard Haitink, Conductor. CD: Philips, 475 446-2, 1993). A previously validated (Ramos et al., 1996) disturbing and scary piece of music written by the contemporary composer J. Prodromidès for the film *Danton* was chosen to induce fearsome emotions (Warsaw Philharmonic Orchestra, directed by Jan Pruszak, and the Choral Society of Warsaw directed by Maciej Jaskiewicz. CD: Gaumont, RCA PL 33743, 1983.). These pieces produce emotions situated in three of the four quadrants formed by the orthogonal intersection of the hedonic and activation variables of emotion (Díaz and Flores-Gutiérrez, 2001): pleasure–tranquility (Bach), pleasure–activation (Mahler), and displeasure–activation (Prodromidès).

The pieces were sectioned and presented in 10 consecutive segments of 30 s of the same musical piece in progression. The segments were presented in alternation with 10 segments of 30 s of random noise obtained from radio static and proven to consist of a homogeneous and constant sound spectrum. The order of presentation of the three musical excerpts was counterbalanced among subjects.

The tracks were prepared from a selection of each work, edited as required by means of the Sound Forge 5.0 program and recorded in a CD (imation cd-recordable 1×–4× compatible 650 mb/74 min) by means of a digital system (track record 16-bit monophonic, pre-mixing 32-bit). The subjects were comfortably seated with their eyes closed inside a sound-attenuating chamber under dim light and the tracks were played in a Dolby stereo Sony fh-e656 full remote control compact hi-density component system (compact disc receiver model hcd-h1700 speaker impedance use 16 Ohms, 90 W, speaker system magnetically shielded type, rated impedance 6 Ohms, sensitivity level 85 dB, frequency range 50 Hz–50,000 Hz). The two speakers were located 2 m in front of the subjects. The subjects were questioned in terms of possible auditory difficulties and the volume pre-adjusted to a comfortable range before the experiment. The volume reaching the subjects varied between 20 to 80 dB SPL. Subjects were instructed to listen attentively to the music.

2.3. Evaluation of the subjective responses to music

The feelings elicited by each excerpt were evaluated immediately after their presentation by visual-analogue scales of 19 adjectives corresponding to different emotions previously validated in three independent groups of 215, 80, and 40 subjects (Ramos et al., 1996). Each adjective scale consisted of a 10 cm horizontal bar representing absence of the emotion at the left and highest grade at the right. In order to reduce the number of adjectives and discern independent emotional states evoked by the musical pieces, the subjective ratings of all scales corresponding to the three musical pieces were submitted to principal component analysis (PCA) followed by varimax rotation. Only eigenvectors associated with eigenvalues = 1 were considered to construct "rotated orthogonal components" or "factors" expressed as a linear combination of items. Factor loadings ≥0.5 were required to include a scale in a component.

Since the Shapiro–Wilk test showed that more than half of the subjective emotion scales did not have a normal distribution, a non-parametric analysis of the data was undertaken on component scores of each component. Sexual differences for each principal component were analyzed by a Mann–Whitney *U*-test. Differences among the three musical pieces for each principal component were tested with the Friedman test. Post-hoc comparisons with Wilcoxon's tests allowed to determine differences associated with subjective feelings for each component (significance level $p<0.01$). A Bonferroni adjustment for multiple comparisons was made.

2.4. EEG recording and coherent activity analyses

During the music and noise listening periods, the EEG activity was recorded at 19 derivations of the 10–20 International System referred to ipsilateral earlobes. Ipsilateral ear lobes were a reference to minimize contamination of coherent activity by a common signal, at least between the two hemispheres. However, since volume conduction effects cannot be completely ruled out in ipsilateral ear lobe reference recordings, significant differences between pairs of electrodes were not considered and only the changes among conditions in the same pair of electrodes were analyzed. Impedance was kept below 5 kΩ, except for a couple of occasions that never exceeded 10 kΩ. In order to discard off-line EEG epochs contaminated by eye movements, two electrodes for vertical and two for horizontal eye movements were fixed slightly lateral to the lateral cantus of both eyes and above and below the right ocular orbit and referred to the same ear lobe.

EEG, EOG activity, and sound tracks were amplified using a Neurodata polygraph with filters set at 1 and 70 Hz, digitized at a sampling rate of 512 Hz and stored on a PC using the acquisition program GRASS-GAMMA version 4.4 for the entire duration of the stimuli. EEG was segmented into non-overlapping two-sec epochs synchronized with musical and noise tracks. The first and last two-sec epochs of each music and noise epochs were discarded in order to avoid transition effects. A minimum of 465 artifact-free two-sec epochs per subject entered the analysis. Cross-correlation spectra between pairs of derivations for each subject and condition were obtained for all artifact-free two-sec epochs at 0 time-lag as indicative of simultaneously synchronized oscillations related to verified emotional states using the program POTENCOR (Guevara et al., 2002). This program initially calculates the Fast Fourier Transform and then the correlation coefficients in the time domain within narrow spectral bands, a widely used and powerful procedure to obtain linear relationship between two signals. Correlation values were transformed to Fisher *Z* scores to approximate them to a normal distribution before

Please cite this article as: Flores-Gutiérrez, E.O., et al., Differential alpha coherence hemispheric patterns in men and women during pleasant and unpleasant musical emotions, Int. J. Psychophysiol. (2008), doi:10.1016/j.ijpsycho.2008.07.007

statistical analysis. The Fisher *Z*-transformed correlation values were averaged over 1 Hz bins, and over all epochs of the same condition for each subject and pair of derivations.

A principal component analysis (PCA) was used in order to reduce the number of variables and to obtain independent broad bands based on the actual EEG activity recorded during music listening. Two alpha bands were identified that allowed interpreting the EEG coherent activity in terms of lower (8–10 Hz) and upper (11–14 Hz) alpha bands (Klimesch, 1999). A more detailed description of the EEG recording and processing methods was presented in the previous communication (Flores-Gutiérrez et al., 2007).

2.5. Statistical analyses

Fisher *Z*-transformed correlation values for each frequency bin within the range of the two alpha bands were compared by separate Student *t*-tests for men and women between pleasant and unpleasant emotions, level of emotional activation, and between emotionally unspecific responses to music and noise. With the purpose of analyzing the unspecific effects of music which are not related to the evoked emotion, the results from the three music pieces and the three noise blocks were averaged over the three musical pieces and over the three noise blocks. The statistical comparisons were done for all electrode pair combinations of the same hemisphere including those over midline, excluding combinations between non-homologous interhemispheric regions. A complete exploration of all ipsilateral intrahemispheric and matching interhemispheric electrode combinations was performed.

Potential sex differences in the patterns or networks between men and women were not analyzed in terms of a statistical comparison between the sexes, but in terms of the identification of different networks of coherent activity between cortical regions during the feeling of pleasant and unpleasant musical emotions. Thus, the Bonferroni correction for multiple comparisons was applied to test for differences among musical emotions in cortical temporal coupling and not among regions (pairs of electrodes) nor among EEG frequencies. A significance level of $p<0.01$ was established. Only data exceeding the corrected significance level are reported and drawn in brain surface figures as lines connecting electrodes.

Table 1 summarizes the uncorrected probability values. The representation of the electrode location used a distribution verified by MRI and superposed upon Evans human brain average image by Okamoto et al. (2004). This allocation does not imply that the activity is generated in the area below the electrode but provides a relevant cortical locality for the functional interpretation of the results.

Table 1
Coherent activity in alpha band elicited by responses to music

		Left			Right		
		Electrodes	Hz	$p<0.005$	Electrodes	Hz	$p<0.005$
Higher with pleasant emotions	Men	T5 Fp1	10	0.003	T6 T4	10	0.003
		T5 F7	13	0.004			
		T5 C3	10	0.004			
		O1 Fz	13	0.005			
		T5 T3	11	0.003			
	Women	T5 Fp1	13	0.0001	T6 P4	11	0.005
		T5 F7	13	0.0002	F8 Fz	9	0.003
		T5 Fz	13	0.0005			
		T5 F3	13	0.003			
		T5 T3	13	0.001			
		T3 Fp1	12	0.0004			
		T3 F7	14	0.004			
		T3 Fz	12	0.0001			
			14	0.003			
		P3 Fp1	13	0.001			
		P3 F3	13	0.0006			
		P3 F7	13	0.004			
		P3 Fz	13	0.0004			
Higher with unpleasant emotions	Men				Cz Fp2	9	0.003
					Cz P4	11	0.001
					Pz C4	11	0.004
	Women	Fp1 T3	11	0.003	Fp2 Fz	11	0.001
		Fp1 Pz	11	0.002	Fp2 Cz	11	0.0001
		F3 C3	11	0.003	Fp2 Pz	11	0.001
		F3 P3	9	0.005			
		Cz P3	9	0.002			
Higher with relaxing pleasant emotions	Men				Fp2 Cz	13	0.002
					Fp2 Pz	12	0.005
					F4 F8	9	0.001
					F4 Pz	12	0.005
Higher with rousing-pleasant emotions	Women	T3 Fp1	11	0.002			
			12	0.004			
		T3 C3	9	0.004			
		T3 Cz	11	0.0004			
		C3 Cz	11	0.003			
Higher with music (M, B, P>noise)	Men	T3 Fp1	12	0.003	T6 Pz	10	0.004
		T3 Fz	12	0.002	T6 O2	9	0.003
		T3 Pz	11	0.003	T4 O2	9	0.004
	Women	T3 C3	13	0.0003	P4 Cz	8	0.004
		T3 Cz	13	0.004	O2 T6	9	0.004
		T3 Pz	14	0.0006			
		T3 P3	8	0.005			
			10	0.002			
			14	0.0002			
		T3 O1	8	0.0003			
			14	0.0009			
		T5 C3	12	0.002			
		T5 Cz	12	0.001			
Higher with noise (noise>M, B, P)	Men	Fp1 T5	12	0.002	Fp2 Pz	10	0.002
		Fp1 P3	12	0.005	F4 Pz	10	0.001
		F7 Pz	12	0.003			
		F7 T3	12	0.004			
		F7 C3	8	0.001			
			12	0.004			
	Women	Fz Cz	12	0.0006	Fz C4	13	0.0008
			13	0.004			

Pairs of electrodes and frequencies (Hz) showing changes in coherent activity between subjective emotions in Student *t*-test ($p<0.005$). B = Bach; M = Mahler; P = Prodromidès.

3. Results

3.1. Subjective ratings of musical emotions

Principal component analysis of the emotion-describing adjectives evaluated after listening to the three music pieces identified 5 rotated orthogonal components (Flores-Gutiérrez et al., 2007), which are consistent with previous studies (Ramos et al., 1996). Adjectives labelling positive pleasant emotions were found to gather in a different component or factor than negative adjectives. They were labelled Pleasant and Unpleasant components, respectively.

Fig. 1A illustrates the percentage of total variance explained by the Pleasant and Unpleasant components respectively, and the list of adjectives together with factor loadings. Words related with Activation (*lively* and *aroused*), with Sadness (*sad* and *afflicted*), or with Attention (*attentive* and *involved*) were separated in three other components explaining 9%, 9.23% and 10.84% of the total variance respectively. The Mann–Whitney *U*-test of each component performed with the components scores showed that there was not any difference between men and women in the intensity of the pleasant and unpleasant emotions. Main effects of music pieces were significant for the Pleasant ($p<0.004$), Unpleasant ($p<0.0001$) and Activation ($p<0.0004$) components but not for the Sadness and Attention components, indicating that the attention reported to the three musical pieces was similar. Also, as it was expected from preceding studies (Ramos et al., 1996; Flores-Gutiérrez, 2001), post-hoc comparisons revealed that musical stimuli by Bach and Mahler induced significantly higher positive emotions and lower negative emotions in the first two components respectively. Conversely, Prodromidès elicited more negative and less positive emotions than Bach and Mahler.

Please cite this article as: Flores-Gutiérrez, E.O., et al., Differential alpha coherence hemispheric patterns in men and women during pleasant and unpleasant musical emotions, Int. J. Psychophysiol. (2008), doi:10.1016/j.ijpsycho.2008.07.007

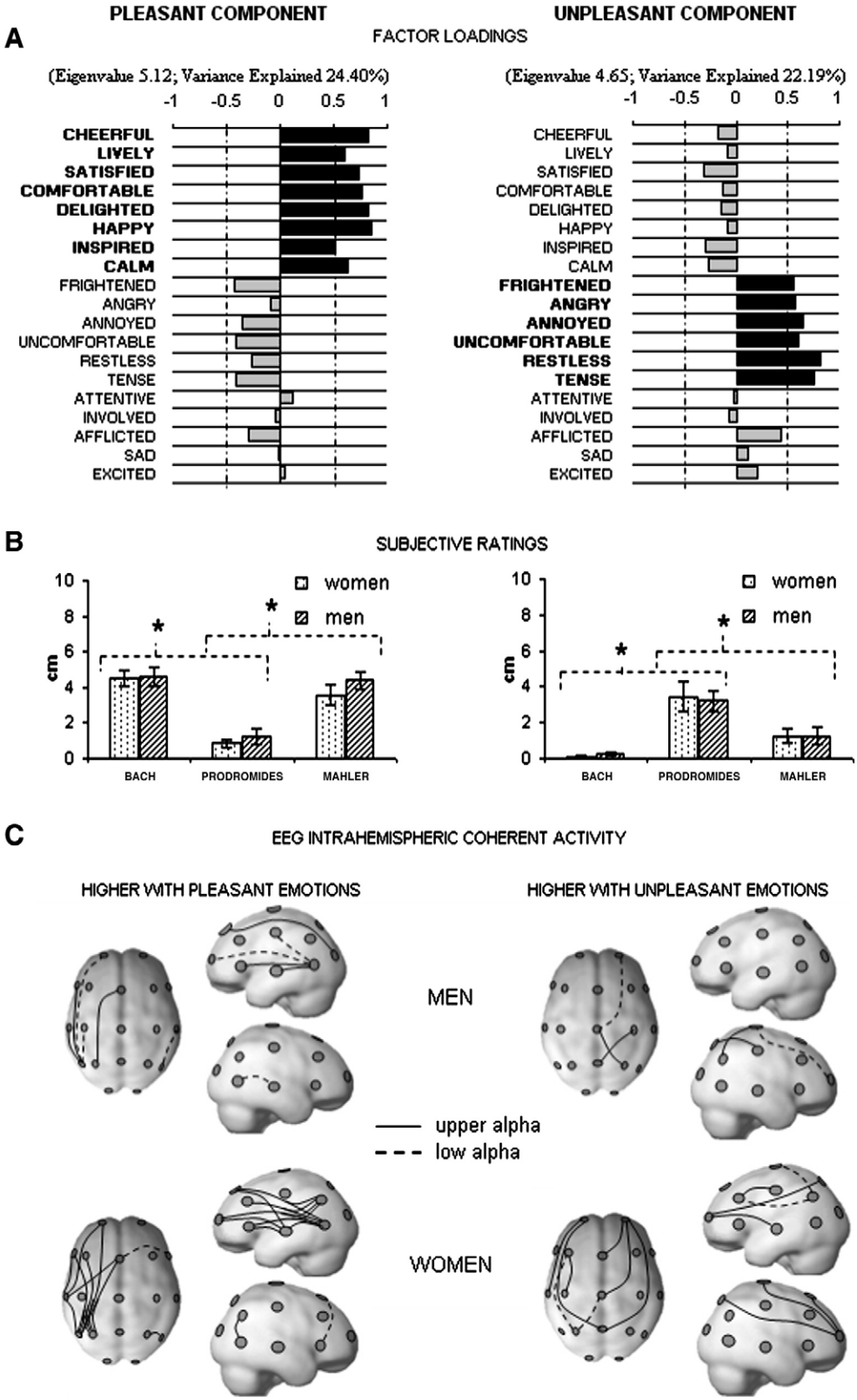

Fig. 1. Intrahemispheric coherent activity in reference to pleasant (left) and unpleasant (right) musical emotions. A: Factor Loadings of emotional adjectives evaluating the subjective effects of music excerpts gathered in a first "pleasant" component and a second "unpleasant" component yielded by Principal Component Analysis (bold capital letters) and vertical dashed lines indicate factor loading = ±0.5. B: Bars represent rating means (±SE) of the 8 pleasant adjectives (left) and 6 unpleasant adjectives (right), elicited by the three musical excerpts in men and women. Asterisks and connecting dashed lines indicate post-hoc significant differences among musical pieces. C. Intrahemispheric coherent activity in low (dotted lines) and upper alpha bands (full lines). Lines connecting electrodes indicate significantly ($p < 0.005$) higher coherent EEG activity with pleasant emotions in the left and unpleasant emotions in the right (see Table 1 for corresponding frequencies and significant level). The location of the electrodes in the surface of the average brain used the Okamoto et al. (2004) distribution.

Please cite this article as: Flores-Gutiérrez, E.O., et al., Differential alpha coherence hemispheric patterns in men and women during pleasant and unpleasant musical emotions, Int. J. Psychophysiol. (2008), doi:10.1016/j.ijpsycho.2008.07.007

Fig. 1B illustrates the mean positive and negative scales, in which statistical comparison corresponds to the component scores. Since there were no significant differences between Bach and Mahler in pleasant/unpleasant components, it was justified to relate coherent activity patterns with pleasant emotion in both pieces. The only subjective score in which Bach and Mahler differed was in the activation component adjectives. Post-hoc comparisons showed that the feeling of being excited was higher for Mahler and Prodromidès than by Bach, and equal for Mahler and Prodromidès. Thus, the few significant differences in coherent activity found between Bach and Mahler can be related to the level of subjective emotional activation but not to hedonic value.

3.2. Pleasant (happy) compared to unpleasant (fear) music emotions

Fig. 1C illustrates the significant EEG results for pleasant compared to unpleasant music emotions, with the probability level for each significant frequency shown in Table 1. Higher coherent oscillations were found with pleasant musical emotions compared to unpleasant ones in both men and women among left hemisphere regions (Fig. 1C, left side). The coherent oscillations found between T5 and F7 and between T5 and T3 at upper alpha frequencies were the only common and significant correlations found in both sexes. Coherent activity was higher with pleasant emotions between T5 and C3, between T5 and Fp1, and between frontal midline and left occipital areas in men. Coherent regions were distinctly more abundant in women during both pleasant musical emotions linking all frontal electrodes with anterior temporal, posterior temporal and parietal sites. Right hemisphere coherent oscillations between anterior midline and right lateral frontal area at slow alpha frequencies and between right posterior temporal and parietal regions at upper alpha frequencies were seen in women and between anterior and posterior temporal electrodes in men. Coherent oscillations lower with pleasant emotions and thus higher with unpleasant ones were very few (Fig. 1C, right side). In men they were found only in the right hemisphere between the midcentral electrode with the right frontopolar and right parietal electrodes, and between posterior midline and right central areas. In women coherent oscillations were bilateral, between left prefrontal, left temporal, and posterior midline, between right prefrontal and the midline, and between left frontal, central, and parietal localities.

3.3. Relaxing-pleasant compared to rousing-pleasant emotions

Only a few significant differences between Bach (pleasant and relaxing piece) and Mahler (pleasant and rousing piece) were found. The coherent activity was higher with rousing-pleasant emotions between T3 and Fp1, between T3 and C3 and Cz, and between C3 and Cz at slow alpha frequencies in women. In contrast, coherent activity was higher with relaxing pleasant emotions between right frontal areas and between right prefrontal areas and central and posterior midline in men (Table 1).

3.4. Composite music effects

Regardless of their hedonic and activation effects, the three pieces of music analyzed together against all three sections of noise modified coherent activity in a different way than that related to emotion (Table 1, Fig. 2). The EEG effects of the three music scores in both men and women increased local functional coupling bilaterally among posterior regions and between left anterior and posterior areas. Temporal electrodes were involved in both hemispheres. Coherent regions were more numerous in the left than in the right hemisphere particularly in women where uniform oscillations involved mainly the anterior temporal electrode (T3) with posterior regions.

The coherent oscillations in the right hemisphere involved only posterior regions, especially in men. A difference in coherent frequencies

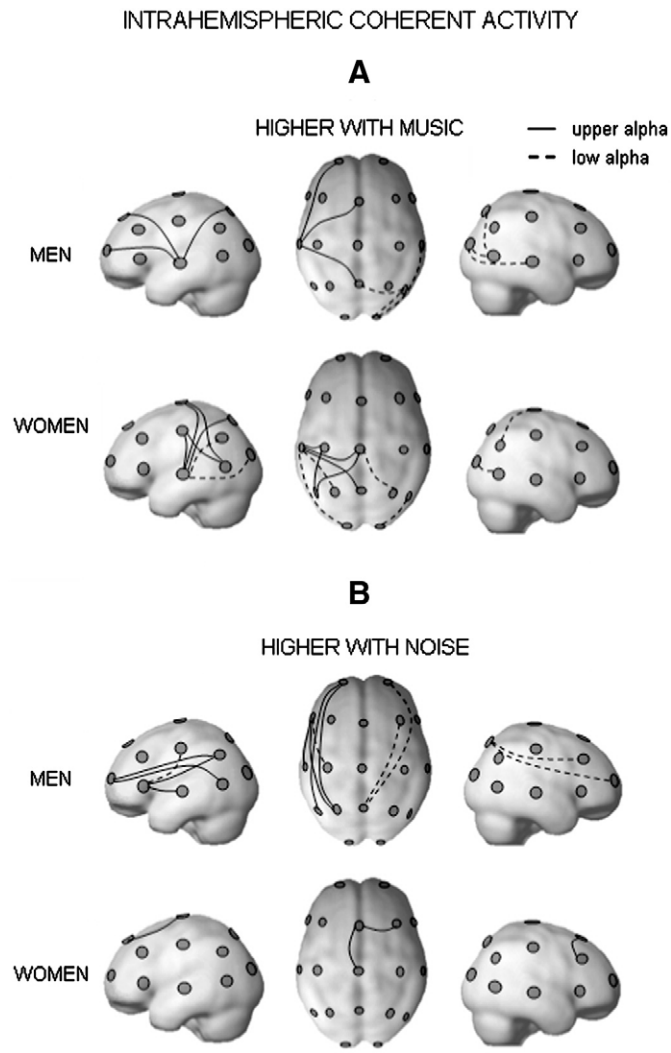

Fig. 2. Intrahemispheric coherent activity during music and noise. For further description see legend of Fig. 1.

was evident between left and right hemisphere during music versus noise listening: coherent oscillations in the right hemisphere were in the low alpha frequencies, while in the left were in upper alpha frequencies in both men and women. Only women showed higher coherent activity in the low alpha frequencies in the left hemisphere. Long functional coupling was lower with combined music as compared to noise between anterior prefrontal and posterior areas of the left hemisphere, and between posterior midline and anterior frontal areas bilaterally in men. Higher functional coupling with noise than with music were only seen in women among anterior midline and right central areas.

4. Discussion

The present correlation analyses within the alpha frequency range revealed gender differences in the patterns of functional coupling between brain regions associated to subjective pleasant and unpleasant music emotions. The significantly increased or decreased relationship among brain sites was obtained from an average of at least 154 s per subject per condition providing a robust measure of their involvement in specific emotions. The different coherent patterns obtained between men and women among cortical regions add new information of the functional organization involved in such emotions and in the perceptual processing of music. Pleasant emotions were sustained by coherent oscillations in the left hemisphere in both sexes, particularly by a larger network in women. Unpleasant emotions were supported by an

Please cite this article as: Flores-Gutiérrez, E.O., et al., Differential alpha coherence hemispheric patterns in men and women during pleasant and unpleasant musical emotions, Int. J. Psychophysiol. (2008), doi:10.1016/j.ijpsycho.2008.07.007

increased coherent activity between midline and posterior regions in the right hemisphere in men and by bilateral networks engaging anterior regions in women. A noticeably larger network of coherent activity with pleasant musical emotion in women as compared to men linked all frontal regions with the left anterior temporal and posterior parieto-temporal association areas, particularly in electrodes close to the prefrontal and cingulate gyri. Such an increased coherent activity between paralimbic frontal and posterior temporo-parietal association areas suggests a functional interaction mediating emotional and perceptual integration. A wider network during musical pleasant emotions in women is consistent with results obtained with metabolic images for other emotions (Bremner et al., 2001; Canli et al., 2002) and greater positive female attributions to music (Altenmüller et al., 2002). The participation of prefrontal and anterior cingulate cortex in women emotions is also supported by neuroimaging studies showing larger anatomical areas (Goldstein et al., 2001; Gur et al., 2002) and greater metabolic activations of these sites (Andreason et al., 1994; Gur et al., 1995).

A significant dissociation in the left and right hemisphere participation during pleasant and unpleasant musical emotions in men and women was observed. Pleasant emotions are sustained by different left hemisphere loops and unpleasant emotions by a bilateral network in women, whereas in men the left hemisphere participates in pleasant emotions and the right in unpleasant emotions. The predominantly bilateral participation in women and the right one in men is consistent with neuroimaging results during recognition of facial expressions (Killgore and Yurgelun-Todd, 2001), remembered unpleasant emotions (Canli et al., 2002) or arousing pictures (Cahill et al., 2004; Schienle et al., 2005). The bilateral generalization in women may be related to their greater susceptibility to be filled by emotion, and agrees with their lower hemispheric specialization (McGlone, 1986) and higher interhemispheric coherent activity (Corsi-Cabrera et al., 1993) in relation to men.

The EEG response to the three combined musical pieces compared to noise allowed the neutralization of emotionally factors in favour of general and perceptual aspects. The resulting coherent activity was very different for positive and negative emotions. Whereas pleasant emotions coupled left temporal areas with frontal regions, combined music listening compared to noise induced bilateral local coherent oscillations predominately between temporal electrodes with posterior regions, and among posterior sensory and association areas, more numerous in the left than in the right hemisphere in women. Increased coherent oscillations among posterior areas regardless of the affective valence suggest that functional interactions among association areas are important for the early or sensory stage of the auditory information processing.

In addition and at the same time, music disrupted coherent oscillations between left anterior association areas with left parietal and occipital areas in men, and between midline and anterior regions in women. Since these areas are an important part of attention systems (Posner and Raichle, 1994), the disruption of coherent oscillations with music as compared to noise may be due to attention-demanding stimuli. As frontal areas are involved in attention, working memory, and emotional functions, it could be expected that frontal electrodes become linked in music conditions to more anterior for emotions and more posterior regions for perceptual processing.

Unpleasant emotions and unspecific musical effects were accompanied by coherent activity in slow alpha oscillations, which are involved in unspecific attention and arousing processes (Klimesch, 1999). The right hemisphere responds more to the combined music vs. noise in lower alpha coherence and the left more in higher alpha coherence. This result is consistent with right hemisphere predominance for dealing with novel cognitive situations and the left hemisphere for predictable cognitive processes, such as language (Podell et al., 2001). The combined music vs. noise effects include significantly increased coherent activity changes in the frequency range of upper alpha activity in women and of low alpha activity in men. Since the upper alpha band is related to working memory and the low alpha band to attention (Klimesch, 1999), one possibility is that music processing involves more working memory mechanisms in women and more selective attention in men.

Coherent activity derived from scalp recordings may be inflated by common input to the electrodes and volume current conduction (Nunez et al., 2001). Since the aim of the present study was to determine changes in EEG temporal coupling in accord to subjective musical emotion, and not differences between derivations, comparisons were done only among conditions. This approach keeps constant frequency bin and electrode pair minimizing the effect introduced by the reference electrodes. Therefore, the changes among experimental conditions may be safely attributed to subjective musical emotions and not to volume conduction effects.

The fact that men show less significant differences than women may imply more subcortical involvement in men and more cortical involvement in women. Another possibility concerns a ceiling effect in men derived from the fact that they show greater intrahemispheric correlation than women (Corsi-Cabrera et al., 1993). Kemp et al. (2004) also reported more widespread and right sided activation in women during the processing of unpleasant visual stimuli particularly within the frontal regions.

The relatively small sample used in this study calls for further confirmation of the sexual differences in musical emotion that may throw light both in the coherent areas and EEG frequencies involved. Nevertheless, these results do indicate that in addition to specific regional activation reported in EEG and metabolic imaging studies (Koelsch et al., 2006; Flores-Gutiérrez et al., 2007), musical emotion entails particular interchanges among cortical regions. Moreover, different regional couplings intervene for positive or pleasant and negative or unpleasant emotions. Musical emotion entails a coherent alpha activity between posterior association areas and frontal regions, predominantly left for pleasant emotions in both men and women. In contrast, the combined and unspecific musical effects that neutralize musical emotion engage posterior association regions. The coherent network is larger in women, both for musical emotion and emotionally unspecific effects. The present results suggest that men and women should not be analyzed together in neurobiological studies of emotion, particularly those involving musical stimuli.

Acknowledgments

Enrique O. Flores-Gutiérrez was supported by a graduate fellowship by the Mexican *Consejo Nacional de Ciencia y Tecnología* (CONACYT) and by Universidad Nacional Autónoma de México DGEP (UNAM). The work was partially supported by grants from DGAPA IN214702-3 (UNAM). The authors wish to thank Fernando Salinas Iñiguez, for the technical assistance in the interface for music recording in the EEG polygraph.

References

Altenmüller, E.O., Shurman, K., Lim, V.K., Parlitz, D., 2002. Hits to the left, flops to the right: different emotions during listening to music are reflected in cortical lateralization patterns. Neuropsychologia 40, 2242–2256.

Andreason, P.J., Zametkin, A.J., Guo, A.C., Baldwin, P., Cohen, R.M., 1994. Gender-related differences in regional cerebral glucose metabolism in normal volunteers. Psychiatry. Res. 51, 175–183.

Azari, N.P., Pettigrew, K.D., Pietrini, P., Murphy, D.G., Horwitz, B., Schapiro, M.B., 1995. Sex differences in patterns of hemispheric cerebral metabolism: a multiple regression/discriminant analysis of positron emission tomographic data. Int. J. Neurosci. 81, 1–20.

Bremner, J.D., Soufer, R., McCarthy, G., Delaney, R., Staib, L.H., Duncan, J.S., Charney, D.S., 2001. Gender differences in cognitive and neural correlates of remembrance of emotional words. Psychopharmacol. Bull. 35, 55–78.

Cahill, L., Uncapher, M., Kilpatrick, L., Alkire, M.T., Turner, J., 2004. Sex-related hemispheric lateralization of amygdale function in emotionally influenced memory: an fMRI investigation. Learn. Mem. 11, 261–266.

Canli, T., Desmond, J.E., Zhao, Z., Gabriela, J.D., 2002. Sex differences in the neural basis of emotional memories. Proc. Natl. Acad. Sci. U. S. A. 99, 10789–10794.
Christensen, P.G., Peterson, J.B., 1988. Genre and gender in the structure of music preferences. Communic. Res. 15, 282–301.
Corsi-Cabrera, M., Ramos, J., Guevara, M.A., Arce, C., Guriérrez, S., 1993. Gender difference in the EEG during cognitive activity. Int. J. Neurosci. 72, 257–264.
Davidson, R.J., Irwin, W., 1999. The functional neuroanatomy of emotion and affective style. Trends. Cogn. Sci. 3, 11–21.
Díaz, J.L., Flores-Gutiérrez, E., 2001. La estructura de la emoción humana: un modelo cromático del sistema afectivo. Salud Ment. 24, 20–35.
Flores-Gutiérrez, E.O., 2001. La respuesta emocional a la música: atribución de términos de la emoción a segmentos musicales. Thesis for Master in Neurobiology. México, DF, Universidad Nacional Autónoma de México.
Flores-Gutierrez, E.O., Díaz, J.L., Barrios, F.A., Favila-Humara, R., Guevara, M.A., del Río-Portilla, Y., Corsi-Cabrera, M., 2007. The metabolic and electric brain patterns during pleasant and unpleasant emotion induced by music masterpieces. Int. J. Psychophysiol. 65, 69–84.
Goldstein, J.M., Seidman, L.J., Horton, N.J., Makris, N., Kennedy, D.N., Caviness, V.S., Faraone, S.V., Tsuang, M.T., 2001. Normal sexual dimorphism of the adult human brain assessed by in vivo magnetic resonance imaging. Cereb. Cortex. 11, 490–497.
Guevara, M.A., Ramos, J., Hernández-González, M., Zarabozo, D., Corsi-Cabrera, M., 2002. POTENCOR: a program to calculate power and correlation spectra of EEG signals. Comput. Methods. Programs. Biomed. 72, 241–250.
Gur, R.C., Mozley, L.H., Mozley, P.D., Resnick, S.M., Karp, J.S., Alavi, A., Arnold, S.E., Gur, R.E., 1995. Sex differences in regional cerebral glucose metabolism during a resting state. Science 267, 528–531.
Gur, R.C., Gunning-Dixon, F., Bilker, W.B., Gur, R.E., 2002. Sex differences in temporo-limbic and frontal brain volumes of healthy adults. Cereb. Cortex. 12, 998–1003.
Hall, J., 1978. Nonverbal Sex Differences: Communication Accuracy and Expressive Style. Johns Hopkins University Press, Baltimore.
Kemp, A.H., Silberstein, R.B., Armstrong, S.M., Nathan, P.J., 2004. Gender differences in the cortical electrophysiological processing of visual emotional stimuli. NeuroImage 21, 632–646.
Killgore, W.D., Yurgelun-Todd, D.A., 2001. Sex differences in amygdala activation during the perception of facial affect. NeuroReport 12, 2543–2547.
Klimesch, W., 1999. EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brains. Res. Rev. 29, 169–195.
Koelsch, S., Maess, B., Grossmann, T., Friederici, A.D., 2003. Electric brain responses reveal gender differences in music processing. NeuroReport 14, 709–713.
Koelsch, S., Fritz, T.V., Cramon, D.Y., Müller, K., Friederici, A.D., 2006. Investigating emotion with music: an fMRI study. Hum. Brain Mapp. 27, 239–250.
Lee, T.M., Liu, H.L., Hoosain, R., Liao, W.T., Wu, C.T., Yuen, K.S., Chan, C.C., Fox, P.T., Gao, J.H., 2002. Gender differences in neural correlates of recognition of happy and sad faces in humans assessed by functional magnetic resonance imaging. Neurosci. Lett. 333, 13–16.
Lehtelä, L., Salmelin, R., Hari, R., 1997. Evidence for reactive magnetic 10 Hz rhythm in the human auditory cortex. Neurosci. Lett. 222, 111–114.
Mandal, M.K., Palchoudhury, S., 1985. Perceptual skills in decoding facial affect. Percept. Mot. Skills. 60, 96–98.
McGlone, J., 1986. The neuropsychology of sex differences in human brain organization. In: Goldstein, G., Tarter, R. (Eds.), Advances in Clinical Neuropsychology. Plenum Press, New York, pp. 1–30.
Nunez, P.L., Wingeier, B.M., Silberstein, R.B., 2001. Spatial–temporal structures of human alpha rhythms: theory, microcurrent sources, multiscale measurements and global binding of local networks. Hum. Brain. Mapp. 13, 125–164.
Okamoto, M., Dan, H., Sakamoto, K., Tadeo, K., Shimizu, K., Cono, S., Oda, I., Isobe, S., Suzuki, T., Johyama, K., Dan, I., 2004. Three-dimensional probabilistic anatomical cranio-cerebral correlation via the international 10–20 system oriented for transcranial functional brain mapping. NeuroImage 21, 99–111.
Podell, K., Lovell, M., Goldberg, E., 2001. Lateralization of frontal lobe functions. In: Salloway, S.P., Malloy, P.F., Duffy, J.D. (Eds.), The Frontal Lobes and Neuropsyhiatric Illness. American Psychiatric Publishing, London, pp. 83–99.
Posner, M.I., Raichle, M.E., 1994. Images of Mind. Freeman, New York.
Ramos, J., Guevara, M.A., Martínez, A., Arce, C., del Río-Portilla, Y., Amezcua, C., Corsi-Cabrera, M., 1996. Evaluación de los estados afectivos provocados por la música. Rev. Mex. Psicol. 13, 131–145.
Rappelsberger, P., Petsche, H., 1988. Probability mapping: power and coherence analyses of cognitive processes. Brain. Topogr. 1, 46–54.
Schienle, A., Schafer, A., Stark, R., Walter, B., Vaitl, D., 2005. Gender differences in the processing of disgust- and fear-inducing pictures: an fMRI study. NeuroReport 16, 277–280.
Schirmer, A., Kotz, S.A., 2003. ERP evidence for a sex-specific Stroop effect in emotional speech. J. Cogn. Neurosci. 15, 1135–1148.
Wager, T.D., Phan, K.L., Liberzon, I., Taylor, S.F., 2003. Valence, gender, and lateralization of functional brain anatomy in emotion: a meta-analysis of findings from neuroimaging. NeuroImage 19, 513–531.

Please cite this article as: Flores-Gutiérrez, E.O., et al., Differential alpha coherence hemispheric patterns in men and women during pleasant and unpleasant musical emotions, Int. J. Psychophysiol. (2008), doi:10.1016/j.ijpsycho.2008.07.007