Gender Event-related Brain Oscillatory Differences in Normal Elderly Population EEG

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Abstract: In most of the scientific publications the data on gender related EEG differences is connected to exploration of disease or abuse-related changes and so takes the gender only as a cofactor. Although no one argues the fact, that gender is one of the greatest factors, influencing EEG results, there is a small number of papers discussing predominantly the gender influence on EEG. That is why the aim of this work is to try to examine the event-related oscillatory differences between a group of male and female individuals being a part of the normal elderly population. We calculated the Event-Related Potentials (ERPs) in time domain, the absolute Fourier power spectrum and S-transform for time-frequency analysis. The reaction times to auditory target stimuli were also calculated and compared. As a result of the present study we found that our female individuals have shown a significantly larger absolute theta and beta1 spectral power compared to male and having a larger N1 and higher P2 event-related potential components. In contrast to these, the male individuals have shown a stronger theta to beta coupling compared to the female individuals.

Keywords: Gender related EEG differences, Event-related potentials, EEG, Brain oscillatory activity.

Introduction

The problem concerning psycho-physiological differences between male and female perception and information processing is well known and investigated in scientific literature. Many authors examined the gender differences in anatomical and functional level of male and female brain, which lead to many speculations but also to many facts concerning brain size Sowell et al. [32], neuronal number Rabinowicz et al. [26], [27], cortical thickness Luders et al. [18], Sowell et al. [32], the size of dendrite tree Barrera et al. [2] and number of the synapses Alonso-Nanclares et al. [1]. In conformity with the fact that normal males and females perform comparably on intelligence tests, many studies demonstrate sex related dimorphism for cognitive abilities presented in different types of mental tasks Wegesin [36]. For example the males have advantage concerning spatial abilities Jones et al. [14] while a

female advantage has been noted for verbal abilities like verbal fluency and verbal memory Sommer [31]. Psycho-physiological differences between male and female perception and information processing are also described in cases when TV advertisements are the stimuli. Although TV advertisements contain numerous and diverse stimuli, all conducted psycho-physiological research show differences in the ways the male and female brain functions Brunel & Nelson [5], Fisher & Dube [12], Putrevu [25]. The gender related brain differences have also their impact on the electroencephalographic (EEG) brain oscillations. The most impressive work with a huge number of subjects (1416 subjects) related to gender EEG frequency differences was the work of Matsuura et al. [19]. The authors found increased beta and theta activity in female compared to male individuals. Other authors also reported increased beta and theta spectral power for women and increased alpha spectral power for men Brenner & Reynolds [3], Veldhuizen et al. [35]. Carrier et al. [6] found clear differences between sexes, and showed that there was a higher power density in female for the delta, theta, low alpha, and also high spindle frequency range compared to male. By examination of sex effects on sleep stages and EEG spectral power in older adults it was found that absolute values of delta and alpha activities in non-rapid eye movement and rapid eye movement sleep were higher in women than in men Latta et al. [16]. In contrast – in EEG recordings during slow wave sleep Nissen et al. [38] didn't find significant differences in the average power spectrum between men and women. It was found that the mean alpha frequency was significantly larger for female compared to male Deakin & Exley [9]. The greatest part of scientific data report increased theta and beta and decreased alpha EEG activity for female compared to male individuals Brenner & Reynolds [3], Veldhuizen et al. [35]. There is evidence of sex related differences in brain hemisphere lateralisation. In conditions with cognitive tasks arranged in different levels of difficulty such as simple counting task, and more complex tasks as addition and multiplication, an interaction between gender and task difficulty was found. The males have relatively higher left-hemispheric activation in difficult and middle-difficult task conditions while the females have relatively left-hemispheric lateralization in simpler task conditions Earle & Pickus [11]. The gender related brain differences were demonstrated also in Event-Related potentials (ERPs) paradigms. There is data supporting the idea that males and females differ in emotional stimuli processing. The gender difference was related to the processing of unpleasant images (relative to neutral images) which is associated with widespread frontal ERP latency reductions (predominantly right sided) in females but not in males Kemp et al. [15]. According to literature data the fronto-central P2 component was less positive and N2 ERP component was more negative in males compared to females Nagy et al. [21]. Ditraglia & Polich [10] reported an increase of P3 amplitude for female individuals in oddball auditory task. Yuan et al. [37] reported that females generated higher amplitude and shorter latencies for P2, N2, and P3 components for the deviant tone. In studies about the effect of gender with appropriately designed paradigm for sensory and cognitive information processing in children it was found, that regardless of task engagement, the amplitudes of ERP components (N1, P2, N2 and P3) were increased for girls only. On the other hand in the spontaneous EEG activity of the same group increased theta activity was observed in girls compared to boys Nanova et al. [22]. Electrophysiological studies of sex differences in language processing revealed earlier and larger N400 in women and larger late positive complex in men Daltrozzo et al. [8].

In most part of scientific literature which provides data on gender related EEG differences the main aim is to explore disease or abuse-related changes and so takes the gender only as a cofactor. Although no one argues the fact, that gender is one of the greatest factors, influencing the EEG results there are a small number of papers discussing predominantly the gender influence on EEG. That's why this problem needs further research. The aim of this

work is to examine the event-related oscillatory differences between a group of male and female individuals in normal elderly population.

Materials and methods

The EEG activity of 71 (35 male and 36 female) healthy volunteers was recorded in auditory mental and sensory-motor task conditions. The subjects were right-handed and between 18 and 50 years old (mean age for male 27.9 with standard deviation 6.2 years and for female 29.4 with standard deviation 8.6 years). An electroencephalogram (bandpass filtered between 0.3-70 Hz) was recorded from Fz, Cz, Pz, C3' and C4', using Ag/AgCl "Nihon-Kohden" electrodes with reference to both processi mastoidei, according to international 10-20 system. An electrode placed on the forehead served as ground. For stimulation we used four equal audio series. Each series was composed of 100 tones arranged in pseudo randomized order of 50 low (800 Hz) and 50 high (1000 Hz) tones with an intensity of 60 dB, duration 50 ms.

The audio stimulation sequence was generated randomly at the beginning of the experimental project and stayed the same by all of the researched volunteers. The same stimulus configuration was used in all task conditions to avoid the EEG differences based on the series structure among volunteers. Only the interstimuli intervals were randomly generated to fit in 2.5-3.5 s time-window. These intervals were different for each couple of tones, experimental series and volunteer. The random generated stimuli series was difficult to be memorized and the subjective perception of the participants was that there are four different audio stimulation series. We changed the type of task by giving different instructions to participants as follows: first (passive listening (PL)) – we instructed the volunteers to listen to the tone series without any task or mental effort; second repetition (binary sensory-motor reaction task (BSMT)) – we instructed the volunteers to press a button of force transducer with their right or left index finger in response to low or high tones respectively. In this task condition we gave the instruction that it is desirable to respond as fast as possible but to avoid making mistakes; third repetition (counting the low tones (CLT)) – we instructed the participants to count the low tones and at the end of the stimulation series we asked about the counted number of the low tones; forth repetition (reacting to the low tones (RLT)) – we instructed the volunteers to press a button of force transducer with their right index finger in response to low tones. In this task condition we gave the instruction that it is desirable to respond as fast as possible but to avoid making mistakes. To avoid blink and to reduce other eye based artifacts, the EEG recording was performed with eyes closed condition in all tasks. For each experimental condition we collected 100 trials with 2 s duration – 0.5 s before and 1.5 s after stimulus presentation. The EEG recording sampling rate was 1000 Hz for better time-frequency resolution of the explored ERP components.

Offline processing

In offline mode after the end of the experiment we inspected manually the recordings and for further analysis only the artefact free trials were left. The trials related to wrong reaction responses in second and fourth task condition where also rejected, to avoid EEG epochs contamination with error related negativity, which appears after wrong motor responses. We calculated the Event-Related Potentials (ERPs) for each person, experimental condition, stimulus (high and low) and electrode position separately. The latencies and amplitudes of N1, P2, N2 and P3 ERP components where set manually. We calculated the Fast Fourier Transformation (FFT) for each trial in time window from 0 to 500 ms after the auditory stimulus presentation and then averaged the FFT power spectra for each person, experimental condition, stimulus and electrode position separately. For further statistical analysis we used

the power spectra area under the different frequency bands. We defined the frequency bands as follows: delta 0.5-3.5 Hz, theta 4-7.5 Hz, alpha1 8-9.5 Hz, alpha2 10.5-12 Hz, beta 1 12.5-22.5 and beta 2 23-32 Hz Chen et al. [7]. The onset of movement response (OMR) and moment of maximal push response force (MPF) to auditory target stimuli was also calculated and compared. Both OMR and MPF time moments were registered as experimentally compared voltage levels obtained from a piezo plate force transducer (provided by the Universität der Bundeswehr München in the framework of the NSF L1413 research project partnership), keeping track of the sensor's dynamic voltage/time characteristic. We used the Mann-Whitney U-test for statistical analysis of gender related ERP components changes, spectral and reaction time differences. To trace the spectral changes in the time course before and after the stimuli presentation we used the S-transform Stockwell [33]. We calculated the S-transform for all trials and then averaged the time-frequency matrixes for each person, experimental condition, stimulus and electrode position separately. For statistical comparison of the time-frequency matrixes between male and female groups we used the Kruskall-Wallis test. All offline mathematical data processing was accomplished in MathWorks MatLab® 6.5.

Results

Reaction time: There were no significant differences between male and female individuals according the onset of the motor response and the moment of maximal push force. However the time interval between the onset of motor response and the moment of maximal push force was significantly shorter for male compared to female individuals. The exact reaction time values are presented in Table 1.

Table 1. The mean values and standard deviations of onset of motor response, moment of maximal push force and the difference between MPF and OMR for male and female individuals

Left hand	Male [ms]	Female [ms]	U	p-level
Onset of motor response (OMR)	420 ± 73	449 ± 75	494.0	0.083
Moment of maximal push force (MPF)	648 ± 164	725 ± 170	480.0	0.058
MPF-OMR	228 ± 120	277 ± 113	456.0	0.031

Right hand	Male [ms]	Female [ms]	U	p-level
Onset of motor response (OMR)	432 ± 72	452 ± 71	531.0	0.188
Moment of maximal push force (MPF)	653 ± 149	723 ± 151	479.0	0.057
MPF-OMR	221 ± 97	270 ± 98	446.0	0.023

ERP components

Passive listening condition: The amplitude of N1 ERP component was more negative for females compared to males. This difference was significant in Cz (U = 242.0; p = 0.009) and Pz (U = 221.0; p = 0.003) for the high tone and Pz (U = 261.0; p = 0.021) electrode position for the low tone. The female participants have also significantly larger P2 amplitudes in Fz (U = 206.0; p = 0.001), Cz (U = 196.0; p = 0.001), Pz (U = 173.0; p = 0.000), C3' (U = 210.0; p = 0.002), C4' (U = 196.0; p = 0.001) for low tone and in Fz (U = 196.0; p = 0.001), Cz (U = 191.0; p = 0.001), Pz (U = 180.0; p = 0.000), C3' (U = 158.0; p = 0.000), C4' (U = 193.0; p = 0.001) for high tone. Female individuals have shorter N1 latencies compared to male in Fz (U = 349.5, p = 0.004), Cz (U = 363.5, p = 0.008), C3' (U = 338.5, p = 0.003) for the high tone and Fz (U = 261.0, p = 0.020), C4' (U = 273.5, p = 0.035) for the low tone. The averaged ERPs for male and female groups in PL condition are shown in Fig. 1A.

Reacting to high and low tones: In binary sensory-motor reaction task condition female individuals wave significantly larger P2 amplitudes in Fz (U = 163; p = 0.0001), Cz (U = 139, p = 0.0001), Pz (U = 147, p = 0.0001), C3' (U = 131, p = 0.0001) and C4' (U = 171, p = 0.0001) recordings for low and in Fz (U = 160, p = 0.0001), Cz (U = 171, p = 0.0001), Pz (U = 183, p = 0.0001), C3' (U = 165, p = 0.0001) and C4' (U = 185, p = 0.0001) for the high tone in comparison to males. In this task condition the N2 component amplitude was more negative in males compared to females. This difference was significant in Fz (U = 243, p = 0.015), Cz (U = 260, p = 0.031), C3' (U = 244, p = 0.015) and C4' (U = 267, p = 0.041) recordings in response only for low tone. Female individuals have shorter N1 latencies compared to male in Fz (U = 208.0, p = 0.001), Cz (U = 189.5, p = 0.0005), C3' (U = 189.0, p = 0.0005), C4' (U = 245.5, p = 0.010) for the low tone and in Fz (U = 221.5, p = 0.003), Cz (U = 220.0, p = 0.003), Pz (U = 260.5, p = 0.020), C3' (U = 187.0, p = 0.0004), C4' (U = 224.0, p = 0.003) for the high tone. The male individuals have shorter N2 latencies compared to female in Cz (U = 257.0, p = 0.01) and Pz (U = 225.0, p = 0.004) for the low tone and in Fz (U = 256.0, p = 0.017), Cz (U = 230.0, p = 0.005), Pz (U = 170.0, p = 0.0001) and C4' (U = 280.5, p = 0.046) for the high tone. The female individuals have shorter P3 latencies compared to male in Fz (U = 211.5, p = 0.0019), Cz (U = 239.5, p = 0.008), C3' (U = 244.0, p = 0.01), C4' (U = 237.5, p = 0.007) for the low tone and in C4' (U = 263.0, p = 0.023) for the high tone. The averaged ERPs for male and female groups in BSMT condition are shown in Fig. 1B.

Counting the low tone task condition: In counting the low tone task condition the female P2 amplitude was significantly larger in Fz (U = 269, p = 0.005), Cz (U = 266, p = 0.004), Pz (U = 284, p = 0.009), C3' (U = 262, p = 0.003) and C4' (U = 279, p = 0.007) recordings for the low (target) tone and in Fz (U = 171.5, p = 0.0001), Cz (U = 167.5, p = 0.0001), Pz (U = 213.5, p = 0.0001), C3' (U = 148.5, p = 0.0001) and C4' (U = 185.5, p = 0.0001) recordings for the high (non-target) tone. For the low (target) tone females have also significantly lager P3 amplitudes in Fz (U = 283, p = 0.009) and Pz (U = 318, p = 0.034) recordings compared to males. Female individuals have shorter N1 latencies compared to male in Fz (U = 220.5, p = 0.003), Cz (U = 240.0, p = 0.008), Pz (U = 281.0, p = 0.047), C3' (U = 228.5, p = 0.004) and C4' (U = 257.0, p = 0.018) for the low (target) tone and in Fz (U = 386.5, p = 0.019), Cz (U = 375.5, p = 0.013), Pz (U = 373.0, p = 0.012), C3' (U = 317.5, p = 0.001) and C4' (U = 408.0, p = 0.037) for the high (non-target) tone. The female individuals have shorter P3 latencies compared to male in Pz (U = 260.5, p = 0.021), for the low (target) tone. The averaged ERPs for male and female groups in CLT condition are shown in Fig. 1C.

Reacting to low tone task condition: The ERP P2 amplitude was larger for females in Fz (U = 175.5, p = 0.008), Cz (U = 184.5, p = 0.001), Pz (U = 181.5, p = 0.001), C3' (U = 216.5, p = 0.004), C4' (U = 201.5, p = 0.002) recordings for the low (target) tone and in Fz (U = 168.5, p = 0.0001), Cz (U = 171.5, p = 0.0001), Pz (U = 172.5, p = 0.0001), C3' (U = 179.5, p = 0.0001), C4' (U = 179.5, p = 0.0001) for the high (non- target) tone compared to males. In this task condition the male subjects have larger P3 amplitude in Pz (U = 234.5, p = 0.04) recording for high no-target tone and in Fz (U = 137.5, p = 0.038) and Cz (U = 207.5, p = 0.042) recording for low target tone. Female individuals have shorter N1 latencies compared to male in Fz (U = 168.5, p = 0.0007), Cz (U = 171.5, p = 0.0008), Pz (U = 234.0, p = 0.024), C3' (U = 163.0, p = 0.0005) and C4' (U = 156.5, p = 0.0003) for the low (target) tone and in Fz (U = 185.5, p = 0.002), Cz (U = 192.5, p = 0.002), Pz (U = 249.5, p = 0.047), C3' (U = 176.5, p = 0.001) and C4' (U = 232.0, p = 0.022) for the high (non-target) tone. The male individuals have shorter N2 latencies compared to female in

Cz (U = 2369.0, p = 0.03) and Pz (U = 215.5, p = 0.01) for the low (target) tone and in Fz (U = 219.0, p = 0.012), Cz (U = 176.5, p = 0.001), Pz (U = 155.0, p = 0.0002), C3 (U = 171.5, p = 0.0008) and C4' (U = 231.0, p = 0.02) for the high tone. The females have shorter P3 latencies in C4' (U = 201.5, p = 0.0049) for the low (target) tone and in C4' (U = 223.0, p = 0.014) for the high (non-target) tone. The averaged ERPs for male and female groups in RLT condition are shown in Fig. 1D.
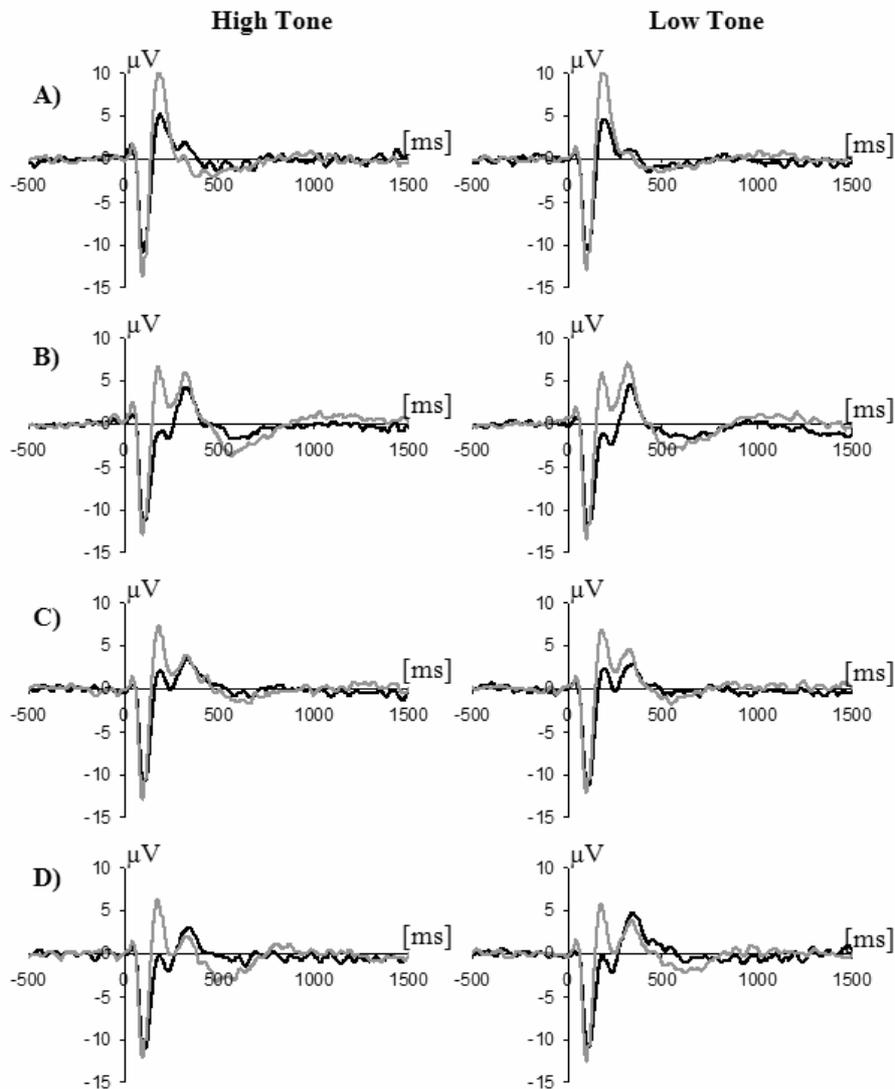
Fig.1 ERP differences: male (black), female (grey); A) ERPs from Cz electrode position in passive listening condition; B) ERPs from Cz electrode position in binary sensory-motor reaction task condition; C) ERPs from Cz electrode position in counting the low tone task condition; D) ERPs from Cz electrode position in reacting to the low tone task condition. The significant between group ERP amplitude and latency components differences are described in the text.

Frequency bands comparison

Passive listening condition: In passive listening condition the power spectrum was larger in females for theta frequency band and low tone in electrode positions Cz (U = 158.0, p = 0.002), Pz (U = 149.0, p = 0.001), C3' (U = 202.0, p = 0.021) and C4' (U = 200.0, p = 0.019) and in Cz (U = 158.0, p = 0.002), Pz (U = 148.0, p = 0.001), C3 (U = 203.0, p = 0.02), C4(U = 201, p = 0.02) for the high tone. The power spectra in beta1 frequency range was also significantly larger in females compared to males in Pz (U = 221, p = 0.052) electrode positions for low tones and in Pz (U = 224.0, p = 0.059) for the high tones. The power spectra in beta2 frequency range was also significantly larger in females compared to males in Pz (U = 224, p = 0.059) electrode positions for low tones and in Pz (U = 217, p = 0.043) for the high tones (Fig. 2A).

Reacting to high and low tones: The absolute power spectra for females was significantly larger in the theta frequency band in Cz (U = 202.0, p = 0.005), Pz (U = 177.0, p = 0.001), C3' (U = 229.0, p = 0.019), C4' (U = 226.0, p = 0.017) electrode positions for the low tone and in Cz (U = 214.0, p = 0.009), Pz (U = 178.0, p = 0.001), C3' (U = 224.0, p = 0.015), C4' (U = 226.0, p = 0.017) for the high tone. In this task condition the female individuals have also larger alpha1 power spectra in Cz (U = 229.0, p = 0.019), Pz (U = 218.0, p = 0.011) and C4' (U = 248.0, p = 0.045) electrode positions for low tone and in Cz (U = 214.0, p = 0.009), Pz (U = 178.0, p = 0.001) and C4' (U = 248.0, p = 0.045) for the high tone. The beta1 and beta2 power spectra were larger for females compared to males. For beta1 power spectrum this difference was significant in C4' (U = 246.0, p = 0.041) recordings for high tone and Pz (U = 238.0, p = 0.029) and C4 (U = 246.0, p = 0.041) recordings for low tone. The power spectrum in beta2 frequency band was significantly larger for females in Pz (U = 242.0, p = 0.035) for the low tone (Fig. 2B).

Counting the low tone task condition: Similar to both previous series the females generated significantly larger theta power spectra in Cz (U = 182.5, p = 0.002), Pz (U = 169.5, p = 0.001), C3' (U = 246.5, p = 0.041) and C4' (U = 214.5, p = 0.009) recordings for the low tone and in Cz (U = 220.5, p = 0.013), Pz (U = 225.5, p = 0.016), and C4' (U = 249.5, p = 0.047) for the high tone. The alpha1 power spectra was also significantly larger for females compared to males in Pz (U = 228.5, p = 0.019) recordings for the low (target) tone and in Cz (U = 232.5, p = 0.022), Pz (U = 238.5, p = 0.029) and C4' (U = 236.5, p = 0.027) for the high tone (Fig. 2C).

Reacting to low tone task condition: In the last task condition the female participants generated significantly larger absolute theta power spectra in Cz (U = 239.5, p = 0.020) and Pz (U = 23.5, p = 0.015) electrode positions for the low (target) tone and in Cz (U = 207.5, p = 0.004), Pz (U = 191.5, p = 0.002) and C4' (U = 245.5, p = 0.026) for the high (non-target) tone. The alpha1 power spectra was significantly larger for females compared to males in Cz (U = 234.5, p = 0.016), Pz (U = 228.5, p = 0.012) and C4' (U = 241.5, p = 0.022) recordings for the low (target) tones and in Cz (U = 239.5, p = 0.020), Pz (U = 224.5, p = 0.010) and C4' (U = 258.5, p = 0.044) for the high tone. The beta1 power spectra were significantly larger in females in Pz (U = 260.5, p = 0.048) recordings for the low tones compared to male individuals (Fig. 2D).
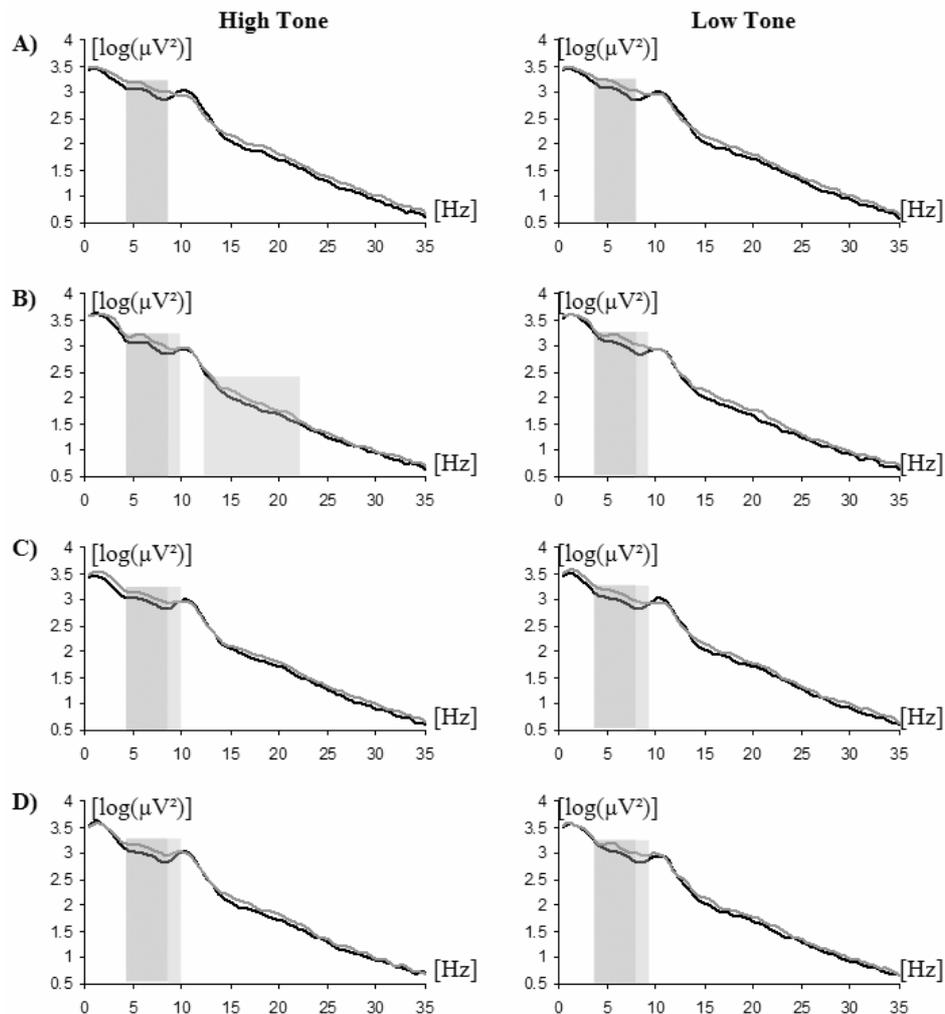
Fig. 2 FFT differences: male (black), female (grey); Fast Fourier Transformation (FFT) of time interval from 0 to 500 ms after the auditory stimuli presentation. For Cz electrode position the significant between group frequency band differences are marked with colored areas in the figure and the significant differences for the other electrode positions are described in the text; A) FFT of Cz electrode position in passive listening condition; B) FFT of Cz electrode position in binary sensory-motor reaction task condition; C) FFT of Cz electrode position in counting the low tone task condition; D) FFT of Cz electrode position in reacting to the low tone task condition.

Time-frequency analysis

The time-frequency analysis showed larger power spectrum for females compared to males in the delta, theta, alpha1, beta 1 and beta 2 frequency bands in all task conditions for both tones (target and non-target), but the differences were significant only in the theta and beta1 frequency bands. On Fig. 3 are shown only the graphics for Cz electrode position as most representative for the overall EEG activity.
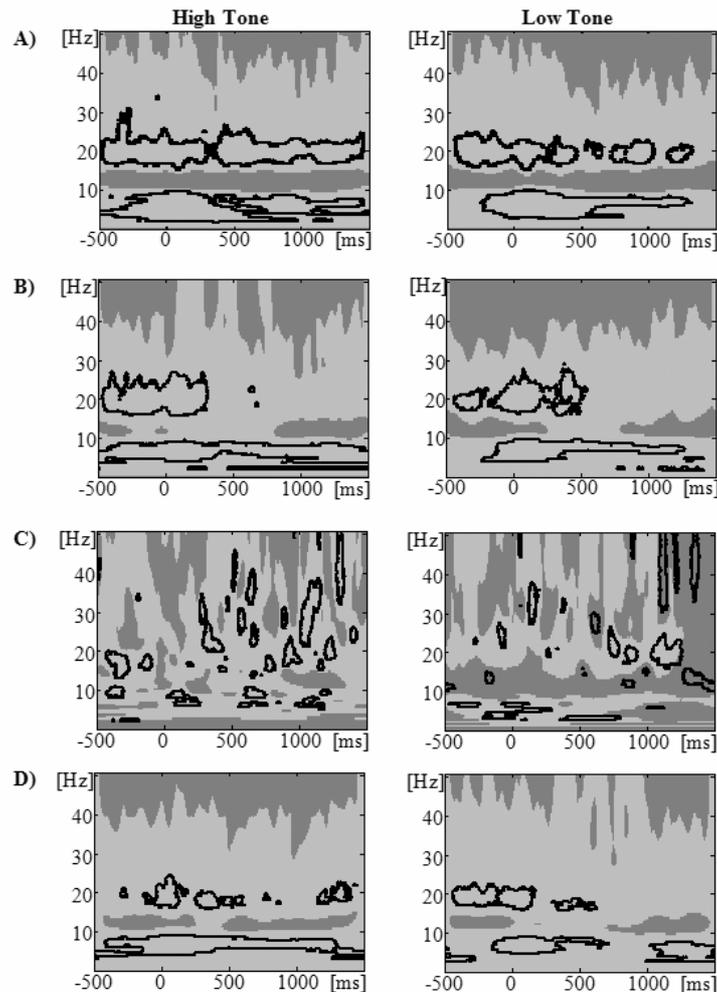
Fig. 3 Time-Frequency differences for Cz electrode position. The time-frequency differences for the other electrode positions are described in the text; dark grey – indicates the areas where the male have larger power spectrum compared to female individuals; light grey – indicates the areas where the female have larger power spectrum compared to male individuals; the enclosed areas indicates the places were the differences are statistically (Kruskal-Wallis test) significant ($p < 0.05$); A) Passive listening condition; B) Binary sensory-motor reaction task condition; C) Counting the low tone condition; D) reacting to the low tone condition.

In PL task condition the significant theta and beta1 differences were prominent in the entire time interval from 500 ms before to 1500 ms after stimulus presentation in Cz, Pz, C3' and C4' but not in Fz electrode position. The delta and beta 2 frequency bands were not significantly larger for females and the alpha 2 band was not significantly larger for male compared to female individuals.

In BSMT condition the females showed significantly larger power spectrum in the theta frequency band in the entire time interval from 500 ms before to 1500 ms after stimulus presentation in Cz, Pz, C3' and C4' but not in Fz electrode position. The females have significantly larger power spectrum in the beta1 frequency band in the time interval from 500 ms before to 500 after auditory stimulus presentation and in the time interval from 500 ms to 1500 after auditory stimulus presentation they have also larger beta1 power

spectrum although not significant. The delta and beta 2 frequency bands were not significantly larger for females compared to males.

In RLT condition female individuals showed increased power spectrum compared to male individuals in the whole time window from 500 ms before to 1500 ms after stimulus presentation. In this task similar to BSMT condition the beta1 power spectrum was significantly increased only in the time interval from -500 to 500 ms after stimulus presentation. The delta and beta 2 frequency bands were not significantly larger for females compared to males.

In CLT condition again the power spectrum in females was increased in the theta and beta1 frequency bands compared to males for the high (non-target) tone, but the differences were not significant in such a sustainable pattern in the other three series. This entirely mental task was the only condition where the female beta1 and theta prevalence seems to diminish and males showed significantly larger alpha2 power spectrums for the low (target) tone.

As a whole the use of S-transform didn't show significant spectral gender differences in Fz electrode position, but in Cz, Pz, C3' and C4' recordings.

The spectral differences between males and females were consistent and significant in the theta and beta frequency ranges. This result poses the question of the relation between the theta and beta frequency bands in its dependency on gender. To answer that question we used the methodology of Schutter et al. [30] and correlated the individual theta and beta1 frequency bands for male and female groups separately. The theta to beta correlation in both groups was positive, but in male individuals it was significantly stronger compared to female group. The results are shown in Fig. 4.

Discussion

Gender differences were found in N1, P2, N2 and P3 ERP components. The most consistent findings were the smaller P2 amplitude in males and more negative N1 amplitude in females. Also the female individuals had shorter N1 latencies. The finding that females have significantly larger N1 and P2 amplitudes compared to males supports old literature data Nagy et al. [21], Nanova et al. [22], Yuan et al. [37]. The N1 component is related to the sensory reaction and its amplitude increases by increasing the stimulus intensity Bruneau et al. [4], Neukirch et al. [23] and attention demands Rorden et al. [28]. Also the P2 amplitude increases by stimulus intensity, but decreases by increasing the attention demand to the stimulus Okita [24]. We excluded the hypothesis that N1-P2 gender differences are based on larger processing negativity (PN) in male individuals. The broad temporal effect of the Processing Negativity cannot only add negativity to attended ERPs at N1 latencies, thus creating the N1 effect, but also to later positive deflections such as the P2, and would thus shift negatively in attended relative to ignore conditions. If PN was larger in males they must have not only more negative P2, but also more negative N1 amplitudes Näätänen [20], Teder et al. [34], which was not the case. Also we didn't find significant N1 and P2 amplitude differences in attended relative to ignored stimuli in both genders in CLT and RLT conditions. The main factors that can modulate the latencies and amplitudes of N1 and P2 components are first, sensory processing, second, the level of selective attention, and, third, the frequency patterns of row EEG. It is admitted that N1-P2 wave component is strongly related to theta and low alpha band frequencies Bruneau et al. [4]. So significantly larger native theta spectral power found in females can be considered as a basis of N1 and P2 amplitude increase. The type of instruction had no significant impact on the N1 and P2

amplitude and latency differences between sexes. The stimulus type, target versus non-target in CLT and RLT conditions also didn't show impact upon the N1 and P2 gender differences. In this case we can conclude that the main factor which gives rise to N1 P2 amplitude gender differences was the enhanced basic theta oscillatory activity in female compared to male individuals.
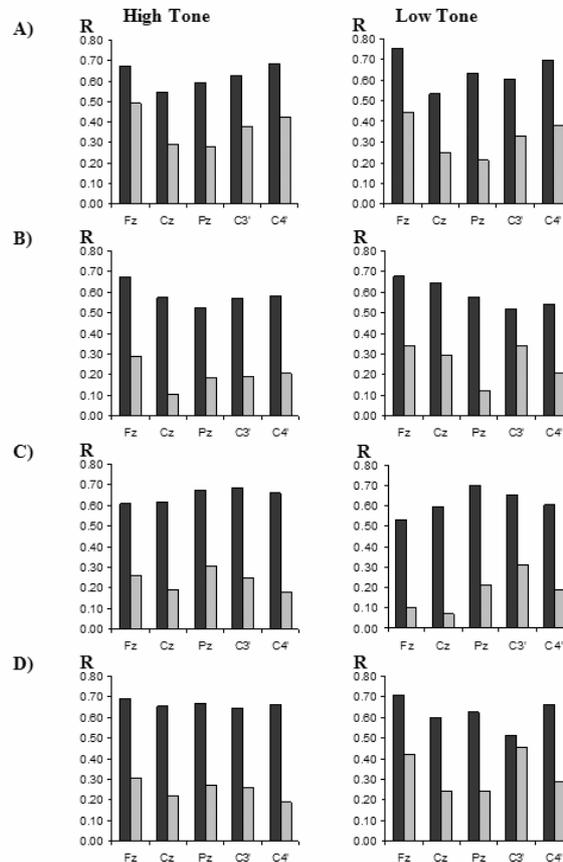
Fig. 4 Spearman R correlation between theta and beta1 power spectra
for male (black) and female (grey) individuals

Our results showed significant theta and beta1 power spectra increase in female compared to male individuals. This increase was independent from the presence or absence of auditory stimuli and task condition. In comparison to male, there was an overall increase in female power spectra in all frequency bands (nevertheless the differences are significant only in the theta and beta bands) and the only exception was the alpha 2 band, where the opposite pattern was observed.

To explain the overall increased EEG activity in female compared to male individuals, we may consider the hypothesis that gender differences in EEG power are influenced by differences in cranial thickness. There is little support of the idea that the increased EEG activity in the delta, theta, alpha1 and beta frequency ranges is based on differences in cranial thickness. The thicker cranium must obstruct more strongly the EEG transmission from source to scalp electrode, but according to Li et al. [17] the cranium thickness is larger in females compared to males, which must lead to the fully opposite results. By taking into consideration the fact that females on average have thicker cranium, the intracranial gender EEG power differences must be even stronger. Another study that related the cranium thickness and EEG activity found only mediocre association between EEG alpha power at

frontal, temporal, and parietal sites and the thickness of the underlying skull Hagemann et al. [13]. The authors concluded that intracranial sources contribute much more variance to the surface EEG than variations in skull thickness do.

The generators of beta EEG activity are considered mainly to have cortical origin. The sustainable significant increase of beta spectral power supports the idea of gender related differences in cortical architecture. There are other scientific papers Alonso-Nanclares et al. [1], Barrera et al. [2], Luders et al. [18], Rabinowicz et al. [26], [27]; Sowell et al. [32] discussing the idea that there are gender differences in cortical architecture: the orientation and connections of cortical pyramid cells, the number of cortical neuronal cells and the number of synapses. The data of Rabinowicz et al. [26] provide morphologic evidence of considerable cerebral cortical dimorphism with the demonstration of significantly higher neuronal densities and neuronal number estimates in males, though with similar mean cortical thickness, implying a reciprocal increase in neuropil/neuronal processes in the female cortex. Indeed there is some evidence of cortical architecture differences between males and females, but until now the empirical data is insufficient to draw definitive conclusion.

Most probably the sex difference in EEG theta frequency range is caused by differences in the thalamus-cortex connectivity. There is a connection between the oscillatory generators of theta and beta thalamic activity Sarnthein et al. [29]. Also this theta and beta thalamic activity is synchronized with the theta and beta EEG activity recorded over the scalp. This leads us to the hypothesis that the significant gender EEG differences in theta and beta frequency bands have their basis in thalamus and thalamo-cortical mechanisms that couple the theta and beta activity. The correlation between theta and beta1 in male individuals was significantly positive and stronger compared to the female group. Our results that males have significantly lower theta power spectra compared to females and stronger theta to beta1 correlation confirm literature data that low theta individuals have stronger theta to beta coupling compared to high theta individuals Schutter et al. [30]. The same publication also discusses the theta to beta coupling as a measure of cortico-cubcortical crosstalk. The results of Schutter et al. [30] showed that relatively high versus low slow wave activity, but not high versus low fast wave activity during resting state was accompanied by the decoupling of slow and fast frequency EEG. The data indicates that, at least during resting state conditions, cortico-cubcortical crosstalk is predominantly controlled by the subcortical system. This leads us to the conclusion that the most important gender difference is in the theta power spectrum. Our data extends the data of Schutter et al. [30] in terms of the fact that the cross-frequency relationships in EEG have a strong gender dependency. The generators of theta activity in humans are far from clear because of the small number of papers dealing with human data. There are attempts to transfer the data and interpretation made for animals to humans, but these parallels can be argued. The results of increased theta in females but better theta-beta synchronization in males can be explained with the presence of more than one ("at least" two) parallel working mechanisms of theta generation. The first should be involved in theta-beta coupling and the second not. The second mechanism is more active in females, which leads to increased theta in females, but also to decreased concordance between theta and beta oscillatory activity in females compared to males.

Acknowledgements

References

1. Alonso-Nanclares L., J. Gonzalez-Soriano, J. R. Rodriguez, J. De Felipe (2008). Gender Differences in Human Cortical Synaptic Density, Proceedings of the National Academy of Sciences, 105 (38), 14615-14619.
2. Barrera Á., L. Jiménez, G. M. González, J. Montiel, F. Aboitiz (2001). Dendritic Structure of Single Hippocampal Neurons According to Sex and Hemisphere of Origin in Middle-aged and Elderly Human Subjects, Brain Research, 906(1-2), 31-37.
3. Brenner R., R. Ulrich, C. Reynolds (1995). EEG Spectral Findings in Healthy, Elderly Men and Women – Sex Differences, Electroencephalography and Clinical Neurophysiology, 94(1), 1-5.
4. Bruneau N., S. Roux, P. Guérin, B. Garreau, G. Lelord (1993). Auditory Stimulus Intensity Responses and Frontal Midline Theta Rhythm, Electroencephalography and Clinical Neurophysiology, 86(3), 213-216.
5. Brunel F., M. Nelson (2003). Message Order Effects and Gender Differences in Advertising Persuasion, Journal of Advertising Research, 43(3), 330-341.
6. Carrier J., S. Land, D. Buysse, D. Kupfer, T. Monk (2001). The Effects of Age and Gender on Sleep EEG Power Spectral Density in the Middle Years of Life (Ages 20-60 Years Old), Psychophysiology, 38(2), 232-242.
7. Chen A. C., W. Feng, H. Zhao, Y. Yin, P. Wang (2008). EEG Default Mode Network in the Human Brain: Spectral Regional Field Powers, Neuroimage, 41(2), 561-574.
8. Daltrozzo J., N. Wioland, B. Kotchoubey (2008). Sex Differences in Two Event-Related Potentials Components Related to Semantic Priming, Archives of Sexual Behavior, 36(4), 555-568.
9. Deakin J., K. Exley (1979). Personality and Male-female Influences in the EEG, Biological Psychology, 8, 285-290.
10. Ditraglia G., J. Polich (1991). P300 and Introverted/Extraverted Personality Types, Psychophysiology, 28(2), 177-184.
11. Earle J., A. Pickus (1982). The Effect of Sex and Task Difficulty on EEG Alpha Activity in Association with Arithmetic, Biological Psychology, 15, 1-14.
12. Fisher R., L. Dube (2005). Gender Differences in Responses to Emotional Advertising: A Social Desirability Perspective, Journal of Consumer Research, 31(4), 850-858.
13. Hagemann D., J. Hewig, C. Walter, E. Naumann (2008). Skull Thickness and Magnitude of EEG Alpha Activity, Clinical Neurophysiology, 119(6), 1271-1280.
14. Jones C., V. Braithwaite, S. Healy (2003). The Evolution of Sex Differences in Spatial Ability, Behavioral Neuroscience, 117, 403-411.
15. Kemp A., R. Silberstein, S. Armstrong, P. Nathan (2004). Gender Differences in the Cortical Electrophysiological Processing of Visual Emotional Stimuli, NeuroImage, 21(2), 632-646.
16. Latta F., R. Leproult, E. Tasali, E. Hofmann, E. Van Cauter (2005). Sex Differences in Delta and Alpha EEG Activities in Healthy Older Adults, Sleep, 28(12), 1525-1534.
17. Li H., J. Ruan, Z. Xie, H. Wang, W. Liu (2007). Investigation of the Critical Geometric Characteristics of Living Human Skulls Utilizing Medical Image Analysis Techniques, International Journal of Vehicle Safety, 2(4), 345-367.
18. Luders E., K. Narr, P. Thompson, D. Rex, R. Woods, H. Deluca, L. Jancke, A. Toga (2006). Gender Effects on Cortical Thickness and the Influence of Scaling, Human Brain Mapping, 27(4), 314-324.

19. Matsuura M., K. Yamamoto, H. Fukuzawa, Y. Okubo, H. Uesugi, M. Moriiwa, T. Kojima, Y. Shimazono (1985). Age Development and Sex Differences of Various EEG Elements in Healthy Children and Adults – Quantification by a Computerized Wave form Recognition Method, Electroencephalography and Clinical Neurophysiology, 60(5), 394-406.

20. Näätänen R. (1992). Attention and Brain Function, Hillsdale, New Jersey: Lawrence Erlbaum Associates.

21. Nagy E., G. Potts, K. Loveland (2003). Sex-related ERP Differences in Deviance Detection, International Journal of Psychophysiology, 48, 285-292.

22. Nanova P., L. Lyamova, M. Hadjigeorgieva, V. Kolev, J. Yordanova (2008). Gender-specific Development of Auditory Information Processing in Children: An ERP Stud., Clinical Neurophysiology, 119, 1992-2003.

23. Neukirch M., U. Hegerl, R. Kötitz, H. Dorn, U. Gallinat, W. Herrmann (2002). Comparison of the Amplitude/Intensity Function of the Auditory Evoked N1m and N1 Components, Neuropsychobiology, 45, 41-48.

24. Okita T. (1979). Event-related Potentials and Selective Attention to Auditory Stimuli Varying in Pitch and Localization, Biological Psychology, 9(4), 71-84.

25. Putrevu S. (2001). Exploring the Origins and Information Processing Differences between Men and Women: Implications for Advertisers, ICFAI Journal of Marketing Management, 2(1), 47-66.

26. Rabinowicz T., D. Dean, J. Petetot, G. M. De Courten-Myers (1999). Gender Differences in the Human Cerebral Cortex: More Neurons in Males; More Processes in Females, Journal of Child Neurology, 14(2), 98-107.

27. Rabinowicz T., J. Petetot, P. Gartside, D. Sheyn, T. Sheyn, G. M. De Courten-Myers (2002). Structure of the Cerebral Cortex in Men and Women, Journal of Neuropathology & Experimental Neurology, 61(1), 46-57.

28. Rorden C., C. Guerrini, R. Swainson, M. Lazzeri, G. Baylis. (2008). Event Related Potentials Reveal that Increasing Perceptual Load Leads to Increased Responses for Target Stimuli and Decreased Responses for Irrelevant Stimuli, Frontiers in Human Neuroscience, 2(4), 1-7.

29. Sarnthein J., A. Morel, A. Von Stein, D. Jeanmonod (2003). Thalamic Theta Field Potentials and EEG: High Thalamocortical Coherence in Patients with Neurogenic Pain, Epilepsy and Movement Disorders, Thalamus & Related Systems, 2, 231-238.

30. Schutter D., C. Leitner, J. Kenemans, J. Honk (2006). Electrophysiological Correlates of Cortico-subcortical Interaction: A Cross-frequency Spectral EEG Analysis, Clinical Neurophysiology, 117(2), 381-387.

31. Sommer I., A. Aleman, A. Bouma, R. Kahn (2004). Do Women Really Have More Bilateral Language Representation than Men? A Meta-analysis of Functional Imaging Studies, Brain, 127, 1845-1852.

32. Sowell E., B. Peterson, E. Kan, R. Woods, J. Yoshii, R. Bansal, D. Xu, H. Zhu, P. Thompson, A. Toga (2007). Sex Differences in Cortical Thickness Mapped in 176 Healthy Individuals between 7 and 87 Years of Age, Cerebral Cortex July, 17(7), 1550-1560.

33. Stockwell R. (2007). A Basis for Efficient Representation of the S-transform, Digital Signal Processing, 17(1), 371-393.

34. Teder W., K. Alho, K. Reinikainen, R. Näätänen (1993). Interstimulus Interval and the Selective-attention Effect on Auditory ERPs: "N1 Enhancement" versus Processing Negativity, Psychophysiol, 30, 71-81.

35. Veldhuizen R., E. Jonkman, D. Poortvliet (1993). Sex Differences in Age Regression Parameters of Healthy Adults-normative Data and Practical Implications, Electroencephalography and Clinical Neurophysiology, 86(6), 377-384.
36. Wegesin D. (1998). A Neuropsychologic Profile of Homosexual and Heterosexual Men and Women, Archives of Sexual Behavior, 27(1), 91-108.
37. Yuan J., Y. He, Z. Qinglin, A. Chen, H. Li (2008). Gender Differences in Behavioral Inhibitory Control: ERP Evidence from a Two-choice Oddball Task, Psychophysiology, 45(6), 986-993.
38. Nissen C., B. Feige, U. Voderholzer, M. Berger, D. Riemann (2002). Gender-dependent Age Effects on Sleep EEG Power Density in Major Depression, Somnologie, 6(1), 7-12.

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