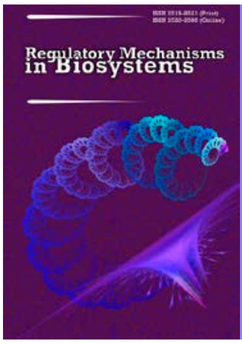

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Cortex electrical activity during switching of motor programs among men and women

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The inhibition of motor response is considered as an important aspect of executive control, as a way of changing behaviour. Gender, as a biological characteristic, stipulates different peculiarities of brain processes and, as a consequence, different behaviour of men and women. In the context of the Stop-Change task, the aim of our study was to examine whether there were differences in the brain processes between men and women. The method of "event-related desynchronization / synchronization" – ERD / ERS EEG – was used to clarify that issue. 36 men and 38 women, healthy, between the ages of 18 and 22, right-handed, participated in the experiment of compliance with bioethical requirements. The application of Stop-Change task required from the participants under the condition of a low tone (600 Hz sound) to quickly press with the help of the index finger and release the left button of the remote control. If there was a high tone (1600 Hz sound) the participant had to rapidly press and release with the help of middle finger the right button of the console. The prevalence of event-related synchronization phenomena of the α- and β-EEG-activity in cortical areas was distinguished in groups of men and women. It was apparently related to some deactivation of the cortex during the switching of motor program that was launched. At the same time, cortical electrical activity acquired certain specific features of the frequency-spatial organization, which could indicate the existence of certain gender characteristics of the brain processes. The weaker ERG EEG among women (compared with men) at 10 Hz, 16 Hz in symmetrical frontal and left central and parietal areas was found. Instead, the relative increase of ERS EEG among women was set in the range of 10 Hz (right central areas), 13 Hz (frontal central areas) and 19 Hz (central parietal areas). Gender differences in the electrical activity of the cortex in the range above 25 Hz of the EEG were characterized by some instability of the ERS and ERD responses in the frequency and spatial aspects.

Keywords: event-related desynchronization; event-related synchronization; manual movements; Stop-Change task

Introduction

In all spheres of activity a person constantly tries to control their own manual motor skills and to change them according to their needs. Manipulator coordination requires the permanent cancellation and updating of motor programs and commands. The analysis of literature data showed that the modified version of the Go-No Go paradigm, the so-called Stop-Change task (Logan & Burkell, 1986; Verbruggen et al., 2008), is the most commonly used in study the processes that involve the motor responses inhibition. The Stop-Change task requires the involvement of the Go process, the braking process and the alternative action process. All three of them can be considered as independent (Verbruggen & Logan, 2009). According to the neurovisualization data obtained in the Stop-Change task situation, involvement of the prefrontal cortex and basal ganglia in the process of motor response inhibition has been established (Simmonds et al., 2008; Chambers et al., 2009). Isoda & Hikosaka (2007), Neubert et al. (2010) also defined that in the process of reprogramming preSMA participates. This fact, in their view, is relevant to the inhibition of irrelevant actions and facilitates the launch of an alternative answer. Neurophysiological studies of motor response inhibition conducted by Stop-Change task showed a peak negativity about 180 ms of parietal-occipital electrodes of both hemispheres and, later, about 220 ms of frontal and central (Rangel-Gomez et al., 2015). The research conducted by Rangel-Gomez et al. (Rangel-Gomez et al., 2015) indicates that there is no lateralization of negative cortical activity in parietal areas. Taking into consideration the importance of the obtained results, it should be noted that there is some insufficiency in creating a complete concept of brain processes during the switching of motor programs of human movements.

Gender, as a biological characteristic, stipulates different peculiarities of brain processes and, as a consequence, different behaviour of men and women. Available literary sources give information about gender differences in the analysis of cognitive and emotional stimuli (Wager et al., 2003; Hamann & Canli, 2004; Wager & Ochsner, 2005). For example, among women, the activation of the left prefrontal cortex and mesolimbic pathways was fixed; it was manifested to a greater extent than that of men, reflecting a greater degree of processing (Azim et al., 2005) among women. Gender differences in the local brain activation were also observed in behavioural problems that required word formation (Bell et al., 2006), spatial attention (Bell et al., 2006), working memory (Gaab et al., 2003; Goldstein et al., 2005; Bell et al., 2006; Ragland et al., 2006; Mitchell, 2007), spatial navigation (Maguire et al., 1999), visceral stimulation (Kern et al., 2001; Naliboff et al., 2003) and odour identification (Bengtsson et al., 2001; Royet et al., 2003). According to the following authors (Meyers-Levy & Loken, 2015; Silva & Ravindran, 2015; Morenko et al., 2016) cognitive sexual differences may be due to the peculiarities in the organization of brain networks, due to evolutionary tendencies, hormonal influences or other developmental factors. On the other hand, numerous studies have revealed that males are more susceptible to impairment in inhibitory control and increased levels of impulsivity compared with females (Petry et al., 2002; Fillmore et al., 2004; Li et al., 2006; Cotto et al., 2010). Schizophrenic patients show deficits in executive control tests such as stop-signal tasks, and cognitive impairments are much more exaggerated in male patients (Han et al., 2012). In a study by Mansouri et al. (2009) women have shown that they are more capable of resorting to previous influence and practice of using executive control in complex cognitive tasks than men. Despite their importance, the results underscore a certain lack of information about the gender specifics of cortex electrical activity precisely when switching motor programs of manual movements. In the context of the Stop-Change task, the aim of our study was to examine whether there were differences in the brain processes between men and women. The method of "event-related desynchronization / synchronization" – ERD / ERS EEG – was used to clarify that issue. According to data from literature sources (Pfurtscheller & Lopes da Silva, 1999; Pfurtscheller, 2001; Neuper et al., 2006), the application of ERD / ERS is the most appropriate method for analyzing the dynamic activity of brain oscillatory systems under motor responsive conditions and allows one to distinguish from the background rhythmic activity precisely the reaction associated with the event. The detection by the above-mentioned method of the EEG markers of the brain processes, related directly to the motor response to Stop-Change signals has not only fundamental scientific significance for understanding the mechanism of switching of motor programs of targeted MM. The use of such EEG markers in perspective can qualitatively improve early diagnosis of cortical dysfunctions of the neuromotor apparatus, as well as rehabilitation programs for controlling behaviour in neuropsychological disorders.

Materials and methods

The participants in our study were 36 male and 38 female volunteers from the ages of 19 to 21, each of whom has given written consent. Biomedical ethics rules in accordance with the Helsinki Declaration of the World Medical Association on the Ethical Principles of Scientific and Medical Research involving Human Subjects were adhered to during the experiment. All the testees were healthy, had normal hearing according to the judgment and advisory conclusions of medical professionals, had the right profile of manual and auditory asymmetries, which were evaluated by the nature of responses during the survey and the performance of motor and psychoacoustic tests (Zhavoronkova, 2007). Time of sensorimotor responses in the choice of one of three objects as signals (triangles, circles, squares) was determined by computer diagnostic complex "Diagnost-1" (Certificate of measuring equipment type № UA-MI / 2p- 2613-2008 05.08.2008, Ukraine). All testees had to respond to the certain stimuli as quickly as possible by pressing and releasing the button panel by the right hand.

EEG experiment procedure envisioned the use of the Stop-Change task. Beforehand each examinee received an instruction according to which, on the appearance of low tone (sound of 600 Hz) s/he needed to press and release the left button of the console (Go-response) quickly with the help of the right index finger. If there was a high tone (1600 Hz sound) s/he had to rapidly press and release with the help of middle finger the right button of the console. Under experimental conditions, all stimuli sounds were served in pairs. In some stimuli pairs both sounds were low-pitched, in the others the first sound was of low tone, and the second – high tone. If the stimuli in the pair were unequal, then there was a braking of the running motor program (pressing the right index finger on the left button of the console), followed by switching to the alternative one (Stop-Change) (Fig. 1).

The duration of each beep was 50 ms, between stimuli interval representation of signals was 5000 ms (Pfurtscheller &d Lopes da Silva, 1999). The correlation of stimuli pairs with both low sounds (600 Hz) and stimuli pairs with both low and high sounds (600 and 1600 Hz) in the sample was 70/30. Time delay after first sound was 140 ms. This period included tactile (hidden) and partially motor components of sensory-motor responses, which are related to the perception of signal analysis, the decision on the motion, the formation of motor programs (Lyzogub et al., 2015; Rangel-Gomez et al., 2015).

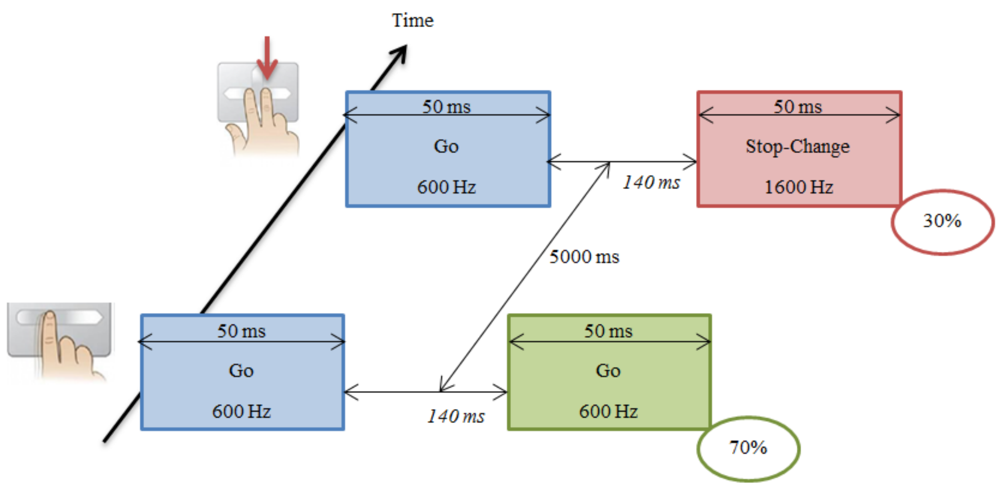

Fig. 1. Scheme of the conducted experimental Stop-Change task: Go – the first sound in stimuli pair, in response to which the testee had to start moving. Go, Stop-Change – the second sound in stimuli pair, confirm initiated movement; 70% and 30% – correlation between stimuli pairs in the sample

During the electroencephalographic stage participants were in a specially equipped sound and lightproof room, in a reclining position with eyes closed. EEG recording was performed using electroencephalographic hardware and software complex "Neurokom" (Certificate of compliance with technical regulations on medical devices N753 dated 25 January 2017). EEG registration was performed monopolar, 19 active electrodes were placed on the surface of the scalp on the international system 10/20. As reference electrodes, combined ear electrodes were used A1 and A2, which were attached to the left and right ear lobes respectively. Additionally, referential electrodes Ref were used (placed between frontal and lateral parts) and N (Nasion). Artefact activity rejection of native EEG was carried out by applying ICA-analysis (Independent Component Analysis). Changes of brain activity was measured in the frontal (F3, F4), central (C3, C4) and parietal (P3, P4) leads. The choice of such assignments was associated with existing published data that demonstrate the greatest part of these cortical areas in the processsing of motor data and motor programming (Haaland et al., 2000; Ioffe, 2003; Bai et al., 2005; Neubauer et al., 2006; Morenko & Korzhik, 2016).

Event-related desynchronization (ERD) and event-related synchronization (ERS) of EEG frequency (1–35 Hz) were estimated. Calculation of ERD/ERS maps was conducted in Matlab environment (MathWorks, 2015) in accordance with the procedure described by Pfurtscheller and Lopes da Silva (Pfurtscheller & Lopes da Silva, 1999). The content of the technique ERD/ERS was as follows: 1) collecting of EEG data for N stimulus presentation was conducted; 2) the signals were sequentially filtered for all stages N of analysis; 3) the filtered signals were summed in the square to calculate the signal strength for each reference in every stage; 4) the received power level for each period of time in the analysis stage was summarized for all stages (point-to-point); 5) the calculation of ERD/ERS was repeated for several consecutive frequency ranges in increments of 1 Hz, and the received values were represented in a variety of colours of the spectrum, which gave ERD/ERS maps, as a result. Stage of analysis was 5 seconds, which included 2 seconds before the submission of the second sound in the stimuli pair (reference interval, RI) and 3 seconds after the filing (post stimuli interval, PI). Change of spectral power EEG was evaluated in regard to a referential time interval (RI).

Test samples for normality of distribution were carried out using criterion of Shapiro Wilk (W, at $P > 0.05$). The differences were evaluated by t-criterion of Student (for independent samples). Differences at $P < 0.05$ are considered reliable. Gender changes of ERD/ERS of EEG frequency components in each leads between motor responses to significant stimuli under the conditions of the Stop-Change task were analyzed. Statistical analysis was conducted in the Statistica 8.0 program (StatSoft Inc.) and Matlab (MathWorks, 2015).

Results

The time of the sensory-motor response among male participants was 368.72 ms, among female – 382.67 ms.

Analysis of the results indicates enhancement effects associated with the event-related synchronization in the range of α- and β-EEG rhythms in a situation of the motor running program inhibition, followed by switching to an alternative movement among women compared with men. Poststimuli time interval in the sensory-motor responses comparable noted the growing role of ERS EEG ($P < 0,05$) among women at frequencies of 8 and 10 Hz in the right central lead (PI: 170–478 ms) 13 Hz in both frontal and central areas (PI: 148–1014 ms). Along with that, among women over a period sensory-motor response was set lower ERS EEG ($P < 0.05$) in the frequency range of 10 Hz in the right and left frontal areas of the central (PI 0–520 ms) than among men (Fig. 2–4).

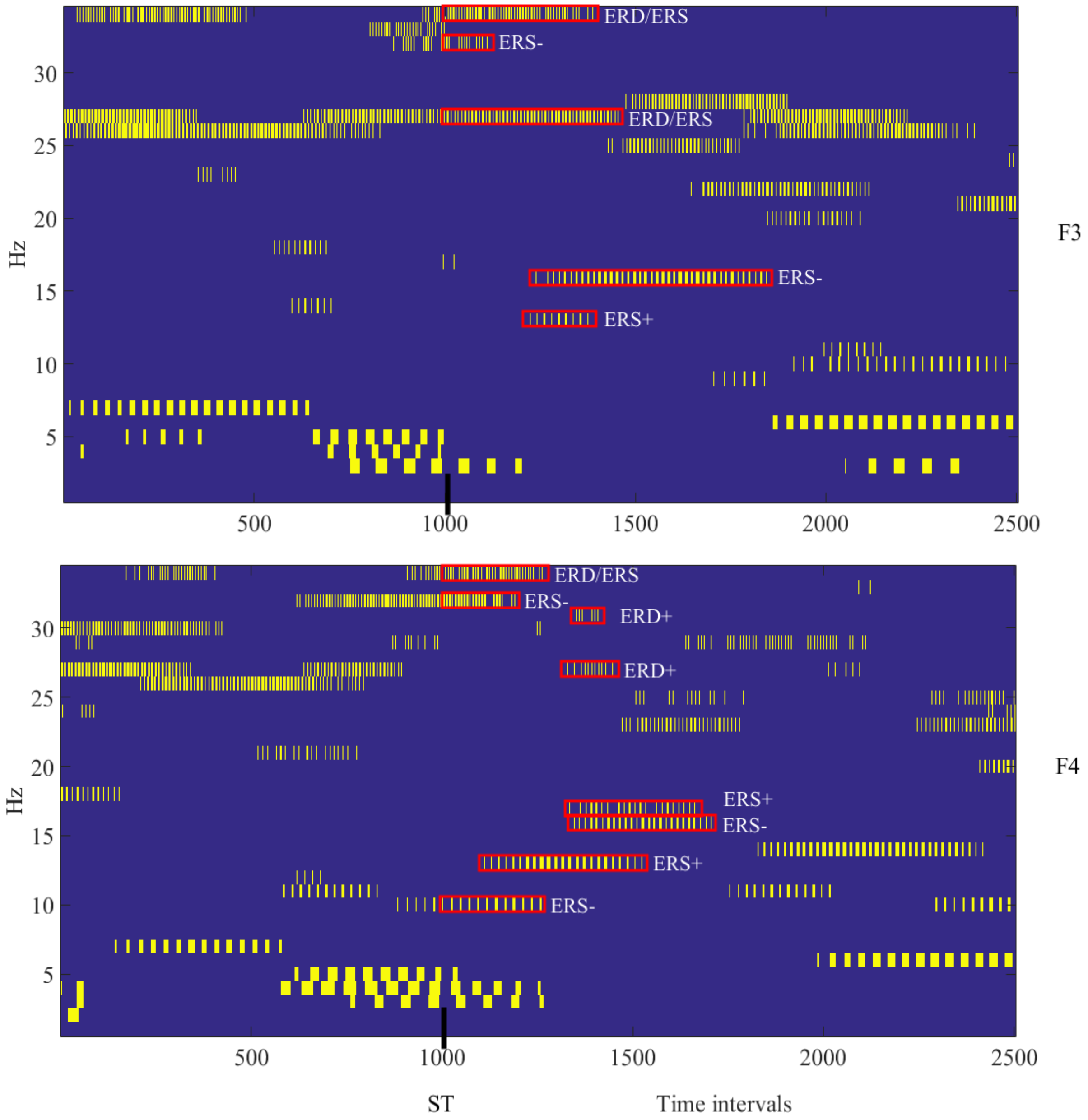

Fig. 2. ERD / ERS EEG in the frontal leads during responses to Stop-Change stimuli among women compared to men: 500 time durations correspond to 1 second. Within the limits of the mark of 1000 time durations, depending on the experimental set, a significant stimulus (ST) was given; yellow colour in a red frame on the figure indicates statistically significant differences ($P < 0.05$), and blue colour – its absence; ERS +/- or ERD +/- reflect the increase / decrease of reaction to Stop-Change stimuli response among women compared to men, $P < 0.05$. ERS / ERD (or ERD / ERS) in the schemes indicate the change in the type of reaction to the Stop- Change stimuli (second from the pair) among women in relation to those in men, (first in the pair), $P < 0.05$.

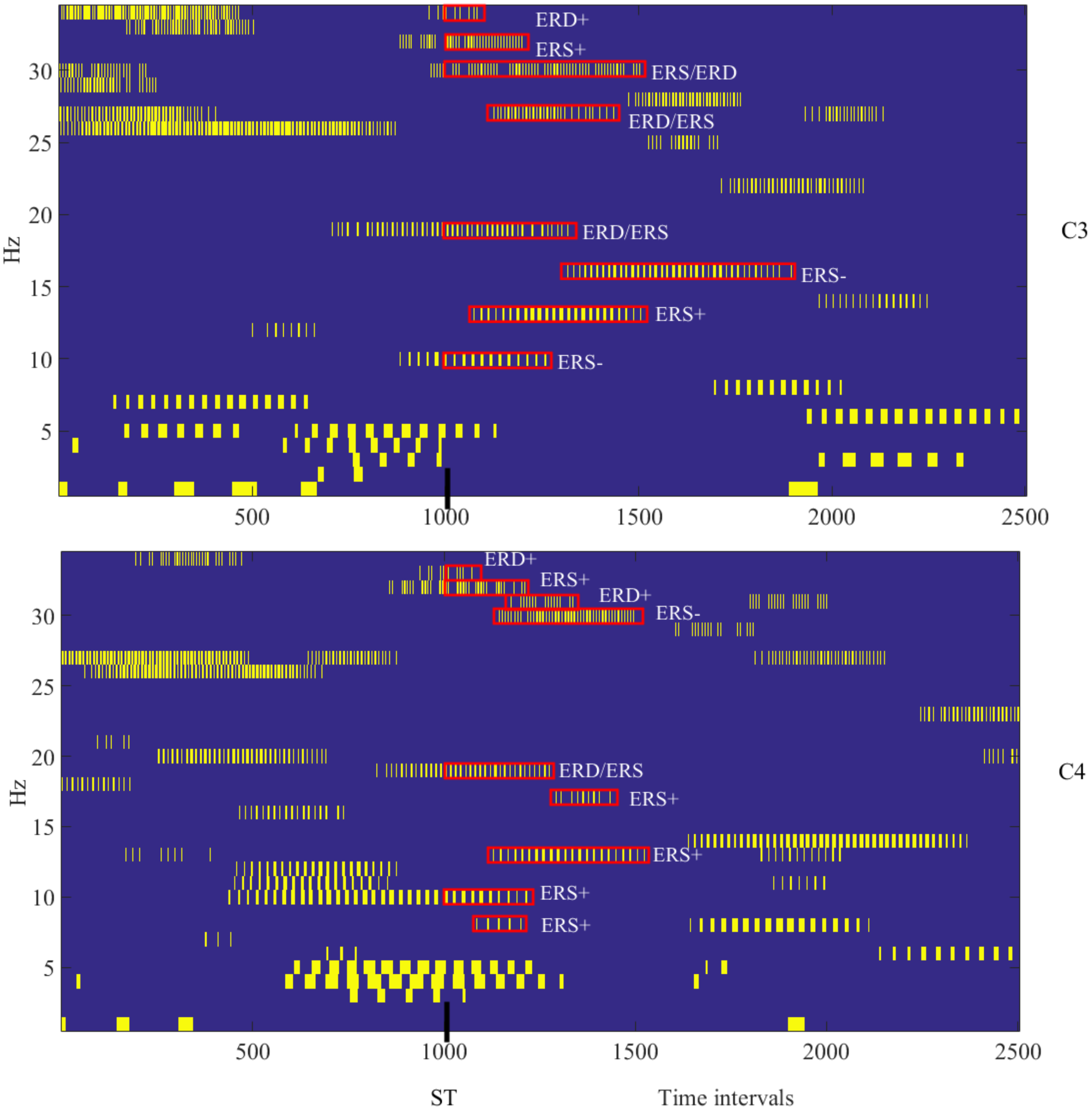

Fig. 3. ERD / ERS EEG in the central leads during responses to Stop-Change stimuli among women compared to men

In the 19 Hz range, women showed ERS EEG as opposed to ERD in men ($P < 0.05$). Such differences were found in the central and parietal cortex in the left (PI: 0–604 ms) and right (PI: 0–478 ms) hemisphere of the cortex ($P < 0.05$) (Fig. 2–4).

During the above mentioned testing, gender differences in cortical processes were noted that had a longer duration than the time sensory-motor response of the choice of the surveyed. At a frequency of 16 Hz, the lower level of ERS EEG among women was recorded in both frontal (PI: 510–1690 ms), left central and parietal cortex areas (PI: 662–1788) ($P < 0.05$) compared with men. At the same time, at the frequency of 17 Hz, the ERS of the EEG became highter in women in the right frontal (PI: 640–1326 ms) and central cortical areas (PI: 582–814 ms) ($P < 0.05$).

The gender differences in cortical electrical processes in the range of high-frequency β_2 activity (over 25 Hz) indicated some instability of ERS and ERD changes.

Discussion

Our paper was aimed at studying gender specifics of cortex electrical activity during switching motor programs of manual movements in the context of the Stop-Change task. We tried to examine whether there were differences in the brain processes between men and women with use of the method of "event-related desynchronization / synchronization" – ERD/ERS EEG. We found an enhancement of the event-related synchronization in the range of α- and β-EEG rhythms in a situation of the motor running program inhibition, followed by switching to an alternative movement among women compared with men. According to some authors (Neuper & Pfurtscheller, 2001; Pfurtscheller, 2001; Bai et al., 2005; Li et al., 2006; Lopes da Silva, 2006; Morenko & Morenko, 2016), synchronization in this frequency EEG spectrum generally meets escalating decontamination processes in the respective populations of cortical neurons and can be traced in a position to reduce information processing, full or partial suspension of motor behaviour. In terms of our experiment, such patterns can indicate a greater role the downstream inhibitory cortical influences during the exercise among women.

At the same time, cortex electrical activity acquired certain specific features of the frequency-spatial organization, which could indicate the existence of certain gender characteristics of the brain processes. Weaker ERG EEG among women (compared with men) at 10, 16 Hz in symmetrical frontal and left central and parietal areas were found. Instead, the relative significance of ERG EEG among women was set in the range of 10 Hz (right central areas), 13 Hz (frontal central areas) and

19 Hz (central parietal areas). Relevant results probably meant that in such a frequency range associated with the event, a synchronous relationship between the main neural elements among women was lower (Pfurtscheller, 1999; Neubauer et al., 2006) than among men. From the point of view of a number of researchers, in the desynchronized system, readiness for activity and information capacity increases (Thatcher et al., 1983), the level of activation of cortical neurons increases (Steriade et al., 1990; Neubert et al., 2010). In terms of our experiment desynchronization processes, that were established in the 19 Hz range among men and their cortical topography, could be associated with a greater degree of their differentiated attention, provided that the switching on an alternative motor task is required.

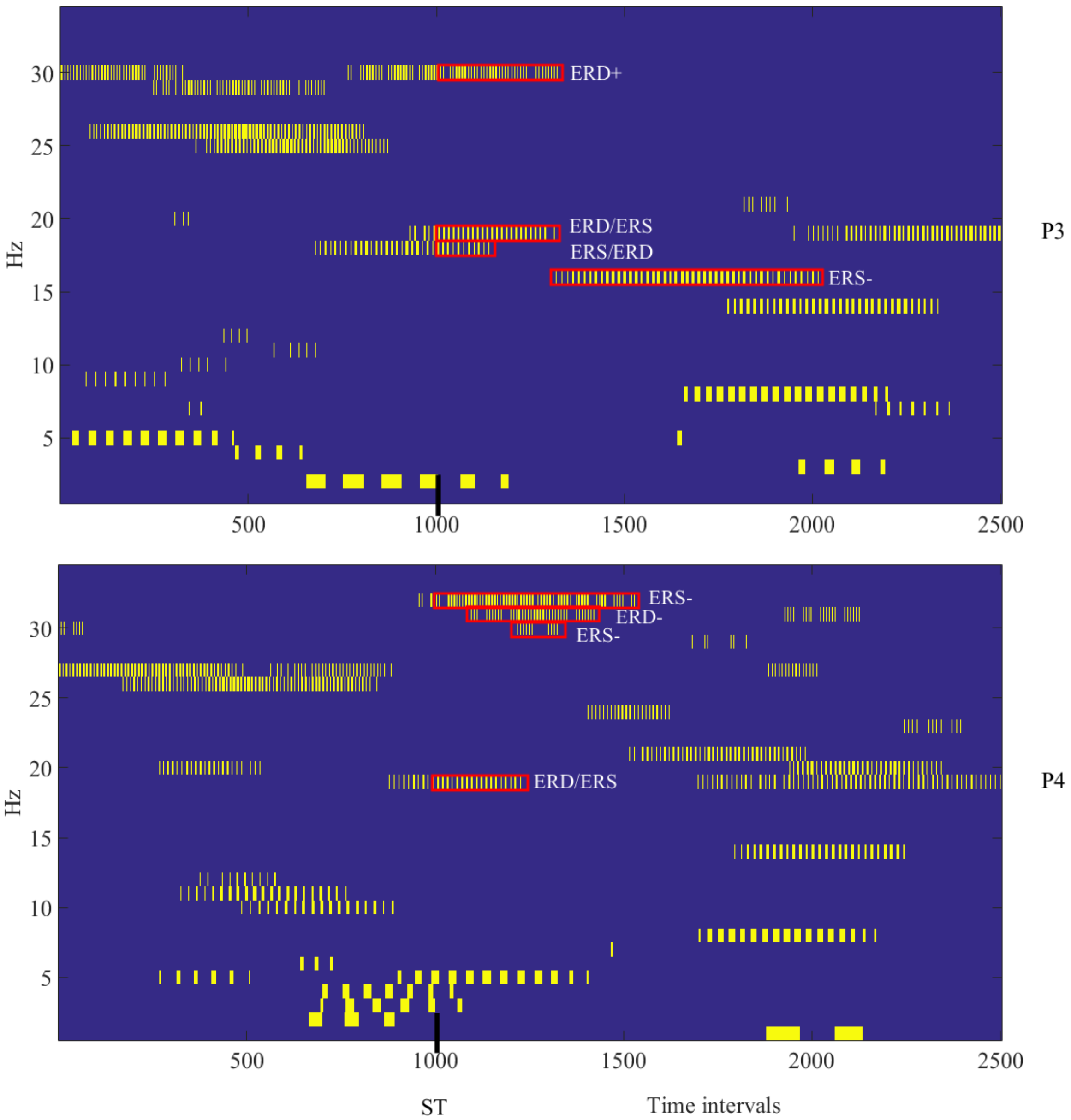

Fig. 4. ERD/ERS EEG in the parietal leads during responses to Stop-Change stimuli among women compared to men

During the above mentioned testing, gender differences in cortical processes were indicated that had a longer duration than the time of sensory-motor response of the choice of the surveyed. At a frequency of 16 Hz, the lower level of ERS EEG among women was recorded in both frontal, left central and parietal cortex areas compared with men. At the same time, at the frequency of 17 Hz, the ERS of the EEG became highter in women with right frontal and central cortical areas. Such gender differences may also be a reflection of the increased involvement of these cortical areas in preparation for the next manual response.

The gender differences in cortical electrical processes in the range of high-frequency β_2 activity (over 25 Hz) indicated some instability of reaction changes (ERS and ERD, respectively). We assume that according to the "horse-race model" (Verbruggen & Logan, 2009; Neuper et al., 2006), the processes of activation and inhibition of neuronal ensembles at such frequencies of EEG in our experiments occurred independently of each other, and their success or failure could be determined by the fact of which process was the first.

Conclusion

The prevalence of event-related synchronization phenomena of the α- and β-EEG-activity in cortical areas was distinguished in groups of men and women. It was apparently related to some deactivation of the cortex during the switching of motor program that was launched. At the same time, cortical electrical activity acquired certain specific features of frequency-spatial organization, which could indicate the existence of certain gender characteristics of the brain processes. Weaker ERG EEG among women (compared with men) at 10 and 16 Hz in symmetrical frontal and left central and parietal areas were found. Instead, the relative increase of ERS EEG among women was set in the range of 10 Hz (right central areas), 13 Hz (frontal central areas) and 19 Hz (central parietal areas). Gender differences in the electrical activity of the cortex in the range above 25 Hz of the EEG were characterized by some instability of the ERS and ERD responses in the frequency and spatial aspects.

This research has been performed within the framework of scientific topic of the Faculty of Biology of Lesya Ukrainka Eastern European National University "Neurophysiological mechanisms of human motor activity".

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