Gender differences in brain processes during inhibition of manual movements programs

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KEY WORDS

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ABSTRACT

Background: Motor response suppression can be regarded as an important aspect of the executive control, as a way of changing the behavioral pattern depending on the internal state or external factors.
Purpose: The aim of our study was to examine whether there were differences in the ability of cortical inhibition of triggered motor program (in the context of the Stop-Signal task) between females and males.
Methods: We examined differences in the patterns of event-related EEG synchronization/desynchronization (ERS/ERD) in young volunteers under the conditions of complete inhibition of the triggered motor program of a manual movement. Thirty-six male and thirty-eight female (ages of 19 to 21) took part in the tests. The ERS and ERD indices were estimated within the EEG frequency range 8–35 Hz in frontal, central and parietal leads.
Results: In both gender groups, as a global pattern, the prevalence of connected phenomena with the EEG synchronization event in the range of α-activity of the EEG, apparently associated with inhibition of the running motor program was noted.
Conclusion: Cortical electrical activity acquired certain specific features of the frequency-spatial organization, which could indicate the course of somewhat different brain processes of men and women.

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Introduction

An executive control over the personal actions in everyday life is extremely important for carrying out the relevant tasks and for achieving the goals. Motor response suppression can be regarded as an important aspect of the executive control, as a way of changing the behavioral pattern depending on the internal state or external factors [1–2]. In all spheres of activity, a person constantly tries to control his or her own manual motor skills and to change it according to his or her needs. In order to study the processes that are associated with the motor responses inhibition, the most widespread is the modified version of the Go-No Go paradigm, the so-called Stop-Signal task [3–4]. Within this task, participants are instructed to perform a repetitive reaction time task (go trials), while in a small subset of trials, a stop signal will appear immediately after the onset of the go cue, and the participants are asked to withhold their responses (stop trials) [5]. The delay in the onset of the stop signal after the presentation of the go cue (Stop-Signal delay) is modulated to alter the probability of successful inhibition. Imaging studies have investigated the neural substrate of these processes, particularly that of inhibitory control. It was revealed that in the stop trials, which required response inhibition, the anterior cingulate cortex had significantly higher activation in comparison with that detected within the go trials [6]. Furthermore, Hughes *et al* [7] found activation in the right inferior frontal gyrus, dorsolateral prefrontal cortex, and parietal cortex when inhibition of responses was required and reported altered activation patterns in schizophrenic patients [8] during the Stop-Signal task. These studies suggest that areas involved in executive control of behavior [9] support cognitive processes in the stop-signal task.

Gender, as a biological characteristic, stipulates different peculiarities of brain processes and as a consequence, different behavior of men and women. 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 [10–11]. Schizophrenic patients show deficits in executive control tests such as Stop-Signal tasks, and cognitive impairments are much more exaggerated in male patients [12]. In a study by Mansouri *et al* [13] using the stop-signal task, women have shown that they are more capable of resorting to previous influence and practice of using executive control in complex cognitive tasks more than men. There is evidence that inhibition of motor reaction under Go–No Go and Stop paradigms develops throughout adolescence and into adulthood [14]. Gender differences in the conditions of the motor response inhibition become more pronounced in adolescence. This feature is associated with hormonal changes during puberty [15]. Male's exhibit steeper developmental slopes in grey matter reduction and white matter increase than females [16–17], partly explained by earlier maturation peaks in females in frontal, striatal and temporal areas [18–19]. According to Rubia *et al* [20] the superior reliance on functional frontal mechanisms in females, and on functional parietal mechanisms in males, during inhibitory control, is determined by gender differences in the post-adolescent functional development of these brain regions.

The aim- Taking into account the available results, it is worth noting a certain lack of information about gender specifics of brain processes precisely during motor program inhibition of manual movements. Stop-Signal task is an established motor task that requires inhibition capability. In the context of this task, the aim of our study was to examine whether there were differences in the ability of cortical inhibition of started motor program between females and males. The method of "related to the desynchronization / synchronization event" (ERD / ERS) EEG – was used to clarify that issue. According to data from literature sources [21–23], the application of ERD / ERS is the most appropriate method for analyzing the dynamic activity of brain oscillatory systems under the motor responsive conditions and allows distinguishing from the background rhythmic activity precisely the reaction associated with the event. The detection by the above-mentioned method of the EEG markers in perspective can qualitatively improve early diagnosis of cortical dysfunctions of neuromotor apparatus, as well as rehabilitation programs for controlling behavior in neuropsychological disorders.

Methods

The participants in our study were 36 male and 38 female volunteers from the ages of 19 to 21. All the participants were healthy, had normal hearing with regard to the judgment and advisory conclusions of their 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 [24]. The contingent is formed from young students of the Biological Faculty of the Lesya Ukrainka Eastern European National University for the qualitative achievement of the research aim and the avoidance of manifestation of age-related effects of changes in the structure and functions of the brain, for example decreasing with age the global energy and spectral powers of EEG frequency bands [25].

Procedure

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 participants had to respond to certain stimuli as quickly as possible with pressing and releasing the button panel by the right hand.

EEG experiment procedure envisioned the use of the *Stop-Signal* task. Beforehand examinee received an instruction due to which, in case of the appearance of low tone (sound of

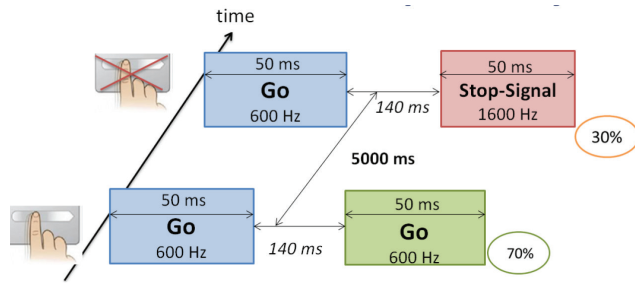

Fig. 1: Scheme of the conducted experimental *Stop-Signal task. Go* - the first sound in stimuli pair, in response to which the examinee should start moving. *Go, Stop-Signal*– the second sound in stimuli pair, confirm initiated movement (*Go*), or stop initiated movement (*Stop-Signal*). 70% and 30% –correlation between stimuli pairs in the sample.

600 Hz) he needs to press and release the left button of the console (Go-response) quickly with the help of the right index finger. If there is a high tone (1600 Hz sound) he needs to stop pressing [26]. Under experimental conditions, all stimuli sounds were served in pairs. Some stimuli pairs both sounds were low-pitched, in the others the first sound was of low tone, and the second – high tone. Examinees in each case started moving right index finger at the first sound (Go). The second sound in stimulus pair had confirmation of the value or movement or its stop (*Stop-Signal*) (Fig. 1).

The duration of each beep was 50 ms, between stimuli interval representation of signals was 5000 ms [23]. The correlation of stimuli pairs with both low sounds (600 Hz) and stimuli pairs with both low and high sounds (600 Hz and 1600 Hz) in the sample was 70/30. Time delay after first sound was 140 ms. This period included a 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 [27–28].

Registration and processing of EEG data

During the electroencephalographic stage participants were in specially equipped sound and lightproof room, in reclining position with closed eyes. 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 used combined ear electrodes 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 leads) 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 is associated with existing published data that demonstrate the greatest part of these cortical areas in the processing of motor data and motor programming [29–31].

Desynchronization (event-related desynchronization, ERD) and synchronization (event-related synchronization, ERS) of EEG frequency (1 Hz to 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 [23]. Stage of analysis was 5 seconds, which included 2 seconds before the submission of the second sound in 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).

Statistical processing of the results

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 $p \leq 0.05$ are considered reliable. Changes of ERD / ERS of EEG frequency components in each leads between motor responses to significant stimuli under the conditions of the *Stop-Signal* paradigms were analyzed. Statistical analysis was conducted in the Statistica 8.0 program (StatSoft. Inc) and Matlab (MathWorks, 2015).

Results and Discussion

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

The analysis of the obtained results shows the predominance of the actions associated with the synchronization event in the range of EEG α - rhythm in terms of inhibition of the running motor program of manual movement of men and women. According to a number of authors [22,32–33] the synchronized activity in the EEG frequency spectrum, in general, corresponds to the transition to a deactivated state of the corresponding population of cortical neurons and can be traced in a state of reduced information processing, total or partial cessation of motor behavior. Under the conditions of our experiment, such patterns may indicate the spread of the phenomena of downtrodden braking control as a general trend during the emergency stoppage of the motor program running. At the same time, lower ERS EEG ($p \leq 0.05$) was found among woman in the frequency range of 7 Hz in the right frontal and symmetric central cortex leads (RI: 0–730 ms), 11 Hz in the frontal areas (RI: 0–394 ms) (Fig. 2–4).

Instead, in the 9–10 Hz band (RI: 0–540 ms, left 0–218 ms), 13 Hz (RI: 440–884 ms) the reverse pattern was revealed, namely, the relatively higher values of EEG among women are generalized in the cortex ($p \leq 0.05$). The weaker ERS EEG phenomena were found among women at α1-activity frequencies, and their higher significance in the range of high-frequency α-activity compared to men, may be a feature of some shift of the most significant inhibitory cortical effects in the band of higher α-frequencies of women and relatively lower among men.

In the β1-activity range of EEG, relatively less ERS EEG ($p \leq 0.05$) was established among women at 15–16 Hz in frontal (RI: 0–814 ms), central (RI: 0–632 ms) and

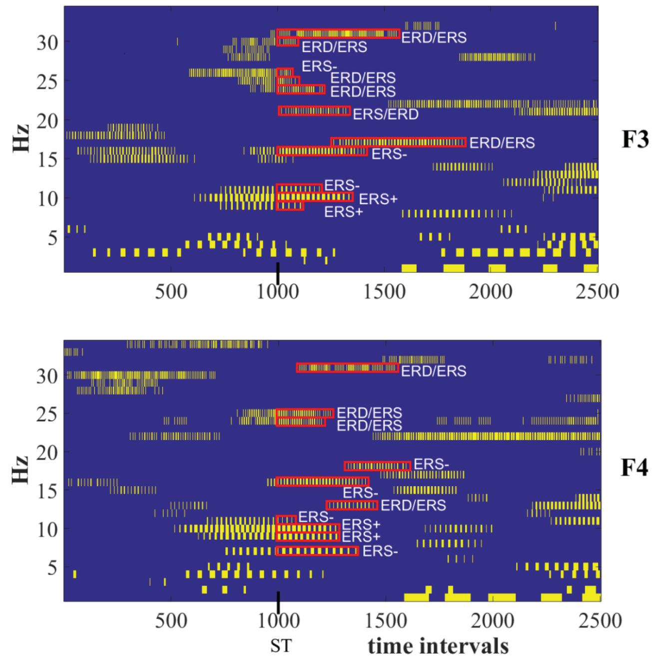

Fig. 2: ERD/ERS EEG in the frontal leads during responses to *Stop-Signal* stimuli in women compared to men.

Notes to Fig. 2–4

- 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 color in red frame on the figure indicates statistically significant differences ($p < 0.05$), and blue color - its absence.
- ERS +/- or ERD +/- reflect the increase / decrease of reaction to *Stop-Signal* 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-Signal* stimuli (second from the pair) among women in relation to those in men, (first in the pair), $p \leq 0.05$.

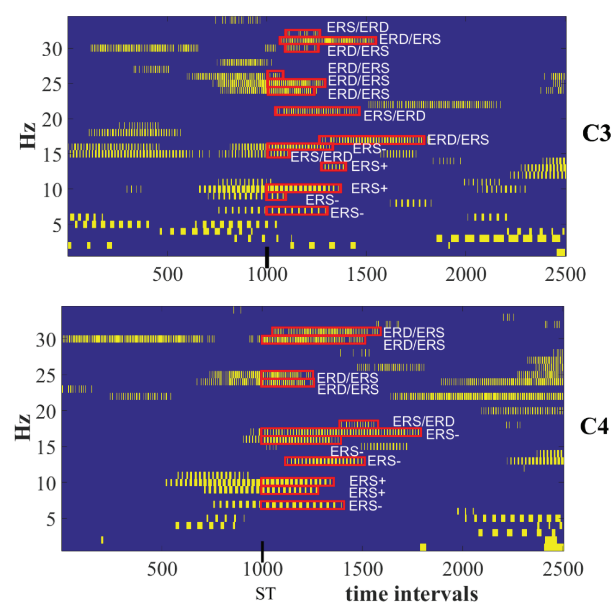

Fig. 3: ERD/ERS EEG in the central leads during responses to *Stop-Signal* stimuli in women compared to men.

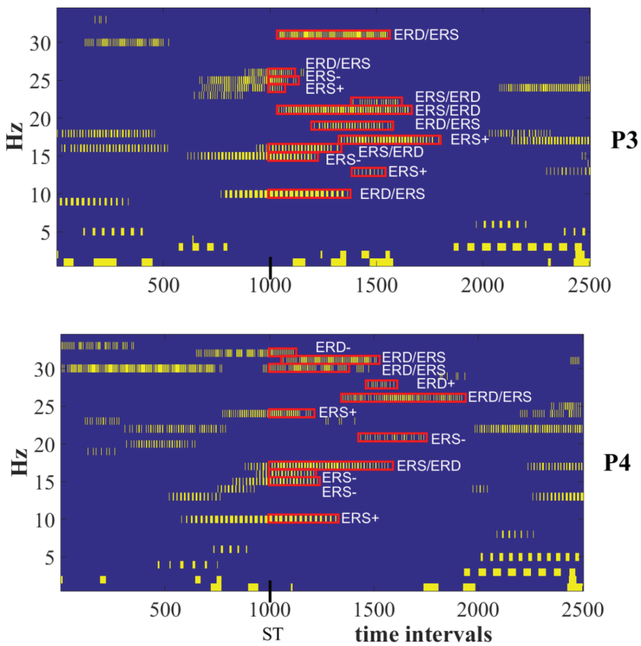

Fig. 4: ERD/ERS EEG in the leads during responses to *Stop-Signal* stimuli in women compared to men.

parietal (RI: 0–426 ms) cortex areas. The corresponding results probably meant that the synchronous relationship between the main neural elements associated with the event was reduced [34], and the level of excitation involved in the implementation of the motor command of cortical site increased somewhat [35]. In the range of 21–22 Hz, this pattern became more significant - among women there were ERD EEG in contrast to the established ERS among men ($p \leq 0.05$). From the point of view of researchers in the desynchronized system, readiness for activity and information capacity increases, the level of cortical neurons activation increases [35]. We also assume that in terms of our experiment desynchronization processes in the range of the indicated frequencies of β1 activity among women were established (21–22 Hz), and their cortical topography could be more related to motor programming and increase of the differentiated attention level of the participants compared to the lower frequencies of the EEG spectrum. A greater prevalence of desynchronization phenomena in the cortex in the band of EEG mentioned frequencies among women indicated a greater role of non-specific activation. Such processes had a longer duration than the time of sensory-motor response of the women choice and were noted after the completion of the latter. At the same time, among men at the frequency of 17 Hz in the left frontal (RI: 528–1730 ms) and central leads (RI: 558–1640 ms), 19 Hz - in the left parietal excision (RI: 438–1132 ms) the ERD EEG phenomena was noted, while among women - ERS EEG ($p \leq 0.05$). Such differences among men (in the time interval after the end of the sensory-motor response of choice) may also be a reflection of the increased attention and participation of the indicated cortical leads in motor programming, but obviously in the context of preparation for the next manual response.

Cortical electrical processes in the high-frequency band of β-activity (24–26 Hz, RI: 0–244 ms, 30–31 Hz, RI: 0–736 ms) among women indicated ERS in the cortex, as opposed to the registered EEG among men ($p \leq 0.05$). This feature testifies to the great mutual integration of widely distributed cortical neural networks [36] among women compared with men in providing motor responses to sensory signals, namely the urgent stopping of a running motor program. At the same time, in the band of 28 Hz (RI: 944–1210 ms) and 32 Hz (RI: 0–228 ms), the prevalence of ERD EEG events among women was higher than among men ($p \leq 0.05$). The attention is paid to the different orientation and certain instability of response changes (ERS and ERD, respectively) in the range of EEG β2-activity. We assume that according to the "horse-race model" [4] the processes of activation and inhibition of neuronal ensembles at such frequencies of EEG in terms of our experiment occurred independently of each other, and their success or failure could be determined by the fact that which process was the first.

Conclusion

Our study showed that execution and inhibition of manual movements gender-dependently influenced and changed cortical activity. In both gender groups, as a global pattern, the prevalence of connected phenomena with the EEG synchronization event in the range of α-activity of the EEG, apparently associated with inhibition of the running motor program, was noted. At the same time, cortical electrical activity acquired certain specific features of the frequency-spatial organization, which could indicate the course of somewhat different brain processes of men and women. Such differences are related to changes in the dynamic oscillatory activity of the EEG during inhibition of manual movements programs under the Stop-Signal paradigm. The obtained results probably may be indicative of a slightly different in the neural processes that underlying motor and cognitive control in men and women.

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Authorship contribution

All authors of the paper were equally involved in the investigation and the manuscript processing. KO as the first author conducted an experiment, made statistical processing. OM analysed and descripted of literary sources. MA analysed and interpreted of own results. IK managed our investigation. The manuscript complies with ICMJE guidelines.

Ethical statement

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. Subjects have given their informed consent and the study protocol has been approved by the Lesya Ukrainka Eastern European National University's Committee on bioethics. Ethical approval number is 1, provided on the 10th of January in 2017. The Committee has determined that the experimental studies presented in this manuscript do not contradict generally accepted bioethical standards regarding conducting experimental and clinical studies and can be used in publications.

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Conflicts of interest

Authors do not have any conflicts of interest.

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