EEG features during maintaining a human body balance.

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***Abstract*—We have conducted an experiment involving keeping balance on a platform to research the perception of maintaining body posture. The objective of the present work was to characterize the common features of cortical activity during postural control. Regarding the cortical basis of performance differences during unstable conditions, EEG analysis suggest that central-frontal areas may underlie the cortical interaction including oscillations in general, maybe underlie cortical monitoring of changes in postural state of the body. The obtained results show that the neuronal activity in the β-frequency band can be utilized as the neurophysiological marker of the subject's ability to maintain the equilibrium state.**

***Index Terms*—EMG, EEG, balance, activity, posture**

I. INTRODUCTION

Capability to keep dynamic balance and stability of the body posture take an important part in everyday life, helping a person to avoid injuries and, at the same time, save energy spent on unnecessary actions. It was assumed that postural regulation is under the control of subcortical structures of the cerebrum and the spinal cord, but more studies have emerged to suggest complex cortical involvement in the postural response [1]. The cerebral cortex and central nervous system play integral roles in postural control, incorporating information from visual, somatosensory, and vestibular systems to carry out the corrective motions needed to maintain balance [2]. The role of the central nervous system and subcortical structures for the innate generation of feedforward and feedback adaptive adjustments to reduce the risk of balance loss is well documented in literature [3]–[5].

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Some studies have found an interaction between postural control and cognitive task performance, indicating that postural control is not a fully automatic process but rather may require active cognitive processes [6], including complex information processing [7], such as perception, decision-making and motor control [8], [9]. While many tools have been employed to study neurocognitive processes in this regard, the use of electroencephalography (EEG) as a neuroimaging technique remains disparately reported. Nonetheless, extant literature has investigated the utility of EEG through the examination of evoked potentials related to the balance perturbation [10], [11].

However, the simultaneous whole-body estimation of the human kinematics and dynamics are not well understood and leave areas for further research. Moreover, most of the experimental works use a one-side approach when subjects only passively react to the balance perturbation without interaction [12]–[16]. That means no effective learning and feedback essential for performance improvement [17].

II. EXPERIMENTAL SETUP

A series of experimental works in a group of 12 unpaid conditionally healthy volunteers (8 male and 4 female) was carried out. Age of the volunteers ranged from 25 to 42 years, the physical conditions corresponded to the characteristics of a normal body mass index and an average level of physical activity. All volunteers were instructed before conducting the research to observe the regime of full night rest for three days. Studies were conducted in the morning and afternoon periods (9 AM – 1 PM) 2 hours after a healthy meal with limited consumption caffeine and (or) other stimulating additives to food.

The duration of the experiment was about 45 minutes. During the recording of signals, subjects were standing on the balance platform Fig. (1). The structure of the experiment included three 10-minutes sessions with two 5-minutes rest pauses between them. Pre-registration of background (BG) activity without subject performing special instructions was carried out for 3 minutes. All of the subjects were instructed to maintain balanced posture during their attempts. We especially note the fact that no volunteers had the opportunity to train their ability to maintain balance before the experiment and, thus, the study was conducted with untrained operators. This is important because recent studies have shown that trained subjects (such as athletes) have different spectral activity distribution in comparison with untrained. Specifically, lower reduction in amplitude of EEG oscillations at dominant alpha rhythms were observed during different posture keeping experiments [18], [19]. Attempt was registered if subject was able to reduce absolute value platform angle from border position to less than $\pm$ 19 °. If the duration of the attempt was longer than 1 s. During the postural session, platform angle, platform speed, electromyography (EMG), and 32-channels EEG data were recorded continuously according to the standard "10-10" configuration. As shown on the scheme of the EMG electrodes in Fig. 2), arrangement included next muscles: *Tibialis Anterior* (1), *Gastrocnemius* (2), *Rectus Femoris* (3), *Semitendinosus* (4). We recorded 31 signals with two reference electrodes A1 and A2 on the earlobes and a ground electrode N just above the forehead. The signals were acquired via the cup adhesive Ag/AgCl electrodes placed on the "Tien–20" paste (Weaver and Company, Colorado, USA). Immediately before the experiments started, we performed all necessary procedures to increase skin conductivity and reduce its resistance using the abrasive "NuPrep" gel (Weaver and Company, Colorado, USA). The impedance was monitored after the electrodes were installed and measured throughout the experiments. Usually, the impedance values varied within a 2–5 kΩ interval. The electroencephalograph "Encephalan-EEG-19/26" (Medicom MTD company, Taganrog, Russian Federation) with multiple EEG channels and a two-button input device (keypad) was used for amplification and analog-to-digital conversion of the EEG signals. This device possessed the registration certificate of the Federal Service for Supervision in Health Care No. FCP 2007/00124 of 07.11.2014 and the European Certificate CE 538571 of the British Standards Institute (BSI). The raw EEG signals were filtered by a band-pass filter with cut-off points at 1 Hz (HP) and 100 Hz (LP) and by a 50-Hz notch filter by embedded a hardware-software data acquisition complex. Signals were recorded at a sampling frequency of 250 Hz with a 12-bit resolution. Variations of spectral power were calculated to assess whether changes in postural control and balance keeping were significantly different. To do this, power spectral density values were extracted for all EEG electrodes and averaged within the following frequency bands: theta (3–7 Hz), alpha (8–13 Hz), beta (14–24 Hz). Although the EMG signals were used as additional balance and for the body movement activity monitoring in this study, they would help us in a future studies.

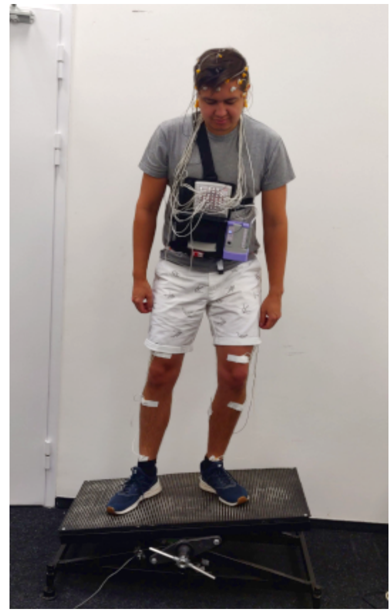

Fig. 1. A photo of the experimental setup.

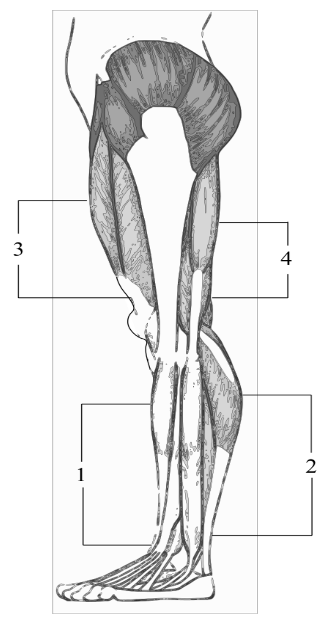

Fig. 2. Schematic representation of the subject leg with 4 connected electrodes for measuring EMG signals during the experiment.

III. Results

According to the recent works [7], [9], We analyzed the EEG signals power in α- and β-frequency bands, using the continuous wavelet transformation. The wavelet power spectrum $E^n(f,t) = (W^n(f,t))^2$ was calculated for each EEG channel $X_n(t)$ in the frequency range $f \in [1, 30]$ Hz. Here,

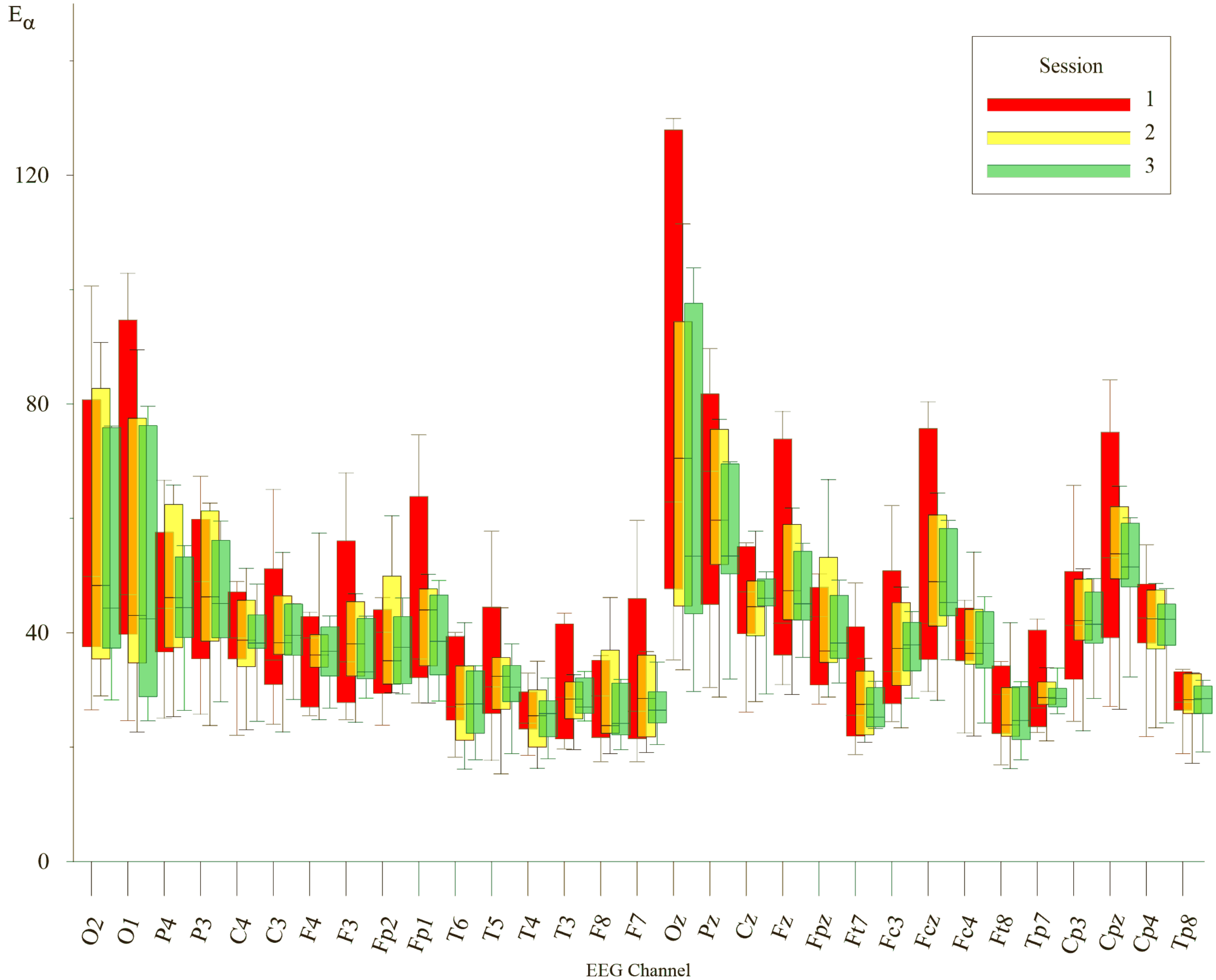

Fig. 3. Distribution of the the β-band spectral energy across EEG channels. Data are shown as mean, quartile ranges, min/max.

$W^n(f,t)$ is the complex-valued wavelet coefficients calculated as [20]

$$W^n(f,t) = \sqrt{f} \int_{t-4/f}^{t+4/f} X_n(t)\psi^*(f,t)dt, \tag{1}$$

where $n = 1, ..., N$ is the EEG chanel number ($N = 31$ is the total number of chanels used for the analysis) and "*" defines the complex conjugation. The mother wavelet function $\psi(f,t)$ is the complex Morlet wavelet which is defined as

$$\psi(f,t) = \sqrt{f}\pi^{1/4}\mathrm{e}^{j\omega_0 f(t-t_0)}\mathrm{e}^{f(t-t_0)^2/2}, \tag{2}$$

where $\omega_0 = 2\pi$ is the central frequency of Morlet wavelet.

For α- and β-frequency bands the wavelet amplitudes $\bar{E}^n_\alpha(t)$, $\bar{E}^n_\beta(t)$ were calculated as

$$\bar{E}^n_{\alpha,\beta}(t) = \frac{1}{\Delta f_{\alpha,\beta}} \int_{\Delta f_{\alpha,\beta}} E^n(f',t)df', \tag{3}$$

where $\Delta f_\alpha = 8 - 12\,\mathrm{Hz}$ and $\Delta f_\beta = 15 - 30\,\mathrm{Hz}$.

At the first stage, the time intervals $\tau_{1,2,3}$, corresponding to the maximal duration of the equilibrium state were defined for each of three sessions.

The length of these intervals was analyzed in the group of participants via a nonparametric Friedman test for three related samples. As the result a significant difference was observed for the different experimental sessions $\chi(2) = 8.167, p = 0.017$. The post hoc analysis based on the Wilcoxon signed rank test revealed the insignificant change of τ_2 when compared with τ_1 ($Z = -1.490, p = 0.136$) and insignificant change between τ_2 and τ_3 ($Z = -1.177, p = 0.239$). At the same time, the significant increase was observed for τ_3 when compared with τ_1 ($Z = -2.981, p = 0.003$). Based on the obtained results we have concluded that the maximal duration of the equilibrium state growths with the time spent in the experiment. This allows to suppose that the observed training effect can be associated with the specific features of the neuronal cortical activity.To test this hypothesis we analyzed the values of wavelet energy, calculated for all EEG channels in the frequency bands using the repeated measures ANOVA as in [20]. The EEG channel and the experimental session were considered as the within subject factors. The most significant results were observed in the β-band, (average wavelet energy of each EEG channel along with their quartile ranges and standard deviations are presented in Fig. 3 for all three sessions). For the β-band ANOVA with the Greenhouse-Geisser correction revealed significant change of the wavelet energy between the sessions ($F_{1.252,13.775} = 5.983, p = 0.023$) and the significant change between the different EEG channels ($F_{2.185,24.03} = 10.992, p < 0.001$). The post hoc analysis based on the Wilcoxon signed rank test revealed the significant increase of τ_2 when compared with τ_1 ($Z = -2.353, p = 0.019$) and insignificant change between τ_2 and τ_3 ($Z = -1.098, p = 0.272$). At the same time, the significant increase was observed for τ_3 when compared with τ_1 ($Z = -2.589, p = 0.01$).

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IV. Conclusion

The obtained results confirm that the process of the body balance maintaining is controlled by the cortical neuronal activity. The decrease in spectral power in the alpha (8–13 Hz) and beta bands (14-40 Hz) were observed in the sensorimotor cortex during the balance keeping. That could possibly mean that the task of postural control demands activation of the task-related brain activity in frontal-parietal areas during active balance seeking but not so much during balance keeping. Moreover, the neuronal activity in the β-frequency band can be utilized as the neurophysiological marker of the subject's ability to maintain the equilibrium state. Latter is important for the human-machine systems aimed at restoring and training the human ability to maintain dynamic balance and stability of the body posture.

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