Dynamical analysis of the neural and equilibrium seeking movement activity

Vladimir Khorev
Center for technologies in robotics and mechatronics components
Innopolis University
Innopolis, Russia
Orcid: 0000-0001-6613-8940

Vadim Grubov
Center for technologies in robotics and mechatronics components
Innopolis University
Innopolis, Russia
v.grubov@innopolis.ru

Artem Badarin
Center for technologies in robotics and mechatronics components
Innopolis University
Innopolis, Russia
a.badarin@innopolis.ru

Semen Kurkin
Center for technologies in robotics and mechatronics components
Innopolis University
Innopolis, Russia
Orcid: 0000-0002-3438-5717

***Abstract*—This work is devoted to the study of the process of maintaining equilibrium in an experiment with a balance platform. The conducted experiment is very original in comparison with similar experiments conducted using stabilized platforms with remote control due to the presence of active feedback from the subject. We have analyzed the effect of learning from session to session during the experiment. We observe the changes in the patterns of electrical activity of the brain that occurred at the time of equilibrium for the main EEG activity frequency ranges.**

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

I. Introduction

In modern living conditions, humans are faced with the need to solve complex motor tasks in educational, labor, everyday life and sports activities, while high demands are made on him in terms of motor training [**?**], [1], [1]–[5]. Most of the studies in this field is devoted to the study of simple motor acts [2]–[4] or the imagination [5]–[7] of these acts. At the same time, the equilibrium of the human body in an upright position in the process of various motor activities seems at first glance a fairly simple function due to habituality its manifestations and natural formation from the day of birth. However, numerous studies of physiologists, clinicians, scientific researchers in the field of sports show that the equilibrium function is very complex and its value in human life is very great, and sometimes crucial [7]–[11]. In this work, we will try to expand the understanding of these processes with the experiment involving natural feedback for the subject performing on a balance platform. This is an important difference between this work and existing studies where subjects only passively response on the balance disturbances. 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]–[14], [16]. That means no effective learning and feedback essential for performance improvement [17].

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II. Experimental setup

We conducted a series of experiments involving the placement of subjects on the originally designed balance platform as shown in Fig. 1. The number of volunteer subjects was 20 (15 male, 5 female) aged from 25 to 42 years. We instructed all volunteers before conducting the research to observe the regime of full night rest for three days. We conducted the experimental study 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. While recording signals, subjects were standing on a balance platform. The design of the experiment included three 10-minute sessions with two rest breaks between them. Preliminary registration of the background (BG) activity of the subject without performing special instructions was carried out for 3 minutes.

All subjects were instructed to ensure balanced posture during their attempts. Subjects were not able to train their ability to maintain balance before the experiment, and thus we conducted the study with untrained volunteers. This is important because some studies have shown differences in the

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distribution of spectral activity between trained and untrained people. For example, the amplitude of task-related power decrease in high alpha band (10–12 Hz) was lower in athletes than in the non-athletes at right frontal, left central, right central, and middle parietal areas [17]–[19]. Despite this, nevertheless, the balance of the human body is limitedly stable due to the small footprint determined by the contours of the feet and the space between them, as well as the high location of the general center of mass of the body. Therefore, even the most insignificant internal or external influences can upset the balance and bring down the body.

During the experimental session, we were recoding EEG, EMG, angle and velocity of the balance platform signals simultaneously. Such criteria as the center of gravity position were not available for the recordings. EEG channels data were recorded continuously according to the standard "0–10" configuration. As shown on the scheme of the EMG electrodes in Fig. 1, arrangement included next muscles: Tibialis Anterior, Gastrocnemius, Rectus Femoris, Semitendinosus. 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 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-1926" (Medicom MTD company, Taganrog, Russian Federation) with multiple EEG channels. This device possessed the registration certificate of the Federal Service for Supervision in Health Care No. FCP 200700124 of 07.11.2014 and the European Certificate CE 538571 of the British Standards Institute. We filtered raw EEG signals with a band-pass filter with cut-off points at 1 Hz (HP) and 100 Hz (LP) and with a 50 Hz notch filter embedded in a hardware-software data acquisition complex.

III. Data analysis and results

Typical time series of an angle data from the balance platform is shown in Fig. 2. Yellow fields mark the successful attempts to maintain the equilibrium. For the analysis of behavioral characteristics during training, we used indicators such as the duration of the longest successful attempt (L_{max}) of maintaining equilibrium, the total duration of successful sections of maintaining equilibrium (L_Σ):

$$L_\Sigma = \sum_i L_i, \tag{1}$$

Total number of attempts to maintain equilibrium (N), the percentage of successful attempts:

$$R = \frac{N_{succ}}{N} 100\%, \tag{2}$$

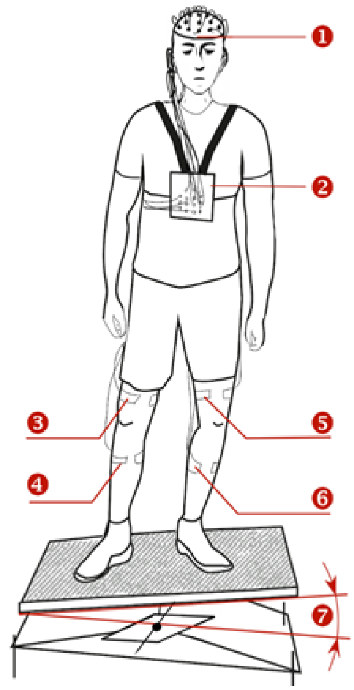

Fig. 1. Scheme of the experimental setup and EMG electrodes placing. 1 – EEG cap, 2 – Encephalan-EEG-recorder, 3 – Rectus Femoris EMG, 4 – Tibialis Anterior EMG, 5 – Gastrocnemius, 6 – Semitendinosus, 7 – the platform angle.

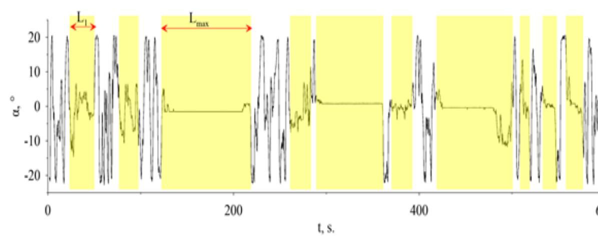

Fig. 2. The change of the angle during the experiment (based on the single subject data). Yellow fields mark the successful attempts to maintain the equilibrium.

Dynamics of changes between the characteristics are shown in Fig. 3 for sessions and for parts of sessions. We observe significant changes between sessions for L_{max}, N and L_Σ. As one can see on Fig. 3a) L_{max} increases from session to session. Most of the longest equilibrium intervals were observed in the 3rd session (15 out of 20 subjects have the longest interval in the 3rd session, four in the 2nd and one case for the 1st session). The length of these intervals was analysed 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 p = 0.007. The post hoc analysis based on the Wilcoxon signed rank test [20] revealed the significant increase for S2 when compared with S1 (p = 0.002), for S3 when compared with S2 (p = 0.006), for S3 when compared with S1 (p = 0.001). Based on the obtained results we have concluded that the maximal duration of the equilibrium state growths with the time spent

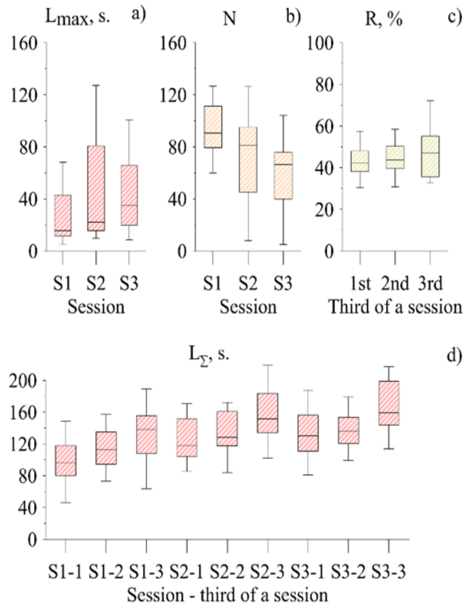

Fig. 3. distributions of a) the maximal balance keeping times L during the experimental sessions; b): the number of attempts to maintain equilibrium N during the experimental sessions; c) the success rate (R) distribution during the parts of the experimental sessions; d) the total duration of the equilibrium through the parts of all sessions; all characteristics are shown with their respective standard deviation and quartile ranges.

in the experiment. Overall number of attempts to maintain the equilibrium (successful or unsuccessful) decreases from session to session as shown on Fig. 3b). The length of these intervals was analysed 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 ($p = 0.001$). The post hoc analysis based on the Wilcoxon signed rank test revealed the significant increase for S2 when compared with S1 ($p = 0.001$), for S3 when compared with S2 ($p = 0.012$), for S3 when compared with S1 ($p = 0.001$). This effect is not so surprising, as the experiment is not very easy for the untrained subjects and humans start to wear due to fatigue [21], [22].

For the dynamics inside sessions, R and L_{Σ} were the most interesting. The percentage of successful attempts significantly increases during the session that demonstrates the process of successful learning during the exercise. A significant difference was observed for the different parts of sessions $p = 0.041$. The post hoc analysis based on the Wilcoxon signed rank test revealed the insignificant increase for the 2nd part when compared with the 1st part ($p = 0.166$), for the 3rd when compared with the 2nd ($p = 0.332$), but significant for the 3rd when compared with the 1st ($p = 0.009$).

Total duration of successful sections of maintaining equilibrium as can be seen on Fig 3d) is constantly increasing not only from session to session, but inside sessions as well. This characteristic can be used as the steadiest for the estimation of learning efficiency. For the characteristic of total duration we calculated the repeated measures ANOVA with

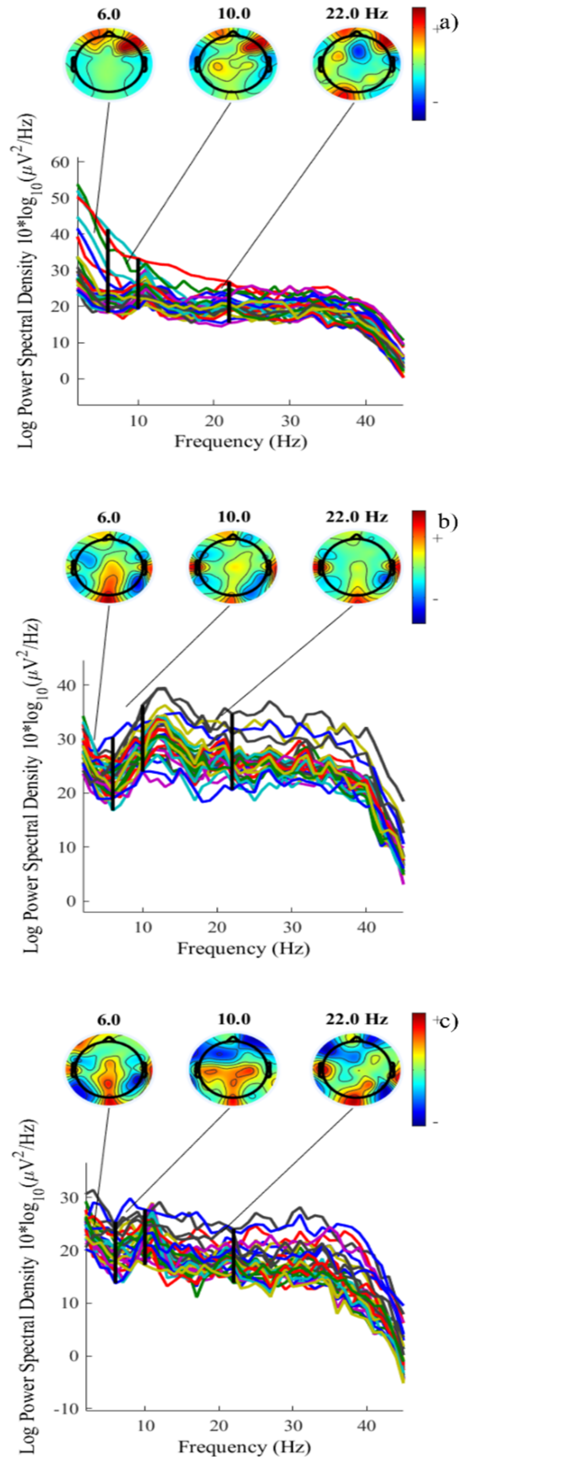

Fig. 4. Power spectral density and top plots of EEG activity on their respective central frequencies during a) background activity, b) longest equilibrium interval of the 1st session; c) longest equilibrium interval of the 3rd session

the Greenhouse-Geisser correction [23] revealed significant change of the value between the sessions (p = 0.001), parts of sessions (p = 0.001). The interaction effect partsession was insignificant (p = 0.462).

To observe the changes in brain activity during the experiment, let us look at the spectral density of EEG leads shown on Fig. 4. All curves were plotted for the 12 s. intervals of one subject during background activity prior to the beginning of session, longest equilibrium attempts in the 1st and 3rd sessions. Background activity (Fig. 4a)) demonstrates increase in the domain of low-frequency oscillations, located topologically in the frontal lobe area. These oscillations most likely connected with the intellectual activity during the anticipation of the exercise. The separate leads wavelet analysis conducted in our previous work demonstrated most apparent changes (amplitude decrease) on the O1, O2, Oz, Pz, Cpz leads. For the β-band of all EEG channels we calculated the repeated measures ANOVA with the Greenhouse–Geisser correction revealed significant change of the wavelet energy between the sessions (p = 0.023) and the significant change between the different EEG channels (p = 0.001). The interaction effect EEG channelsession was insignificant (p = 0.281).

Comparison of the longest equilibrium attempts in the 1st and the 3rd sessions demonstrates more focused activity in the sensorimotor area while the power spectral density shows overall decrease notable for the low beta-band frequency domain (13–29 Hz). This observation can be explained by the developed of neural efficiency proposed in some works for the explanation of the fact that neural activity is reduced in experts compared to untrained subjects.

IV. Conclusion

The obtained results confirm that untrained subjects were able to develop the ability to maintain equilibrium on a balance platform. The learning involves longer and more successful but less frequent attempts. Neural activity in the sensorimotor area of the cortex shows significant changes during balance maintaining process, accompanied by overall activity decrease. The neuronal activity on O1, O2, Oz, Pz, Cpz leads can be utilized as the neurophysiological marker of the subject ability to maintain the equilibrium state. This study supports the theory of the cerebral cortex involvement in maintaining posture during balance tasks.

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