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Analysis of muscle activation patterns during equilibrium seeking activity

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ABSTRACT

The main goal of this project was to identify the patterns of muscular activity of a person in the process of his interaction with the environment, as well as to identify mechanisms that make it possible to adapt behavior in response to changing external conditions. For this, we conducted a series of experiments with subjects placed in an unstable state. We carried out statistical analysis for the received signals of muscle activity. Based on the results of the analysis of behavioral characteristics, we revealed positive dynamics when subjects were reaching a state of balance and a pattern associated with training.

Keywords: signal analysis, correlation, electromyograms, equilibrium, balance

1. INTRODUCTION

According to statistics, approximately 30% of people aged 65 and over experience one or more falls, leading to injuries that cause moderate and serious harm to health.[1] These injuries increase the risk of death and can also lead to the loss of some motor functions. Falls usually occur due to external factors such as dirt or icing of the surface, poor lighting, type of shoes. However, internal factors such as age, pathology, fatigue, physical condition also contribute to falls.[2] Currently, more attention is paid to the study of human motor functions from the point of view of classification of EEG corresponding to various types of movements,[3,4] age-related changes,[6,7] rehabilitation,[5,8,9] etc. Man's control of the state of equilibrium,[10] as well as changes in this state[11] under the influence of internal and external factors, attracts the attention of the scientific community.[12–14] Balance control includes coordinated posture correction, for example, stabilization of the head and trunk position.[15] In environmental conditions, these adjustments depend on the reliability of sensory feedback and the planning and execution of complex motor factors.[16] Sensory and mechanical disturbances that affect the maintenance of a state of equilibrium include visual information flow,[17] somatosensory functions,[18] as well as motor reactions.[19]

Our idea was to determine the set of interacting muscles involved in maintaining balance, when performing tasks that require postural control[20] are involved in the control system including muscles of the thigh, and to investigate their interaction during learning. However, experiments with real movements require more interaction between muscles.[21–24] Analysis of EMG consistency and multiple regression analysis[25] show that it is necessary to use three or four pairs of muscles in one synergy.[26] The results of[27] highlight the ability of the posture control system to use asymmetric muscle combinations for achieving acceptable level of stability.

2. METHODS

We conducted a series of experiments involving the placement of subjects on the originally designed balance platform as shown on 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

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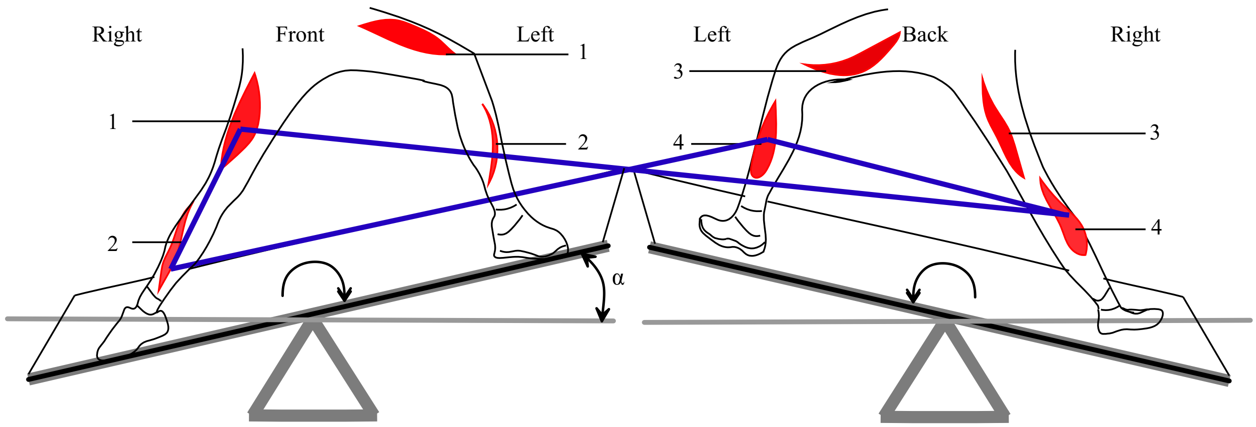

Figure 1. Schematic illustration of the pairs of muscles whose correlation coefficient significantly changes between the sessions with blue lines (1 – Rectus Femoris, 2 – Tibialis Anterior, 3 – Semitendinosus, 4 – Gastrocnemius).

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 activity of the subject without performing special instructions was carried out for five 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 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.[28] It should be noted that the balance of the human body is not indefinitely stable due to the small radius determined by the contours of the feet and the space between them, and in addition to the high location of the general center of mass of the body. Therefore, even some small-scale internal or external influences can upset the balance and bring the body out of a stable state.

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 "10–10" configuration. As shown on the scheme 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.[29] 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.

3. RESULTS

Based on the analysis of electromyography data, we identified characteristic regularities and patterns of muscle activity that are formed during successful balance training. The blue lines in Fig. 1 show the connections between pairs of this pattern. 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 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 in the experiment. Overall number of attempts to maintain the equilibrium (successful or unsuccessful) decreases from session to 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 ($p = 0.001$).

4. DISCUSSION

Since nerve synchronization is a mechanism involved in muscle formation, it is reasonable to expect a certain pattern of interaction between muscles that must be coordinated to maintain a balanced posture. Using the analysis of multichannelsignals based on the methods of statistical analysis and nonlinear dynamics features of musles activation was obtained[30] and it was shown the presence of a significant interaction between the muscles. Correlation coefficients between muscles were calculated to find mechanisms for training a person while maintaining balance. Statistical analysis of the correlation coefficient was performed, calculated from experimental EMG signals for each pair of muscles between three sessions using repeated measures analysis of variance (ANOVA). The muscle pairs for which the correlation changes were most significant between sessions are shown in Fig. 1. Based on the results described above, a model could be proposed and implemented to demonstrate the transition to balance maintenance. It should be noted that complex actions require strong interaction between muscles, but strong interaction between all muscles is ineffective and energy-consuming, so a living system requires a strategy of using a limited number of interactions to solve the problem.

5. CONCLUSION

The regularities of the process of training to maintain equilibrium were investigated both from the point of view of behavioral characteristics and from the point of view of muscle activity. Comparative analysis of the data on the angles of the platform, EMG allowed us to determine the moments of maintaining balance during the experimental sessions. Equilibrium was recorded if the platform angle was within the range of $\pm 19\circ$, and the angular velocity of the platform was within $\pm$ 0.03 rad s for at least a second. The distributions of the balance retention times during the experimental session show a tendency to increase for all subjects, which is most likely associated with the learning process of the subjects. The obtained results confirm that both model and untrained subjects were able to develop the ability to maintain equilibrium on a balance platform. The duration of the longest successful attempt changes significantly from session to session. It also showed that unlimited increment of correlation even between good pairs will not lead to the longer equilibrium duration time. The correlations between muscle pairs have rather narrow range of values helping to achieve better duration of balance keeping and suggest a consolidtate optimal configuration including both the muscle pattern and the pattern of correlations between the muscles.

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