2021 5th Scientific School Dynamics of Complex Networks and their Applications (DCNA) | 978-1-6654-4283-1/21/$31.00 ©2021 IEEE | DOI: 10.1109/DCNA53427.2021.9587315

Effect of the fatigue in the balance keeping experiment

Vladimir Khorev
Center for Technologies in Robotics and Mechatronics Components
Innopolis University
Innopolis, Russia
Orcid: 0000-0001-6613-8940

***Abstract*—In this work we 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 fatigue during experimental sessions. With the help of the statistical analysis we established that shin muscles were suffering from fatigue more than the hip muscles.**

***Index Terms*—EMG; fatigue; equilibrium; muscles; balance platform;**

I. Introduction

Currently, scientific interest is attracted by the processes occurring in the human body related to the performance of motor activity including age-related changes and rehabilitation [1]–[7]. Many found interesting the influence of both internal and external factors including equilibrium control. Control includes a coordinated correction of the undertical position in the conditions of an inhomogeneous environment. At the same time, the correction of the situation depends on the reliability of sensory feedback and planning and performing complex factors of motor actions, sensory and mechanical disorders that affect the condition of the body [8]–[13]. Effect of the fatigue is one the most interesting factors that could affect the perfomance of the equilibrium seeking task.

II. Experimental work

A series of experimental works in a group of 17 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. The duration of the experiment was about 45 minutes. During the recording of signals, subjects were standing on the balance platform. The structure of the experiment included three 10-minutes sessions with two 5-minutes rest pauses between them. For all sessions on the records of all subjects in this way were calculated total number of attempts, as well as their duration, start position of the platform Before going to a position close to zero slope. For marking successful attempts can use balance keeping duration parameters and the boundary angle of T_{EQ} from which the position is considered to be equilibrium. In the table I brief results of dispersion analysis are given. (ANOVA) for the number of attempts depending on the session factors, success, initial position of the platform. Significant changes in the number of attempts observed between the left and right initial position, successful and unsuccessful attempts. There is also interaction between the session factors and Success, session and position, success and position. In the table II brief results of dispersion analysis are given. For the duration of attempts depending on the same factors. Significant changes in duration of attempts are observed between sessions, trivially different for frequent and unsuccessful attempts, but do not depend on the initial position. Post-Factory analysis based on the criterion of Wilcoxon's iconic ranks showed meaningful increase in the duration of successful attempts for all sessions ($\Delta T_{12} = 2.608, p_{12} = 0.009; \Delta T_{13} = 3.535, p_{13} = 0.028; \Delta.T_{23} = 2.184, p_{23} = 0.028$). Meaningful difference between sessions for unsuccessful Attempts have not been detected.

TABLE I
Total attempts number [N] (ANOVA Summary).

Factors	dF_1	dF_2	**F**	**p**
$Session$	2	34	2.085	0.155
$Success$	1	17	72.757	0.000
$Left - Right$	1	17	5.742	0.028
$Session \times Success$	2	34	8.798	0.003
$Session \times Left - Right$	2	34	5.463	0.009
$Success \times Left - Right$	2	34	11.636	0.003
$Session \times Success \times Left - Right$	2	34	1.993	0.154

TABLE II
Mean attemp duration [Tmean] (ANOVA Summary).

Factors	dF_1	dF_2	**F**	**p**
$Session$	2	34	6.334	0.008
$Success$	1	17	31.878	0.000
$Left - Right$	1	17	1.643	0.217
$Session \times Success$	2	34	6.345	0.008
$Session \times Left - Right$	2	34	0.995	0.347
$Success \times Left - Right$	2	34	1.242	0.281
$Session \times Success \times Left - Right$	2	34	1.030	0.337

This work is supported by the President Program for Leading Scientific School Support(grant NSh-2594.2020.2).

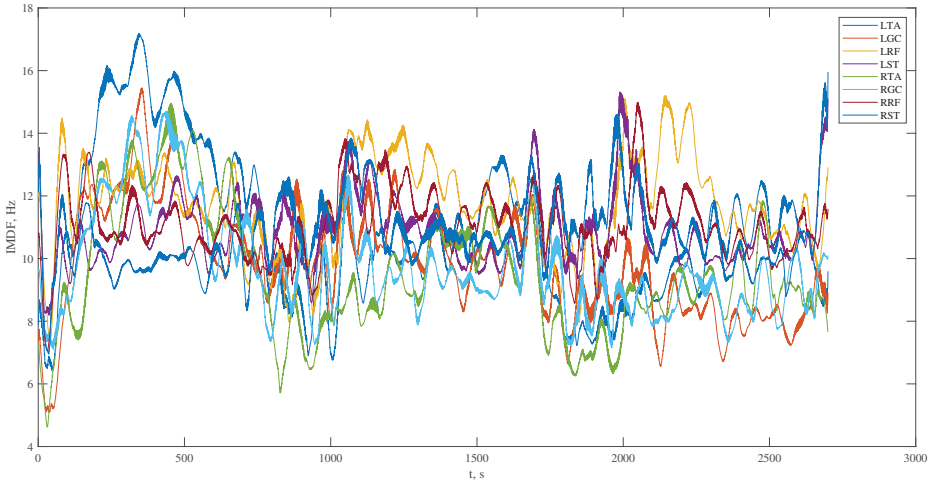

Fig. 1. The IMDF time series for each of the muscles during the experiment

III. Results

For the fatigue estimation we used the method from the work [14]. The instantenious median frequency of the sEMG Wigner-Ville distribution is suitable indicator of the muscle fatigue as the time-frequency distribution of the representative sEMG shows the variation of the instantaneous power spectrum. This variation is associated with the nonhomeginiety of the exercise. These variations may be attributed to the changes in muscle length, subsequent changes in muscle geometry, changes in firing rate, muscle fiber conduction velocity, continuous recruitment and de-recruitment of motor units and the movement of innervation zone with respect to electrode. On the Fig. 1 the IMDF time series for each of the muscles during the experiment is presented. It's easy to see that all of the curves demonstrate three relatively flat periods (corresponding to the experimental sessions). These curves are also drifting towards lower values. This indicates the increasing muscle fatigue for thr corresponding muscle. Mean values of IMDF during the session for each of the muscles were taken into account for the further research. For the obtained mean correlation coefficients, we performed within-session repeated measures ANOVA analysis with the Greenhouse-Geisser correction and revealed that shin muscles were suffering from fatigue more than the hip muscles (Left Tibialis Anterior $p < 0.01$ Left Gastrocnemius $p = 0.05$, Left Rectus Femoris $p = 0.78$, Left Semitendinosus $p = 0.81$, Right Tibialis Anterior $p = 0.04$ Right Gastrocnemius $p = 0.03$, Right Rectus Femoris $p = 0.53$, Right Semitendinosus 0.24). This study shows the importance of the lower leg muscles involvement in maintaining posture during balance tasks.

References

[1] Pitsik, E., Frolov, N., Hauke Kraemer, K., Grubov, V., Maksimenko, V., Kurths, J., and Hramov, A., Motor execution reduces eeg signals complexity: Recurrence quantification analysis study," Chaos: An Interdisciplinary Journal of Nonlinear Science 30(2), 023111 (2020).

[2] Chholak, P., Niso, G., Maksimenko, V. A., Kurkin, S. A., Frolov, N. S., Pitsik, E. N., Hramov, E. A., Pisarchik, A. N., "Visual and kinesthetic modes affect motor imagery classification in untrained subjects," Scientific Reports 9, 9838 (2019).

[3] Frolov, N. S., Pitsik, E. N., Maksimenko, V. A., Grubov, V. V., Kiselev, A. R., Wang, Z., and Hramov, A. E., Age-related slowing down in the motor initiation in elderly adults," Plos one 15(9), e0233942 (2020).

[4] Hramov, A.E., Maksimenko, V. A., Pisarchik, A. N., "Physical principles of brain-computer interfaces and their applications for rehabilitation, robotics and control of human brain states," Physics Reports 918, 1-133 (2021).

[5] Silvoni, S., Ramos-Murguialday, A., Cavinato, M., Volpato, C., Cisotto, G., Turolla, A., Piccione, F., and Birbaumer, N., Brain-computer interface in stroke: a review of progress," Clinical EEG and Neuroscience 42(4), 245–252 (2011).

[6] Maksimenko, V., Kuc, A., Frolov, N., Kurkin, S., Hramov, A. Effect of repetition on the behavioral and neuronal responses to ambiguous Necker cube images. Scientific Reports 11(1), 1–13 (2021).

[7] Kurkin, S., Badarin, A., Grubov, V., Maksimenko, V., Hramov, A. The oxygen saturation in the primary motor cortex during a single hand movement: functional near-infrared spectroscopy (fNIRS) study. The European Physical Journal Plus 136(5), 1–9 (2021).

[8] Rodrick, D. and Jayaprakash, V., Neural mechanisms of anticipatory balance control," Proceedings of the Human Factors and Ergonomics Society Annual Meeting 57(1), 915–919 (2013).

[9] Al-Dirini, R., Reed, M., Hu, J., and Thewlis, D., Development and validation of a high anatomical fidelity fe model for the buttock and thigh of a seated individual.," Ann. Biomed. Eng. 2016, 1–12 (2016).

[10] Markowitz, J. and Herr, H., Human leg model predicts muscle forces, states, and energetics during walking.," PLoS Comput Biol 12(5), e1004912 (2016).

[11] Der, R. and Martius, G., Self-organized behavior generation for musculoskeletal robots," Front. Neurorobot. 11, 8 (2017).

[12] Yao, S., Zhuang, Y., Li, Z., and Song, R., Adaptive admittance control for an ankle exoskeleton using an emg-driven musculoskeletal model," Front. Neurorobot. 12, 16 (2018).

[13] Loram, I., Maganaris, C., and Lakie, M., Paradoxical muscle movement in human standing," J Physiol 556, 683–689 (2004)

[14] Karthick, P. A., Ramakrishnan, S. Surface electromyography based muscle fatigue progression analysis using modified B distribution time–frequency features. Biomedical Signal Processing and Control, 26, 42–51 (2016).