An Approach for Experimental Investigation of Muscle Activities of the Upper Limbs (Right versus Left Arm) of Healthy Subjects and Post-stroke Patients – A Preliminary Study

Rositsa Raikova[1*], Silvija Angelova[1], Vihren Chakarov[1], Dimo Krastev[2]

[1]*Institute of Biophysics and Biomedical Engineering*
Bulgarian Academy of Sciences
105 Acad. G. Bonchev Str., 1113 Sofia, Bulgaria
E-mails: rosi.raikova@biomed.bas.bg, sis21@abv.bg, vihren@biomed.bas.bg

[2]*Medical University of Sofia, Medical College "Jordanka Filaretova"*
3 Jordanka Filaretova Str., 1606 Sofia, Bulgaria
E-mail: dimo_krustev@mail.bg

[*]*Corresponding author*

Received: April 2, 2014 **Accepted: June 20, 2014**

Published: June 30, 2014

Abstract: *The experimental estimation of muscle activities in post-stroke patients with limb motor deficit is often based on surface electromyography signals (EMGs). Besides EMGs processing and interpretation difficulties, the differences in motor control of dominant and non-dominant arm have to be taken into account since the stroke can injure either left or right limb.*

Different motor tasks (under static conditions – different postures, and dynamic ones, i.e. elbow flexions/extensions in the sagittal and in the horizontal planes) were performed consecutively with the dominant and the non-dominant arm of two healthy volunteers and with the non-affected and the affected arm of two stroke patients. Surface EMGs of seven muscles were recorded using a Noraxon telemetric system.

Two custom-made programs written in MATLAB were developed, separately for processing the data from static and dynamic motor tasks. At first the EMG signals were filtered, rectified and smoothed. For static tasks power-frequency analysis was performed, calculating different parameters (mean and median frequency, area under power function, mean values of the smoothed signals, which would be used as coefficients for normalization, etc.). For dynamic tasks one trial of flexion/extension motions was chosen for visual expectation through the saved video records. An analysis of synergistic and antagonistic muscle activities was performed.

Keywords: *EMG signals, Upper limb, Stroke patients.*

Introduction

Stroke is a neurological condition, causing neurogical deficits due to occlusion or rupture of blood vessels supplying the central nervous system. Muscle weakness (loss of muscle force and mass, decrease of muscle strength), spasticity and loss of coordination, limited range of joint motions commonly occur in the limbs of stroke patients [21], thus reducing considerably the functionality of the affected upper or/and lower limbs.

There are two affected issues following initial post-stroke recovery: the muscle structure and connective tissues and the nervous system control mechanisms on movements. Regarding the first changes, it is reported that the muscles of the affected limbs have: fiber length reduction, muscle mass loss, smaller pennation angle, more stretched and compliant tendons [9]. Regarding the motor units of the affected muscles the following is reported: decrease of motor unit firing rates and of the degree of synchronization [4, 10, 15] and an abnormal recruitment [6]. It is reported also that paretic muscles have a tendency toward atrophy of type II fibers [19]. An abnormal joint coupling was also found [12, 17]. A general opinion exists that the most damaged are the neuronal commands and working together (synchronization) of different synergistic and antagonistic muscles [3, 8, 10]. According to [13] all direct functional connections to muscle following stroke recovery come from the contralateral motor cortex. The different effects of the lesion on the proximal and the distal muscles appear to be associated with the strength of the corticospinal pathway. It is stated [5] that the primary source of movement dysfunction in many hemiparetic stroke patients is likely neither spasticity nor muscular weakness but abnormal movement coordination. Also reported are: a formation of novel schemes of coactivation of shoulder abductors with elbow flexors; coactivation of shoulder adductors with elbow extensors; reduction in the number of possible muscle combinations or in the number of possible synergies in the paretic limbs. This reduction could result from loss of descending commands, as well as from loss of selective control of muscle coactivations. Hughes et al. [11] however, found a wide variation in muscle activation patterns in terms of timing and amplitude during performing dynamic tasks by ***healthy adults*** as well.

Both differences, mentioned above, between affected and non-affected limbs have to be taken into account with special attention because of natural differences between dominant and non-dominant extremities, especially in the upper limbs [7, 20]. For example, greater slow type muscle fibers content in muscles of the dominant compared to the non dominant arm is reported, meanwhile no difference in EMG median frequency was observed. According to [1], due to increased number of slow twitch fibers lower average firing rates, lower recruitment thresholds, and greater firing rate are expected in the dominant arm.

The aim of the paper is: 1) to develop suitable experimental setup and computer program packages for investigation of the EMG activity of upper arm muscles and for comparison between dominant and non-dominant arm for healthy subjects and between non affected and affected arm for stroke patients; 2) to apply them for normal subject and for stroke patients and to make conclusions about the possibility to use EMG signals for diagnosis and rehabilitation purposes.

Methods

Experiments

The experimental procedure was described in details in [2]. The surface EMGs from 7 muscles were recorded and stored for further processing, first at the dominant and after that at the recessive upper limbs of two healthy subjects (a woman aged 57 and a man aged 25 – ***Subject 1*** and ***Subject 2***) and at the non-affected and after that at the affected arms of two post-stroke patients (a woman aged 58, 13 month after stroke and a man aged 39, 3 months after stroke – ***Patient 1*** and ***Patient 2***). The four persons were right handed. They filled in an inquiry card and gave informed consent. In both patients the left arm was affected. They were both in good condition and with very well recovered left arm function, so they were able to perform the required tasks.

The investigated muscles were:

(1) pars acromialis of m. deltoideus (**DELacr**),
(2) pars clavicularis of m. deltoideus (**DELcla**),
(3) pars spinata of m. deltoideus (**DELspi**),
(4) m. biceps brachii (**BIC**),
(5) caput laterale of m. triceps brachii (**TRIlat**),
(6) caput longum of m. triceps brachii (**TRIlong**), and
(7) m. brachioradialis (**BRD**).

The reference electrode was placed at the scapular acromion. The telemetric system Telemyo 2400T G2 of Noraxon Inc. and Ag/AgCl circle electrodes "Skintact-premier" F-301 were used [18]. The sampling frequency was 1500 Hz and the maximal recording time of each motor task was one minute.

A total of ten motor tasks were performed (see in [2]), only 5 of them were chosen for processing in this paper. During all tasks the person was seated in a chair without elbow-rests. Static tasks were maintenance of two postures for one minute (hanging arm downwards in the sagittal plane and stretching arm forward in the horizontal plane). Motions were: three trials of maximal elbow flexion in the sagittal plane starting from fully extended arm downwards without and with load of 0.5 kg (***FSP***, ***FSP + Load***); three trials of maximal elbow flexion in the horizontal plane without and with load of 0.5 kg (***FHP***, ***FHP + Load***) starting from arm in the horizontal plane with fully extended elbow (for more details see in [2]). Additionally maximal isometric contractions against resistance were recorded aiming to ensure maximal isometric forces of the investigated muscles for further normalization.

EMG signal processing

The data from the EMGs of the 7 muscles, saved in text format, was input of two custom-made computer programs written in MATLAB. The first one processes the data from the static tasks. It includes: two specially designed high-pass Butterworth filters removing QRS complexes; one band-pass filter removing 50 Hz influence of the electrical set; one low-pass Butterworth filter removing noise; rectification and smoothing (151 samples, 0.1 s time interval). A time period $\mathbf{\Delta t_1}$ with 15 seconds duration was visually chosen with minimal artifacts (Fig. 1a). Power-frequency analysis (Fast Furrier Transformation) was performed over this time window and the two normalized to their maximal value curves for the left and right arm were superimposed for comparison. For this time period $\mathbf{\Delta t_1}$ mean values for each channel were calculated, thus 7 coefficients $\boldsymbol{k_i}$ (i = 1, 2, …, 7) were obtained for further normalization of the EMGs of each muscle. The power-frequency functions were further processed for easy comparison between the right and the left arm (affected and non-affected, respectively). The mean value of the power was calculated for the following frequency intervals [20-40] Hz, [40-60] Hz, …, [220-240] Hz (Fig. 1b,c). The following parameters were also calculated for the power distribution for each muscle EMGs: mean frequency (**MNF**), median frequency (**MDF**) and the area (**APF**) under the power-frequency function between 20 Hz and 250 Hz. According to Phinyomark et al. [16]

$$\mathbf{MNF = \Sigma f_i / \Sigma P_i f_i},$$

where $\mathbf{P_i}$ is the power of the frequency $\mathbf{f_i}$ and the **MDF** is this frequency which divides the area under the power function in halves.

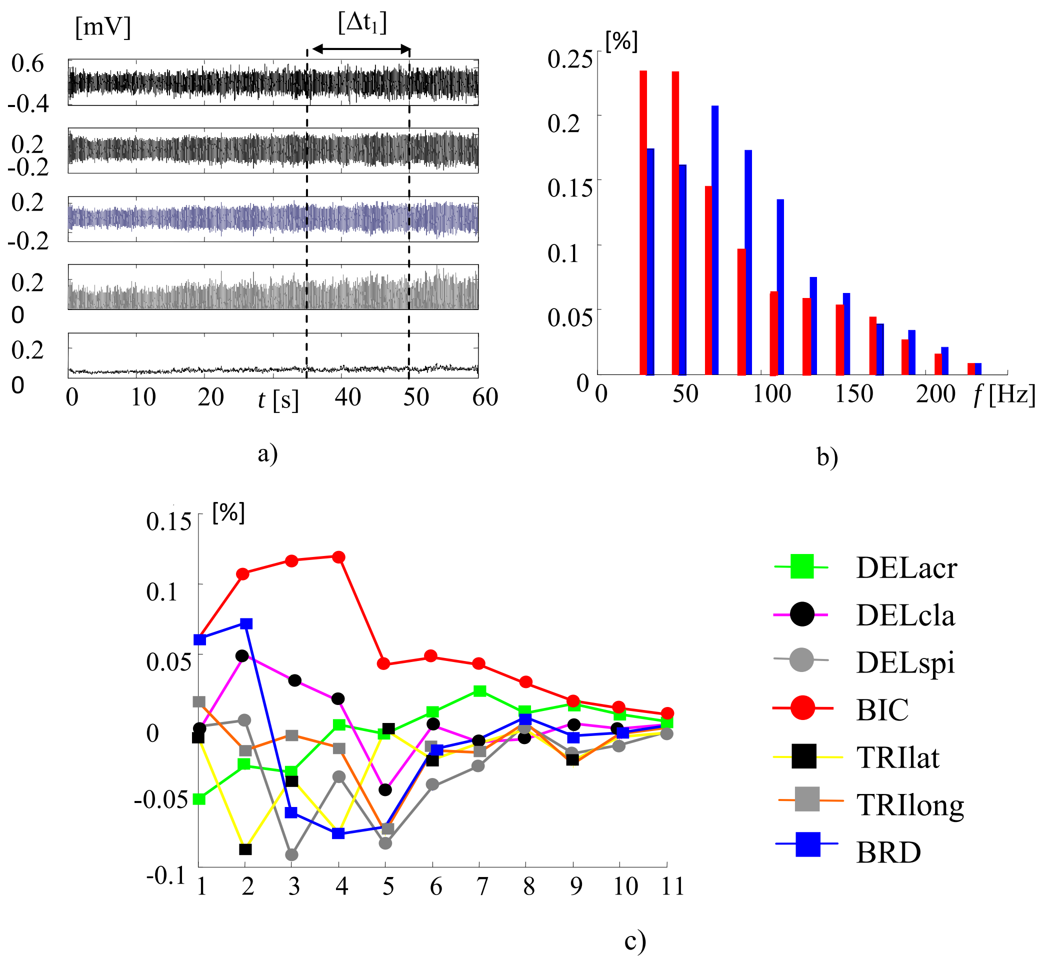


Fig. 1 Successive steps of EMGs processing for static tasks
a) ***Patient 1***, maintenance of a posture for one minute (stretching arm forward in the horizontal plane), **BIC**, left affected hand, from up to down: raw signal, signal after high-pass filtering, signal after low-pass filtering, signal after rectification, signal after smoothing. Note that the scales of the vertical axis are different.
b) Normalized frequency-power dependence compared for the right (red) and the left (blue) arm, the Fourier transformation is made within the time interval $\mathbf{\Delta t_1}$ = 15 s (from 35 s to 50 s). ***Patient 1***, **BRD**, the same motor task. Each column present' the mean of the normalized power for 11 frequency intervals: 20-40 Hz, 40-60 Hz, …, 220-240 Hz.
c) Differences between normalized power for the 11 frequency intervals between right and left hand for all muscles for ***Patient 1***, for the same motor task.

For dynamic task the program contains the same initial steps: filtering, rectification and smoothing (Fig. 2a). After that the data were normalized by using the calculated coefficients $\boldsymbol{k_i}$. Figures with the three trials of flexion/extension, where each channel is normalized to its maximal value were generated to investigate muscle synergistic and antagonistic action, i.e. to detect when the respective muscle starts or finishes its activity and when it reaches its maximal activity (Fig. 2b). Only the best trial among the three ones is taken for further consideration and the data are cut for visualization only during the time interval $\mathbf{\Delta t_2}$. The times of the peak activity during flexion movement were calculated. The motions were also inspected through the video records in Noraxon experimental system. In addition, using the same program, the data from the maximal isometric contractions were processed and other normalization coefficients k_i were calculated by obtaining the maximal EMGs value of each channel during the whole time duration of one minute.

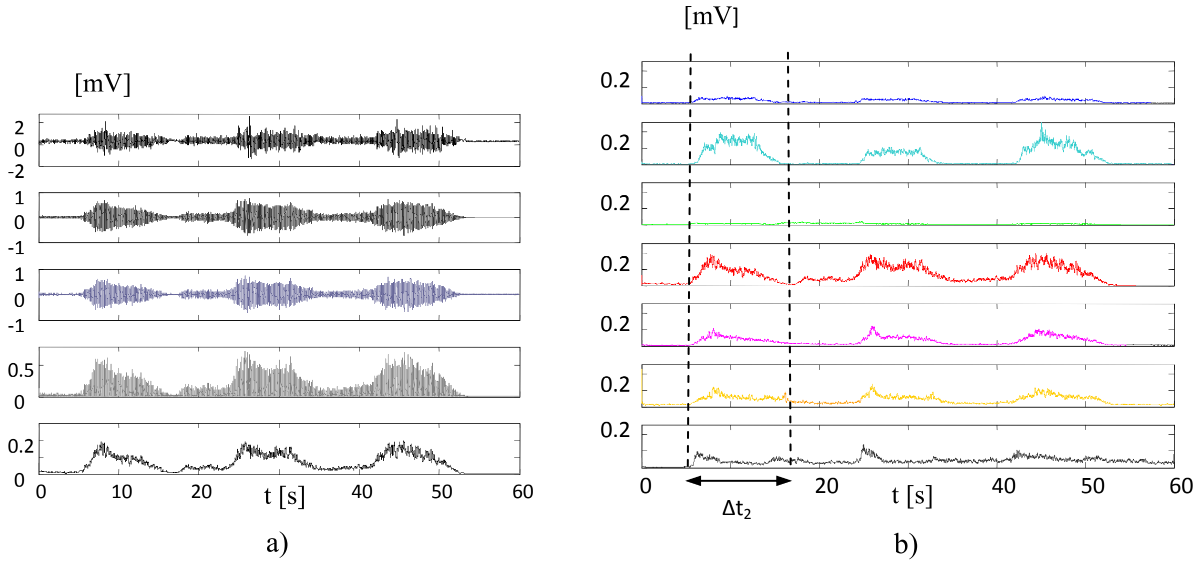


Fig. 2 Processing of EMGs during dynamic tasks
a) **BIC**, ***FSP + Load***, ***Patient 2***, left affected arm, from up to down, raw signal, high-pass filtering, low-pass filtering [14], rectification, smoothing. Note that the scales of the vertical axis are different;
b) smoothed, normalized to the values obtained during maximal isometric contractions against resistance, signals of all muscles for the same movement, ***Patient 2***, left affected arm, from up to down: **DELacr**, **DELcla**, **DELspi**, **BIC**, **TRIlat**, **TRIlong** and **BRD**.

Results

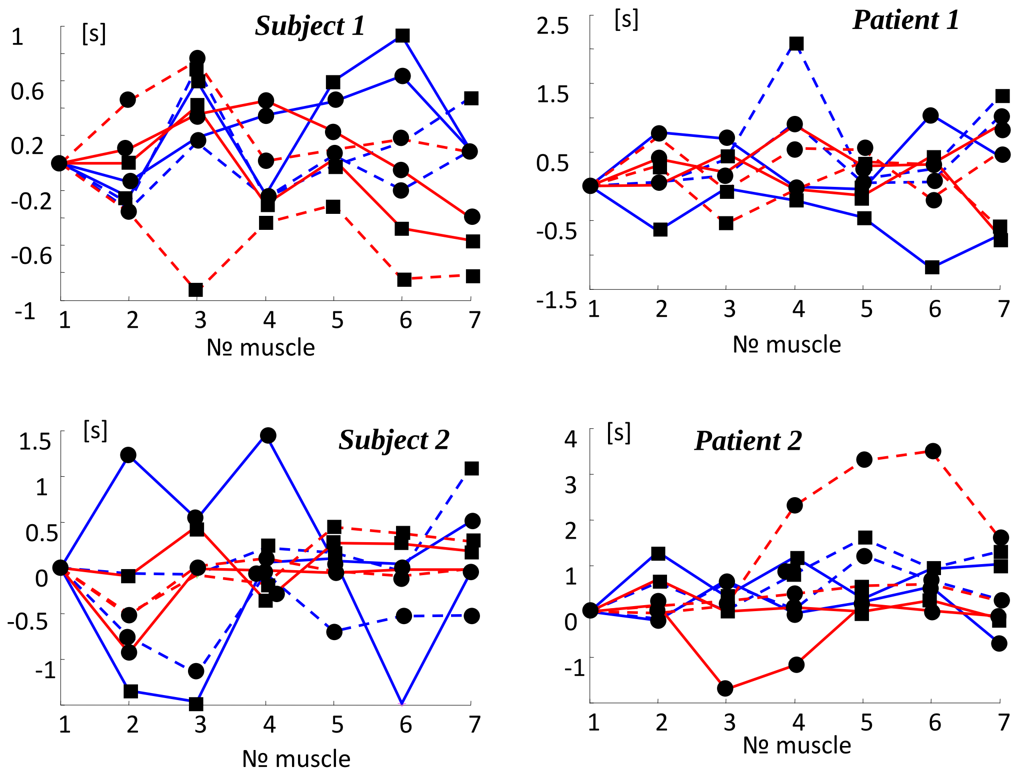
Static tasks

The successive steps of EMGs processing is shown in Fig. 1a. The filtered, rectified and smoothed signal is stable for all muscle and no sign of fatigue during one minute pose maintenance was observed. The comparison between the frequency distribution of the left and the right arm (Fig. 1b and 1c) for all muscles did now show a stable tendency. For some frequency intervals power values for the right arm were bigger, for others it was vice versa.

The same referred to the mean and median frequencies. In particular, it was observed for both patients that the median frequency of **BRD** was higher for the left hand. While for both healthy subjects the inverse case occurred. Other observation was that the area under power function between 20 Hz and 250 Hz of **BIC** for healthy subjects for all frequency intervals was always higher for their left hands comparing with right ones and inverse case was found for the patients.

Dynamic tasks

Processed signals of all investigated movements (Fig. 2a) show that the chosen steps of processing are suitable and coordination between the 7 muscles is well observed visually (Fig. 2b). The chosen quantitative parameter, however, i.e. the maximal value of the EMG signal during one flexion trial (Fig. 3) does not show a stable tendency for muscle synchronization. The same referred to the start times of muscle activities which could not calculated precisely.



FHP, FHP + Load, FSP, FSP + Load, ■ left hand, ● right hand
№ muscles: 1 – **DELacr**, 2 – **DELcla**, 3 – **DELspi**, 4 – **BIC**, 5 – **TRIlat**, 6 – **TRIlong**, 7 – **BRD**

Fig. 3 Time moments when the maximal values of the EMG signals during one flexion trial were reached for the two subjects and the two patients.
As reference for each line the time where the maximal value of muscle **DELacr** is reached is taken. So, positive values mean that these muscles reach their maximal values after this muscle and the negative – before this muscle.

Conclusions

The power-frequency analysis during static tasks did not show stable global differences between left/right (affected/unaffected) arms. It could be concluded that the activation of the motor units was strictly individual and the variability was so broad, comparing left to right arm that this analysis could not help for estimation of stroke after affects in well recovered patients. Probably the condition has not damaged the low-level muscle structures, namely motor units.

The visual inspection of the motions using the video records showed that the patients used different strategies of non affected and affected limb and this referred mainly to the shoulder joint. They compensated the motions with activating other muscle groups. For example ***Patient 1*** performed early shoulder abduction with the affected limb and the limb was not aligned with the forearm, but was ulnarly abducted. For ***Patient 2***, during the ***FSP***, before the start of the elbow motion, a shoulder flexion was observed together with elbow supination, and while returning the arm back to start position, the limb was pronated.

Globally, inspecting the synchrony of the EMGs of the 7 muscles during the motions, it could be concluded that the coordination of the muscles is similar for left/right (affected/unaffected) limb. However, this could not be proved by a quantitative analysis. The visual inspection found an increasing and different activity of the muscle **DEL**. To estimate the quantitative parameters of this observation the angles in the shoulder joint should be measured.

Acknowledgements

This study was partly supported by the Bulgarian National Science Fund, Grand No. DMU 03/75 and by Bilateral Agreement between the Bulgarian Academy of Sciences and Polish Academy of Sciences.

References

1. Alexander A., C. De Luca, Z. Erim (1998). Hand Dominance and Motor Unit Firing Behavior, The American Physiological Society, 80, 1373-1382.
2. Angelova S., R. Raikova, V. Chakarov, H. Aladjov (2013). Estimation of the Upper Arm Motor Deficit in Stroke Patients using EMG Signals – A Preliminary Study, Series on Biomechanics, 28(1-2), 20-27.
3. Cheung V. C., L. Piron, M. Agostini, S. Silvoni, A. Turolla, E. Bizzi (2009). Stability of Muscle Synergies for Voluntary Actions after Cortical Stroke in Humans, Proc Nat Acad Sci USA, 106(46), 19563-19568.
4. Colebatch J. G., S. C. Gandevia, P. J. Spira (1986). Voluntary Muscle Strength in Hemiparesis: Distribution of Weakness at the Elbow, Journal of Neurology, Neurosurgery and Psychiatry, 49, 1019-1024.
5. Dewald J. P. A., S. Sheshadri, M. L. Dawson, R. F. Beer (2001). Upper-limb Discoordination in Hemiparetic Stroke: Implications for Neurorehabilitation, Top Stroke Rehabil, 8(1), 1-12.
6. Dewald J. P., P. S. Pope, J. D. Given, T. S. Buchanan, W. Z. Rymer (1995). Abnormal Muscle Coactivation Patterns during Isometric Torque Generation at the Elbow and Shoulder in Hemiparetic Subjects, Brain, 118, 495-510.
7. Diederichsen L. P., J. Nørregaard, P. Dyhre-Poulsen, A. Winther, G. Tufekovic, T. Bandholm, L. R. Rasmussen, M. Krogsgaard (2007). The Effect of Handedness on Electromyographic Activity of Human Shoulder Muscles during Movement, Journal of Electromyography and Kinesiology, 17(4), 410-419.
8. Ellis M. D., A. M. Acosta, J. Yao, P. A. Dewald (2007). Position-Dependent Torque Coupling and Associated Muscle Activation in the Hemiparetic Upper Extremity, Experimental Brain Research, 176(4), 594-602.
9. Gray V., C. L. Rice, S. J. Garland (2012). Factors that Influence Muscle Weakness Following Stroke and their Clinical Implications: A Critical Review, Physiotherapy Canada, 64(4), 415-426.
10. Hu X. L., K. Y. Tong, L. K. Hung (2006). Firing Properties of Motor Units during Fatigue in Subjects after Stroke, Journal of Electromyography and Kinesiology, 16, 469-476.
11. Hughes A. M., C. T. Freeman, J. H. Burridge, P. H. Chappell, P. L. Lewin, R. M. Pickering, E. Rogers (2009). Shoulder and Elbow Muscle Activity during Fully Supported Trajectory Tracking in Neurologically Intact Older People, Journal of Electromyography and Kinesiology, 19, 1025-1034.
12. Kline T. L., B. D. Schmit, D. K. Kamper (2007). Exaggerated Interlimb Neural Coupling Following Stroke, Brain, 130, 159-169.
13. Mima T., K. Toma, B. Koshy, M. Hallett (2012). Coherence between Cortical and Muscular Activities after Subcortical Stroke, Stroke, 32, 2597-2601.

14. Neto O. P., E. A. Christou (2010). Rectification of the EMG Signal Impairs the Identification of Oscillatory Input to the Muscle, Journal of Neurophysiology, 103, 1093-1103.
15. O'Dwyer N. J., L. Ada, P. D. Neilson (1996). Spasticity and Muscle Contracture Following Stroke, Brain, 119, 1737-1749.
16. Phinyomark A., S. Thongpanja, H. Hu, P. Phukpattaranont, C. Limsakul (2012). The Usefulness of Mean and Median Frequencies in Electromyography Analysis, Computational Intelligence in Electromyography Analysis – A Perspective on Current Applications and Future Challenges, Ganesh R. Naik (Ed.), 195-220.
17. Prange G. B., M. J. A. Jannink, A. H. A. Stienen, H. van der Kooij (2010). An Explorative, Cross-Sectional Study into Abnormal Muscular Coupling during Reach in Chronic Stroke Patients, Journal of Neuroengineering and Rehabilitation, 7, doi: 10.1186/1743-0003-7-14.
18. Raikova R., K. Tahtakov, V. Chakarov (2011). Technical Device for Prevention of Spinal Column Disorders. Pilot EMG Study for Estimation of Back Muscle Activity, Int J Bioautomation, 15(2), 115-130.
19. Toffola E. D., D. Sparpaglione, A. Pistorio, M. Buonocore (2001). Myoelectric Manifestations of Muscle Changes in Stroke Patients, Arch Phys Med Rehabil, 82(5), 661-665.
20. Williams D. M., S. Sharma, M. Bilodeau (2002). Neuromuscular Fatigue of Elbow Flexor Muscles of Dominant and Non-Dominant Arms in Healthy Humans, Journal of Electromyography and Kinesiology, 12, 287-294.
21. Wu Y-N., S-C. Huang, J-J. J. Chen, Y-L. Wang, M. Piotrkiewicz (2004). Spasticity Evaluation of Hemiparetic Limbs in Stroke Patients before Intervention by Using Portable Stretching Device and EMG, Journal of Medical and Biological Engineering, 24(1), 29-35.

Prof. Rositsa Raikova, D.Sc.
E-mail: rosi.raikova@biomed.bas.bg

Rositsa Raikova was born in Shoumen, Bulgaria on 16 October, 1955. She received her Ph.D. in Biomechanics in 1993. She then worked in the Institute of Mechanics and Biomechanics at the Bulgarian Academy of Sciences. Now she is Professor at the Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Sciences and head of the Department "Biomechanics and control of movements". Her research interests are in the field of biomechanics and motor control of the human limbs.

Silvija Angelova, Ph.D. student
E-mail: sis21@abv.bg

Silvija Angelova obtained her M.Sc. degree in Kinesitherapy in orthopedy and traumatology at National Sport Academy "Vasil Levski", Sofia in 2008. Presently works on her Ph.D. in Department "Biomechanics and control of movements", Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Science. Her main interests are in the field of neurological and muscle function in norm and pathology.

Assoc. Prof. Vihren Chakarov, Ph.D.
E-mail: vihren@biomed.bas.bg

Vihren Chakarov graduated the Medical Academy in Sofia, Faculty of Medicine 1976-1984. His special courses were of psychometrics (1992) and of EEG and clinical electrophysiology (1993). His professional experience is: 1. assistant professor in the Brain Research Institute, Department of Electrophysiological Correlates of Behavioral Reactions 1985-1995; 2. assistant professor in the Centre of Biomedical Engineering, Department of Analysis and Modeling of the Excitation of Biological Structures, 1995-2009. Since 2009 he is associate professor in Biomechanics and Control of the Movement Department of the Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Sciences, Sofia. Vihren Chakarov's professional interests are: 1. Electrophysiological correlates of auditory information cognitive processing in normal subjects and in patients with neurological and psychiatric disorders; 2. High resolution EEG, 3D reconstruction depending on the individual anatomy and electrophysiological frequency domain analysis during motor tasks in normal subjects and in patients with neurological disorders.

Assoc. Prof. Dimo Krastev, Ph.D.
E-mail: dimo_krustev@mail.bg

He was born in Sofia, Bulgaria, 1964. Dimo Krastev graduated the Medical University in Sofia, Faculty of Medicine 1994, Faculty of Dental Medicine 1999. In 2011 he graduated Faculty of Public Health. He received Ph.D. in 2008. His special courses were of neuroanatomy (1996) and of medical Rehabilitation (1999). Since 2009 he is associate professor in Anatomy, histology, cytology and embryology in Medical University – Sofia, Medical College "J. Filaretova".