ISSN 1392 – 1215 ELECTRONICS AND ELECTRICAL ENGINEERING 2010. No. 8(104)
ELEKTRONIKA IR ELEKTROTECHNIKA

T 115 MEDICINE TECHNOLOGY
MEDICINOS TECHNOLOGIJA

# Wavelet-Based Entropy Analysis of Electromyography during 100 Jumps

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## Introduction

Surface electromyography (EMG) has been used to investigate muscle and/or central fatigue in healthy subjects under laboratory conditions, by evaluating the responses of the peripheral and central nervous system, to measure the degree of muscle activation. EMG represents the sum of electrical activities of many active motor units in the muscle. So the EMG signal is a form of electric manifestation of neuromuscular activation associated with contracting muscles and there exist many factors affecting its waveform and amplitude, which makes it very difficult to be analyzed. As a signal are often analyzed using amplitude and spectral based methods. Analysis of the median frequency of the power density spectrum defined as the frequency that divides the power density spectrum into two regions of equal power [1, 2, 19]. In 1990, Solomonow et al. [3] looking at individual contributions to motor unit recruitment found that increases in average conduction velocity was a major contributor to variantions in median frequency and suggested using the median frequency as the index to indentify different muscle's recruitment strategies. Many other parameters have been successfully applied to classify EMG signals [4–6], among which nonlinear dynamical analysis is a quite powerful approach. The calculations of most nonlinear dynamic measures, however, are frequently confronted with insufficient data points and noisy backgrounds. The nonlinear dynamic measure as Shannon wavelet entropy was created in 1990 by scientist Tsallis where he proposed a generalization of the celebrated Boltzmann-Gibbs entropic measure [9-10]. The Shannon wavelet entropy appears as a measure of the degree of order or disorder of the signal. It provides useful information about the underlying dynamical process associated with the signal.

EMG amplitude during prolonged maximal volume contraction decreases progressively in muscle and/or central fatigue condition of healthy subjects. Median frequency is the most popular method analyzing EMG signal for frequency, where fatigue can be deduced from EMG signal behavior when simultaneously a drop of median frequency. EMG signal of fatigued muscle decreases complexity that is applicable to noisy and short datasets of a signal. We coundn't find any scientifical articles where EMG signal would be analyzed by nonlinear dynamical measure Shannon wavelet entropy. We hypothesies that nonlinear dynamical measure as Shannon wavelet entropy will help to detect changes of fatigued muscle complexity, where the complexity decreases in muscle fatigue condition. So the aim of the present study was to estimate the complexity of electromyography signals by using wavelet-based Shannon entropy.

## Materials and methods

**Subjects** — healthy and physical active women (n=9) with normal menstrual cycle, whom age 19—23 years, body weight — 58,2 ± 6,1 kg, height — 168,4 ± 5,6 cm. All the participants didn‘t use oral contraceptives during 6 month and had regular menstrual cycle. Subjects were physically active but did not take part in any formal physical exercise or sport program. They had not been involved in any jumping or leg strength training programs during recent years. Each subject read and signed a written informed consent form consistent with the principles outlined in the Declaration of Helsinki. Ethical approval was obtained from Kaunas regional biomedicine of ethics committee (report number BE-2-24).

## Surface electromyography measurements

Bipolar Ag-AgCl surface electrodes were used for EMG recordings (silver bar electrodes, diameter 10 mm, centre-to-centre distance 20 mm) of the long head of the vastus lateralis and biceps femoris (DataLog type no. P3X8 USB, Biometrics Ltd, Gwent, UK). The skin at the electrode site was shaved and cleaned with alcohol wipes. The electrodes were placed half way on a line between ischial tuberosity and fibula head. The ground electrode was positioned on the patella of the same leg. EMG signals were recorded by amplifiers (gain 1000) with signal measurement using a third order filter (18dB / octave) bandwidth of 20 – 460 Hz. The analogue signal was sampled and converted to digital form at sampling frequency of 1 kHz. The EMG signal was telemetered to a receiver that contained a differential amplifier with an input impedance of 10 MΩ, input noise level was less than 5 $\mu$V and the common mode rejection ratio was higher than 96 dB. Before the recordings of EMG, we set 3V for chanel sensivity, 4600 mV for excitation output. Electromyography files were stored on the memory card and copied to PC biometrics Datalog (version 5.03; Biometrics Ltd, Gwent, UK) for data processing and analysis.

## Experimental protocol

After 10—15 min of not-intensive warming-up (slow pedaling velorgometer, with the heart rate of 120—130 b/min) 100 jumps on vertical jump force plate (New Test, Finland) from a 75 cm stage were made, when the participant got to amortization phase while the knee joints were flexed at the angle of 90 (hands on loins). The jump height was measured by formula [7]

$$h = \frac{g \times t_p^{\,2}}{8} = 1{,}22625 \times t_p^{\,2}, \tag{1}$$

where $h$ — jumping height (m), $g$ — acceleration of free fall down (9,81 m / s$^2$), $t_p$ — length of speed phase (s).

Before the jumping the electrodes, biosensers were attached and scoreless biosensers values were set.

## Data analysis and statistics

EMG values were analysed by Shannon wavelet entropy and median frequency using software written in Matlab (The MathWorks, Natick, MA).

By discrete wavelet transform (DWT) the wavelet energy at resolution level $j$ can be defined as

$$E_j = \frac{1}{n_j} \sum_{k=1}^{n_j} \left| C_j(k) \right|^2, \tag{2}$$

where $n_j$ is the number of wavelet detail coefficients $C_j(k)$ available at octave $j$. The total and relative wavelet energy can be obtained in the fashion:

$$E_{tot} = \sum_j E_j, \tag{3}$$

$$p = E_j / E_{tot}. \tag{4}$$

The wavelet Shannon entropy is defined as

$$S_w = -\sum_j p_j \cdot \log_2(p_j) / \log_2(N), \tag{5}$$

where $N$ – number of resolution levels.

The Symlet (sym5) wavelet was used here for analysis and the decomposition of EMG was performed at 6 lewels.

The fatigue index (FI) of jumping height (H) was calculated

$$\mathrm{FI} = \frac{(\text{H before exercise - H after exercise})}{\text{H before exercise}} \times 100, \tag{6}$$

where H before exercise — 3 first H values and H after exercise — 3 last H values.

By the same formula FI of EMG was calculated, where EMG before exercise — 3 first EMG values and EMG after exercise — 3 last EMG values.

The one-way analyses of variance (ANOVA) for repeated measurings were used to determine the effect of median frequencies and Shannon wavelet entropy separately of EMG vastus lateralis and biceps femoris properties before and after exercise. Descriptive data are presented as means ± SD. The level of significance was set at $P < 0.05$. In order to evaluate the relationship between changes in different indicators of jumping height and EMG values before and after exercise Pearson correlation coefficient (r) was established. Based on on alpha level of 0.05, sample size (n = 9), standard deviations and average level before and after exercise power of the test was calculated for all indicators. In all cases power of the tests was more than 80 per cent.

## Research results

The fatigue index of H was 6.53 ± 0.50%.

The median frequencies of EMG vastus lateralis have decreased in last ten jumps than in first ten, but no significant difference were found ($P > 0.05$) (table 1). The median frequencies of EMG biceps femoris have significantly decreased ($P < 0.05$) in last ten jumps than in first ten (table 1).

**Table 1.** The median frequencies of EMG vastus lateralis values in 1-10 jumps and in 91-100 jumps

| Muscles | Value of median frequency 1-10 jumps | Value of median frequency 91-100 jumps |
|---|---|---|
| Vastus lateralis | 64.96 ± 8.19 | 59.57 ± 9.23 |
| Biceps femoris | 36.98 ± 7.14 * | 25.50 ± 4.89 * |

Note: values are means ± SD. * significant ($P < 0.05$).

The Shannon wavelet entropy of EMG vastus lateralis have significantly ($P > 0.05$) increased in last ten jumps than in first ten (table 2). Shannon walvet entrophy of EMG biceps femoris have significantly decreased ($P < 0.05$) in last ten jumps than in first ten (table 2).

There was reverse significant relationship between changes in jumping heigh and Shannon wavelet entropy of EMG vastus lateralis (r=-0.5, $P < 0.05$) and Shannon wavelet entropy of EMG biceps femoris (r=-0.7, $P < 0.05$). There was no significant relationship between changes in jumping height and median frequency of EMG vastus lateralis (r=-0.3, $P > 0.05$), but there was reverse significant relationship between changes in jumping height and median frequency of EMG biceps femoris (r=-0.7, $P < 0.05$).

**Table 2.** The Shannon walvet entropy of EMG vastus lateralis values in 1-10 jumps and in 91-100 jumps

| **Muscles** | **Value of Shannon entropy 1-10 jumps** | **Value of Shannon entropy 91-100 jumps** |
|---|---|---|
| Vastus lateralis | 0.70 ± 0.044 * | 0.76 ± 0.04 * |
| Biceps femoris | 0.69 ± 0.05 * | 0.62 ± 0.06 * |

Note: values are means ± SD. * significant ($P < 0.05$).

## Discussion and conclusions

The findings of the present study indicate that during an eccentric exercise (100 jumps from 75 cm stage) the complexity of electromyography signals was higher using wavelet-based Shannon entropy than median frequency method. Pearson correlation coefficient was significantly stronger compare jumping height values with EMG Shannon wavelet entropy values. In the study [15] of influence of contraction intensity and muscle on median frequency of the quadriceps femoris (QF) where found that distinct differences in QF muscle structure and function are clearly apparent, as outlined. The results demonstrated that this fact is also reflected in the surface EMG signal. It is speculated that the sensitivity of median frequency to reflect progressive muscle fiber recruitment is dependent on the profile of the muscle [15]. Muscles that contain a relatively greater proportion of type I fibers may not demonstrate increases in median frequency with greater forces, despite the additional recruitment of these fibers [15]. As a result, the ability to document progressive muscle fiber recruitment with the median frequency statistic may be limiting in muscles with significant muscle fiber-type homogeneity [15]. This theory proves our data where median frequency of EMG vastus lateralis have decreased in last ten jumps than in first ten, but no significant difference were found ($P > 0.05$). The examination of an EMG frequency-domain statistic (median frequency) to describe intermuscular differences within the QF may provide of a greater number and higher density of $Na^+$ channels within the sarcolemma of fast-twitch muscle fibers, compared with slow-twitch muscle fibers, the generation of higher frequency action potentials, and hence EMG signals, from fast-twitch muscle fibers, the significant relation between the EMG median frequency and muscle fiber conduction velocity and the progressive recruitment of fast-twitch muscle fibers at higher contraction intensities [8,16-18]. Although it is well known that the surface EMG signal, as measured in the present study, provides limited evidence of specific motor unit recruitment or rate-coding changes, the observed median frequency statistic can be considered to be, in part, a reflection of muscle fiber-type activation [16].

During a prolonged voluntary contraction (100 jumps from 75 cm stage), fatigue is inevitable [11]. Dynamometry and EMG have been used to investigate muscle fatigue and central fatigue, by evaluating the responses of the central nervous system (i.e. changes in the motor unit recruitment) [11]. Many researchers support a positive correlation between the level of fatigue and EMG [13]. More specifically, during prolonged maximal volume contraction the EMG amplitude decreases progressively. In the present study median frequency and Shannon wavelet entropy of EMG biceps femoris values have significantly ($P > 0.05$) decreased in last ten jumps than in first ten which have showed muscle fatigue. In the other studies during maximal extension contractions the biceps femoris muscle was performing submaximal isometric contractions, as evidenced by the EMG [12]. In submaximal exercise, mainly slow, non-fatigable motor units would be expected to be recruited. Thus, during the coactivation contractions a separate population of muscle fibres of the biceps femoris muscle was recruited rather than those, which were fatigued by the dynamic flexion protocol. Different fibre populations of the biceps femoris muscle were fatigued in the dynamic protocol than recruited in the extension contractions [12]. The implication of this finding is that, during in vivo exercise, appropriate coactivation and co-ordination around the joint may be maintained, despite exercise induced fatigue of an antagonist muscle group. In the studies with fatiguing exercise showed significant decrease in the maximum voluntary EMG in males, but not in females, crediting this difference to a higher synchronization of neuromuscular activation [14]. Similarly, soleus and gastrocnemius EMG showed a significant decrease during the submaximal jumping. This implies a corresponding reduction in force (and leg stiffness). In the present study Shannon wavelet entropy of EMG vastus lateralis values have significantly ($P > 0.05$) increased in last ten jumps than in first ten. It is very well documented that when human subject perform prolonged voluntary contraction there are parallel declines in force and EMG [11,20]. In contrast, it has been shown that when human sustains a submaximal isometric trial, the EMG of the involved muscles increases [11]. The increase in EMG is mainly thought to reflect a neural-based compesation for the force failure of currently active motor units whereby there is a progressive increase in the recruitment and discharge rate of larger not fatigued motor units [11]. Moreover, it has been suggested that increases in both synchronization and spike duration and slowing of conduction velocity would tend to increase the amplitude of the surface EMG [11]. Furthermore, the possibility of the involment of spinal and supraspinal mechanisms cannot be excluded [11].

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Received 2010 06 02

**L. Daniuseviciute, K. Pukenas, M. Brazaitis, A. Skurvydas, S. Sipaviciene, I. Ramanauskiene, V. Linonis. Wavelet-Based Entropy Analysis Of Electromiography During 100 Jump // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 8(104). – P. 93–96.**

Muscle fatigue is a complex process that is most often defined as an exercise induced reduction in the ability of a muscle to generate force, and has been studied over numerous exercises for decades in an attempt to understand and indentify the mechanisms that lead to the loss of force production. One of muscle fatigue estimation is to assess changes in frequency measures of muscle electromiography signals. Electromiography signal is essentially a non-stationary signal, where muscle contraction can reach very high or small amplitudes. We used wavelet-based Shannon entropy to estimate the complexity of electromiography signals. Wavelet analysis is suitable tool for detecting and characterizing specific phenomena in time and frequency planes. Bibl. 20, tabl. 2 (in English; abstracts in English, Russian and Lithuanian).

**Л. Данюсевичюте, К. Пукенас, М. Бразайтис, А. Скурвидас, С. Сипавичене, И. Раманаускене, В. Линонис. Электромиограммный анализ применения метод вейвлет энтропии в продолжении ста прыжков // Электроника и электротехника. – Каунас: Технология, 2010. – № 8(104). – P. 93–96.**

Мускулатурная усталость – это комплекс процессов, который чаще всего определяется как уменьшение возможностей мышцы развить мышечную силу во время физического упражнения. Учёные уже несколько десятилетий исследуют, пытаются понять и определить механизмы, обуславливающие уменьшение мышечной силы. Одним из методов определения мышечной усталости является электромиограмма мышцы, которая позволяет установить электрическую активность мышцы. Электромиограмма является нестационарным сигналом, амплитуда которого зависит от активности мышцы. Для определения комплексности сигнала электромиограммы используем метод вейвлет энтропии. Метод вейвлет энтропии, позволяет определить и характеризовать частотно-временные свойства сигнала. Библ. 20, табл. 2 (на английском языке; рефераты на английском, русском и литовском яз.).

**L. Daniusevičiūtė, K. Pukėnas, M. Brazaitis, A. Skurvydas, S. Sipavičienė, I. Ramanauskienė, V. Linonis. Elektromiogramos analizė taikant vilnelių entropijos metodą 100 šuolių metu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – No. 8(104). – P. 93–96.**

Raumenų nuovargis - tai kompleksas procesų, kuris dažniausiai yra apibūdinamas kaip raumens galimybių išvystyti jėgą fizinio pratimo metu sumažėjimas. Jau keli dešimtmečiai mokslininkai bando suprasti ir nustatyti raumenų jėgos sumažėjimo mechanizmus. Vienas iš metodų raumenų nuovargiui įvertinti yra raumens elektromiograma, kuri leidžia nustatyti raumens skleidžiamų dažnių pokyčius. Elektromiograma yra nestacionarus signalas, kurį raumuo susitraukdamas gali sukelti padidindamas arba sumažindamas signalo amplitudę. Elektromiogramos signalo kompleksiškumui nustatyti taikėme vilnelių entropijos metodą. Vilnelių entropijos metodas yra įrankis, kuris leidžia įvertinti ir apibūdinti specifinius vyraujančius požymius laiko ir signalo dažnių kitimų plotmėje. Bibl. 20, lent. 2 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

DOI: 10.5755/j02.eie.9237