

## A SIMPLIFIED PROTOCOL TO ANALYSE THE EMG PARAMETERS IN BRACHIORADIALIS CONTRACTION

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Received May 4, 2012

*Abstract.* The new pedagogical ideas about teaching sciences suggest that hands-on experiment is the more effective way of attracting and motivating students. The objective of the present study was to investigate the function of the *brachioradialis muscle* (BR) in different contractions. The analysis of four of the most common sEMG parameters, offers the way to investigate the quality of functions of the brachioradialis muscle. During isometric contractions, sEMG amplitude is smaller than the one in isotonic contractions. The study shows that there is similar power spectral density in different types of isotonic contractions of BR.

*Key words:* electromyography, processing and interpretation, brachioradialis, amplitude, RMS, MAV,  $F_{mean}$ ,  $F_{med}$ , MATLAB.

### 1. INTRODUCTION

Physics has the role of forming scientific conceptions about the laws governing the surrounding world and life. Physics is based on observations and experimentally found facts. Experiments are indispensable in scientific investigations in physics and, in fact, all natural sciences. The study of physics will be more attractive and easier if it is based on investigation, research and processing.

Experiments allow students to find and apply hypotheses, to observe phenomena and understand the physical world. Experiments have the power to motivate, to provide concrete examples of complex concepts. In some teaching activities is necessary to use the concepts, terms and relationships studied in biology, mathematics and chemistry. We can consolidate the study of the physical phenomenon and its laws by using examples from biophysics [1].

The EMG signal is the electrical manifestation of the neuromuscular activation associated with a muscle contraction [2]. Various factors influence the shape and parameters of sEMG: physiological and anatomical properties and characteristics of instrumentation and experimental set-up.

The amplitude of the surface electromyogram (sEMG) is frequently used to measure the muscular effort and muscle force and as the control input to myoelectric prostheses. Spectral analysis of surface EMG signals has been used to study muscle fatigue [3] and to infer changes in motor units (MU) recruitment [4].

A good acquisition of the sEMG signal is very important for good signal processing. This signal is easily affected by the noise from different sources such as 50/60 Hz power lines. For surface electrode technique some inconvenient issues may arise (Skin-electrode contact, electrode size and shape, skin superficial oil content and dead cell density etc) [2, 9].

An EMG signal is not only the expression of total amount of force a muscle can generate. The number of motor units recorded by electrodes will always be less than the total number of activated motor units. The EMG signal amplitude is greater than the increase in force for recruited motor unit situated close to the electrode. For the motor unit located too far from the electrode, the amplitude remains the same but the force will be higher.

Brachioradialis muscle originates in the lateral (outside) of the lower humerus (upper arm) and extends to the wrist. It is oxygenated by the radial artery which branches just below the elbow. Radial nerve innervates the muscle, allowing communication to the brain. Controversial opinions regarding its function can be found as far back as 1756 when Chelseden [5] wrote "Supinator Radii Longus is not a fupernator but a bender of the cubit, and that with a longer lever, is less concerned about turning the cubit fupine than either the extensors of the carpus, fingers or thumb." Later, in 1925, Jackson explained that "The Brachioradialis (Supinator Radii Longus) flexes the forearm. This action is strongest when the forearm is pronated. It acts as a supinator only when the arm is extended and pronated. It then serves to put the arm in a state of semi-pronation. When the forearms flexed and supinated, it acts as a pronator." [5]. Modern opinions found that brachioradialis is an elbow flexor alone. Brachioradialis EMG activity [6] is minimal when it had no load. During a supination motion it had less activity than during a pronation motion.

BR is a muscle with a very good accuracy and reliability [7]. Some results show that brachioradialis muscle has a series-fibered architecture consisting of multiple, overlapping bands of muscle fibres in most individuals and a simple parallel-fibered architecture in some individuals [8].

Muscle fatigue can appear by different mechanisms: the accumulation of metabolites within muscle fibers and even the generation of an inadequate motor command in the motor cortex. Recent opinions reveal the fact that is no global mechanism to produce muscle fatigue.

The objective of this study was to investigate the function of the *brachioradialis muscle* (BR) in different contractions, estimated by means of sEMG parameters, in particular of its behavior as a *supinator* in wrist and forearm contractions. Another purpose is to study the influence of assessments of brachioradialis in various activities which involve its activation. There are studies which show that the activity of Brachioradialis during concentric pronation and

eccentric supination was higher than activity during concentric supination and eccentric pronation [5].

The involvement of BR as supinator results from relationships between RMS (root mean square deviation), MAV (mean absolute value), F mean and F median and contraction type.

Surface electromyograms are usually processed using data describing the amplitude and dominant frequency of the contractions. Four of the most commonly used parameters are RMS (root mean square deviation), MAV (mean absolute value) for amplitude, median frequency ( $F_{med}$ ), and average frequency ( $F_{mean}$ ) of power density spectrum (PDS). All parameters are influenced by the level of muscle strength and fatigue [18], [20]. Power density spectrum of the EMG signal varies from 0 to 400 Hz for most muscles. Above this frequency, the frequency components of EMG signal amplitude were less than 1  $\mu$ V and cannot be distinguished by the recording system.

The relation between EMG parameters is influenced by many factors: thickness of subcutaneous tissue, the recruitment strategy, shape of the intracellular action potentials, the peak discharge rates and synchronization of the different MUs [9]. The locations of the active MUs, interelectrode distances, and changes in muscle fibre membrane electrophysiology may generate different amplitude of the signals [10].

To reduce these perturbations, a simplified protocol for this study was chosen, so it would be easy to build such an experiment in laboratory, even by students themselves.

## 2. METHODOLOGY

One subject who reported no neurological or cardiovascular disorders participated in the experiment. Informed written consent was obtained before participation in the study. The recording of the surface EMG of forearm muscles is performed in a sitting comfortable position, with right hand bent at 90 degrees and placed on a flat surface (a table). The sEMG signal was recorded with a pair of disc electrodes applied 4 cm apart using electro conducting gel with Ag/AgCl<sub>2</sub>. The experimental set-up used Guideline 4000 (FHC Inc., Bowdoin ME) as a sEMG recording system. The signal was sampled at 48 kHz and digitally processed. For preventing low-noise contamination or other mechanical or electrical artifacts a filter input amplifier CMRR (Common Mode Rejection ratio) was used together with an adaptive digital filter of 50 Hz. EMG signal was filtered with a filter "band pass" (50 Hz – 5 kHz) to reduce noise [13, 14, 16]. The signal sEMG was transferred to a computer and analyzed by Matlab (Mathworks Inc., Natick, MA) software with a smoothing algorithm and custom recovery. Data were collected in three cases, under identical experimental conditions, within three days:

1. wrist muscle contraction for 4 s, relaxing break- 4 s, repeated 20 times, supination (Isometric1-C1);

2. isotonic contraction of the forearm: 20 cycles, slow lifting and lowering to 45 degrees, each cycle of 5 s, 20 N weight in hand, supination (Isotonic 2-C2);
3. isotonic contraction of the forearm: 20 cycles of 10 s, fast lifting and lowering to 45 degrees, a weight of 20 N in the hand, supination (Isotonic 3-C3).

For the above described cases the following data were calculated, using Matlab:

1. RMS (root mean square deviation) by squaring the values of the band-pass filtered EMG signal. The mean of these squared values was then computed. The square root of this mean was then calculated to determine the RMS for each cycle.
2. The mean absolute value MAV;
3. M wave amplitude defined as the maximum magnitude of the absolute value of the band-pass filtered time-domain EMG signal;
4. Fmed-Median Power Frequency calculated by applying a fast Fourier transformation to the filtered time-domain signal to obtain the power density spectrum (PDS). The median frequency of this power density spectrum was then calculated as the frequency (F) at which the integral of the left side of the spectrum was equal to that of the right side;
5. Mean frequency, which is achieved for mean EMG power in a cycle;
6. Standard deviations (SD) for each described data;
7. Signal to noise ratio (SNR) of experimental set-up.

### 3. RESULTS AND DISCUSSION

Few representative signals for each of the three situations are illustrated in the Fig. 1 to 3. Both signals, raw and smoothed EMG, are represented and the estimated values for sEMG amplitude are listed in Table 1.

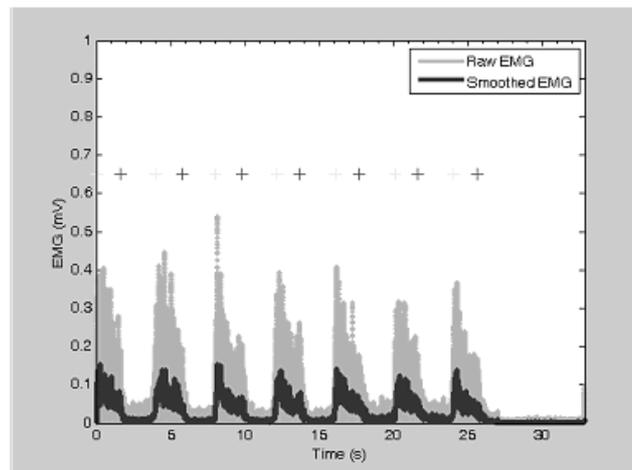


Fig. 1 – sEMG raw and smoothed in isometric contraction 1.

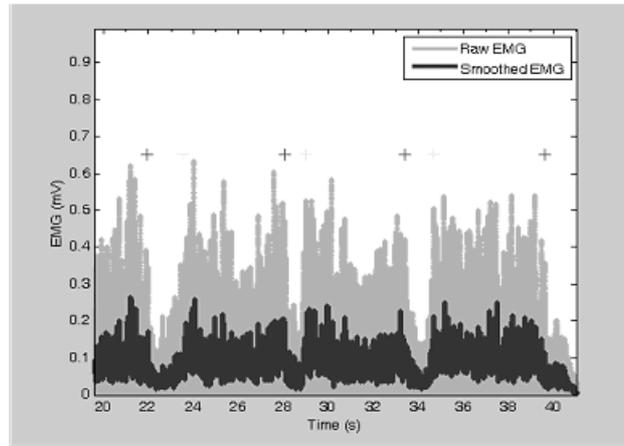


Fig. 2 – sEMG raw and smoothed in isotonic contraction 2.

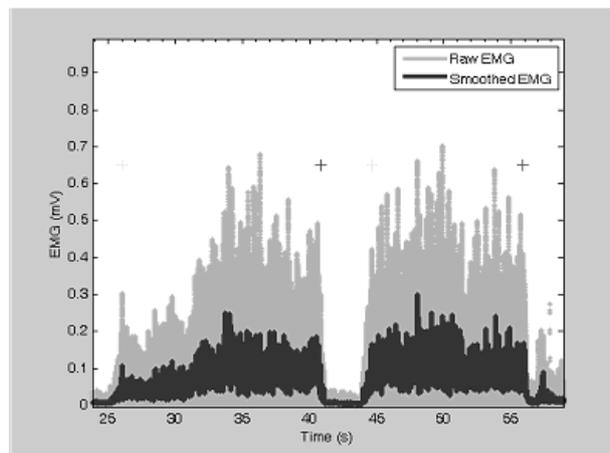


Fig. 3 – sEMG raw and smoothed in isotonic contraction 3.

The analysis of data concludes the following:

1. The maximum amplitude of EMG filtered cases differs greatly in both types of contractions: in the isometric it is almost half of values for isotonic 2 and 3.

*Table 1*

Estimated values for sEMG amplitude in all types of contractions

| Muscle contraction | M wave (mV)     | RMS (mV)        | MAV (mV)        |
|--------------------|-----------------|-----------------|-----------------|
| Isometric 1        | $0.41 \pm 0.07$ | $0.08 \pm 0.01$ | $0.06 \pm 0.01$ |
| Isotonic 2         | $0.60 \pm 0.05$ | $0.13 \pm 0.01$ | $0.10 \pm 0.01$ |
| Isotonic 3         | $0.71 \pm 0.04$ | $0.13 \pm 0.02$ | $0.10 \pm 0.01$ |

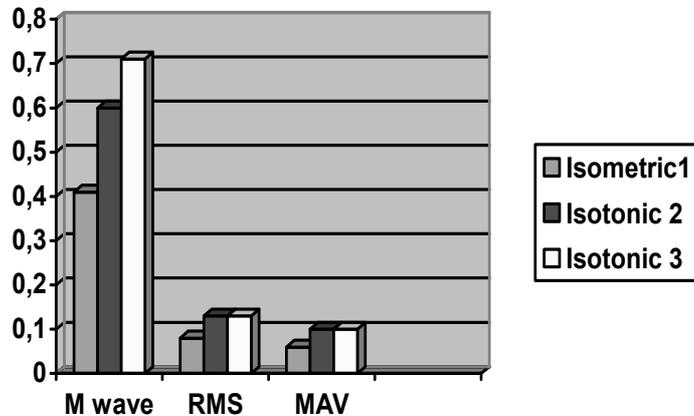


Fig. 4 – Estimated values for sEMG amplitude.

For the M wave, the difference is  $(47.5 \pm 5) \%$  for the contraction 2 and  $(73 \pm 7.3) \%$  for the contraction 3, RMS is  $(62.5 \pm 1) \%$  higher, and MAV is  $(66 \pm 1) \%$  in both isotonic contractions (Table 1 and Fig. 4). SD decreases for M wave from 0.07 mV (for isometric contraction) to about 0.05 mV for the isotonic and remains almost constant for both RMS and MAV, in all situations. Isotonic contractions have similar values for amplitudes, only the M wave presenting a difference  $(18 \pm 1.6) \%$  for the third situation. One can say that the muscle electrical activity reflected in EMG signal is greater in this case.

Table 2

Relative variations isotonic (2 and 3) vs. isometric (1)

| Muscle contraction | M wave %       | RMS %          | MAV %          |
|--------------------|----------------|----------------|----------------|
| Isotonic 2         | $47.5 \pm 5.0$ | $62.5 \pm 1.0$ | $66.0 \pm 1.0$ |
| Isotonic 3         | $73.0 \pm 7.3$ | $62.5 \pm 1.0$ | $66.0 \pm 1.0$ |

During isometric contractions, sEMG amplitude is less than the one in isotonic contraction. A possible explanation is differential recruitment of fibers, based on their size [12]. Load of 20 N of isotonic contractions increase sEMG in amplitude. It is clear that there are possible changes in recruitment patterns in cases 2 and 3. Recruitment is done from small to large fibers, which having high conduction rates, are recruited later, this fact being reflected in the frequency distribution of the PDS. Brachioradialis pronounced EMG activity during contractions involving elbow flexion (2 and 3) indicates that the primary function of BR is strong supporter of the elbow when flexion appears. High values of MAV amplitude  $(66 \pm 1) \%$  and RMS  $(62.5 \pm 1) \%$ , greater in contractions 2 and 3 than in first case, demonstrate this role (Table 2). The similarity in power spectral densities, in the cases 2 and 3, shows that the BR involvement is almost the same, as long as the contraction remains isotonic.

Evidently, different recruitment patterns appear from small to large fibers, this fact being reflected in the frequency distribution of the PDS. This muscle has a 39.8% of type I fibers ("Cinderella"), so it is a phasic muscle [11]. These fibers remain activated during further work with a download speed modulation for low frequencies [12].

Elbow flexion load was kept at 20 N. This load is similar to those of daily activities such as lifting a gallon of milk or a bag of groceries. In situations 2 and 3, the type of contraction has a small influence on the EMG activity, fact revealed by similar values of amplitude in this case. We may conclude that is the result of constant load, which activates almost the same recruitment pattern. The firing rates of activated MU must be similar in both situation C2 and C3.

Table 3

Estimated frequency values

| Muscle contraction | $f_{\text{mean}}$ (Hz) $\pm$ SD | $f_{\text{med}}$ (Hz) $\pm$ SD |
|--------------------|---------------------------------|--------------------------------|
| Isometric 1        | 298 $\pm$ 12                    | 221 $\pm$ 15                   |
| Isotonic 2         | 145 $\pm$ 3                     | 120 $\pm$ 3                    |
| Isotonic 3         | 148 $\pm$ 6                     | 121 $\pm$ 3                    |

Estimated frequencies

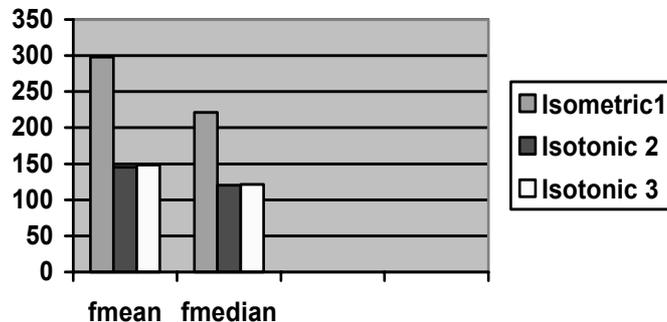


Fig. 5 – Estimated frequency values.

2. The sEMG frequency spectrum is characterized by median frequency, MF, often considered to reflect the decrease in muscle fiber conduction velocity in the case of fatigue. MF decreases as muscle fiber discharges are synchronized. A tired motor unit generates less force to every discharge of motoneurons [15]. This decline should be offset by increasing firing rates and/or recruitment of other MU. Thus, sEMG amplitude (estimated by RMS or MAV) will grow by fatigue, so long as the force remains constant. With fatigue installed at large isometric forces, the extracellular ion concentration changes (particularly for potassium) and conduction

velocity decreases. So, in this way a compression spectrum and a reduction in MF appear [19]. Increased length of intracellular action potential and decreased speed will lead to higher amplitudes. Although this is partially offset by increased spatial dispersion, RMS can indicate an increase of the degree of fatigue [17]. It was observed a decrease of the frequency values characteristic for the first contraction (298 Hz and 221 Hz) and the second (145 Hz and 121 Hz), as it is motivated above (Table 3 and Fig. 5). Lower values of the frequencies, average 50 % ( $f_{\text{mean}}$ ) and 45 % ( $f_{\text{med}}$ ) in isotonic contractions as compared with the isometric, show that fatigue occurs sooner (Table 4). Standard deviations are small.

Table 4

Relative variations isotonic (2 and 3) vs. isometric (1)

| Muscle contraction | $f_{\text{mean}}\%$ | $f_{\text{med}}\%$ |
|--------------------|---------------------|--------------------|
| Isotonic 2         | $-(51 \pm 3)$       | $-(45 \pm 5.4)$    |
| Isotonic 3         | $-(50 \pm 2)$       | $-(45 \pm 5.2)$    |

Negative relative frequency variations, in the cases 2 and 3, show similar power spectral density (PSD) for the two types of contractions (Table 5).

Table 5

Relative parameter variations of isotonic contraction 3 vs. isotonic contraction 2

| Muscle contraction | M wave %     | RMS % | MAV % | $f_{\text{mean}}\%$ | $f_{\text{med}}\%$ |
|--------------------|--------------|-------|-------|---------------------|--------------------|
| 3 vs.2             | $18 \pm 1.6$ | 0     | 0     | $2.1 \pm 0.2$       | $0.9 \pm 0.3$      |

3. When sEMG is assumed as a random process, its density is usually of Gaussian type. This assumption leads to the choice of RMS as maximum estimator of the EMG amplitude [7]. Data are relevant for the experimental protocol, given the values of SNR, calculated as the ratio of average size (RMS or MAV) and the corresponding standard deviation (SD). Rose's criterion is satisfied, all SNR values being higher than 5 [21]. There are high SNR values (Table 6) for RMS, contrary to other studies which give higher SNR ratio calculated for MAV ([7]). We may conclude that RMS is a more effective estimate method of the amplitude for the isotonic supination contractions and of non-fatigue state.

Table 6

Signal to noise ratio (SNR)

| Muscle Contraction | SNR/RMS | SNR/MAV |
|--------------------|---------|---------|
| Isometric 1        | 8       | 6       |
| Isotonic 2         | 13      | 10      |
| Isotonic 3         | 6       | 10      |

#### 4. ONCLUSIONS

The study shows that Brachioradialis pronounced EMG activity is the main argument for the primary function of BR as strong supporter of the elbow when flexion appears. The values of MAV amplitude and RMS, higher in isotonic contractions (2 and 3) than in isometric one, demonstrate this role.

Lower values of the frequencies ( $f_{\text{mean}}$ ) and  $f_{\text{med}}$ ) in isotonic than in the isometric contractions show that fatigue occurs sooner in isotonic contractions, even so in these cases the implication of BR as supinator is greater.

There is a high probability that the contamination of the signal by the neighbouring muscles will appear which lies in the activity of other muscles close to the brachioradialis. One of the triceps brachii muscles (TB) is BR agonist. Its contribution can not be eliminated. In the isometric contraction, that influence is smaller than in isotonic situation, where TB is more activated, fact reflected by the differences in amplitude and spectral frequencies. We cannot always expect perfect muscular fibre coordination.

This study does not suggest that one method or another is better, but the choice can affect the results and this has to be reported.

The use of software (*e.g.*, Matlab) in analysing the experimental data offers the possibility of fast and precise signal processing. Students can use their skills and acquire new knowledge by analysing and computing the parameters of the biosignals. The interdisciplinary approach and correlations (physics/biology/informatics) are done easier by using the experiment. This procedure seems to be more attractive than classical experimental approach, increasing thus the interest of the pupils. For this reason, we should bring more experiments in the classroom, based on the recording and processing new methods, easy to use, in order to stimulate the thinking manner. In that way, the students can collect data from their own bodies, then analyze and compare their own parameters with those of the other students. Using appropriate experimental modules, one can arrange not only experiments according to the curriculum, but also the other complex ones.

*Acknowledgements.* I would like to acknowledge Prof. Emer. Dr. Victor Gheorghe for useful discussions concerning the topic of the present work and Assoc. Prof. Dr. Andrei Barborica for the precious help and support in experimental measurements and data processing.

I am grateful to Prof. Dr. Laura Tugulea who helped me editing the present paper.

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