Advantages of the Area/Amplitude Ratio over Wavelet-derived Parameters, in Monitoring Neuromuscular Fatigue

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Abstract. *The work compares the Raa (Area/Amplitude Ratio) with Instantaneous Mean Scale (IMS) and Instantaneous Median Scale (IMedS) - both computed via Wavelet Transform (WT) - in a fatiguing contraction (Biceps Brachii, 50% MVC, (six females, six males), computed on different epochs (100, 200, 500 ms) from the surface electromyogram (SEMG) and mechanomyogram (MMG) from same motor territory. All three parameters increase from the beginning of the contraction, demonstrating the central component of neuromuscular fatigue. The ANOVA test shows no significant differences (P=0.05) among epochs or between sexes and no interaction between epochs and sexes, which proves Raa as a practical alternative to WT. Raa is 5.52±.97 (MEAN±STDEV) times quicker and requires 285±57 (MEAN±STDEV) times less buffer memory space than the WT. The simple definition and computational efficiency of Raa are major advantages over the WT approach, thus allowing the efficient monitoring of fatigue on very short epochs, also in a dynamic contraction.*

Keywords: Area/Amplitude Ratio, Neuromuscular Fatigue, Electromyography, Mechanomyography, Wavelet.

1. Introduction

A noninvasive method of monitoring the development of NMF is based on the compression of the Power Spectral Density of the SEMG toward lower frequencies, from the beginning of the voluntary contraction [1], due to the reduction of the conduction velocity in direct relation with the muscular fiber membrane excitability and with neural adaptation [2]. As a complementary signal, MMG reflects the mechanical muscle vibrations generated by the spatio-temporal summation of the individual muscle fiber twitches, evoked through motor unit activation by the motor neurons. SEMG and MMG, recorded simultaneously from the same muscles under steady contraction, show a compression of the spectra toward lower frequencies since the beginning of the contraction [3, 4]. In order to study transitional phenomena in muscle contraction and to monitor fatigue in a dynamic contraction, the use of WT has been investigated, via Instantaneous Mean Frequency and Instantaneous Median Frequency [5]. The use of WT was shown on a rather limited scale only for epochs where Fast Fourier Transform can also be consistently used, i.e. windows of signal where no acceleration or deceleration occurs, situation which may just occasionally happen in a steady contraction or in some isokinetic exercise. As an alternative, we explored the use of the Raa parameter (Area/Amplitude Ratio) [6, 7] together with IMS and IMedS, with the purpose to assess its computational efficiency in terms of speed and required memory space.

2. Subjects and Methods

A pair of SEMG electrodes (22.5 x 22.5 mm H59P, MVAP, USA) were placed on the Biceps (six males, six females). The subject sitting on a chair, with a 90^{o} anteflexion between the forearm and the arm had to carry a weight hanging from the wrist via a soft belt. The 100% MVC was estimated, as the maximum weight that could be sustained for two seconds. Tests were performed for 50% MVC up to exhaustion, on different days. An accelerometer (±2g, ICS Sensors, model 3031, USA) and author-made original amplifier (x 50000, 10-250 Hz band pass filter, 250 Hz antialias filter) was used to pick up the MMG. The accelerometer was placed between the SEMG electrodes to pick up the maximal MMG, orthogonal to the muscle from the same motor territory. The SEMG signals were amplified (x 2000, 100 MΩ input impedance, 100 dB CMRR, 250 Hz antialias filter, Beckman R611, USA) and acquired together with the MMG signals via a computerized acquisition system (DAP1200 Microstar Laboratories USA), at 500 Hz sampling rate on all the channels simultaneously.

Parameters

The Raa, IMS and IMedS were computed from the original signals (SEMG, MMG) on successive epochs, for all the subjects, and all epoch widths, using a rectangular window.

Raa – Average Area /Amplitude Ratio, with a dimension of time [ms], is computed from the signal in the time domain, as an average of the Area/Amplitude ratios over the considered epoch, calculated between consecutive transversals of the izoelectric line, called ‘phases’ [6, 7]*:*

$$Raa = \frac{1}{n}\sum_{i=1}^{n}\frac{S_i}{A_i} \qquad (1)$$

with

n - the number of phases within the current epoch,

S_i - current phase area, the integral of the i^{th} phase of the signal within the current signal segment,

A_i - the maximal amplitude of the i^{th} phase of the signal within the current signal segment, selected on all m samples within the current phase.

IMS and IMedS are computed (MATLAB, Mathworks, USA) via the Continuous Wavelet Transform over 30 scales, using the ‘Mexican Hat’ mother wavelet, chosen from a set of mother wavelets (coif5, db3, db4, gaus5, mexhat, meyr, morl, rbio3.5), after the sensitivity of each wavelet was estimated over the same set of recordings, by computing the ratio of variation of IMS and IMedS, over their maximal values. The ‘Mexican Hat’ wavelet gave an average ratio of 15.8± 4.2% comparing to 8.4±3.3% for the others, therefore showing a higher sensitivity, satisfies the admissibility condition and shows excellent localization in time and frequency [8].

Data processing

To provide greater measurement reliability, maximal voluntary intra-subject amplitude normalization was applied to the SEMG and MMG, as a percentage of the maximal value recorded for MVC. Raa, IMS and IMedS were calculated for all the subjects, for each time within the epoch, for all the epochs; their average on each epoch was computed. In each case the processing time and necessary storage were measured, to allow a comparison of the computational efficiency. Statistical processing consisted in applying the two-way analysis of variance (ANOVA) to the data, separately for each specific signal (SEMG or MMG). The existence of any significant difference between the means of the slopes and intercept points respectively, among epochs and between sexes was investigated.

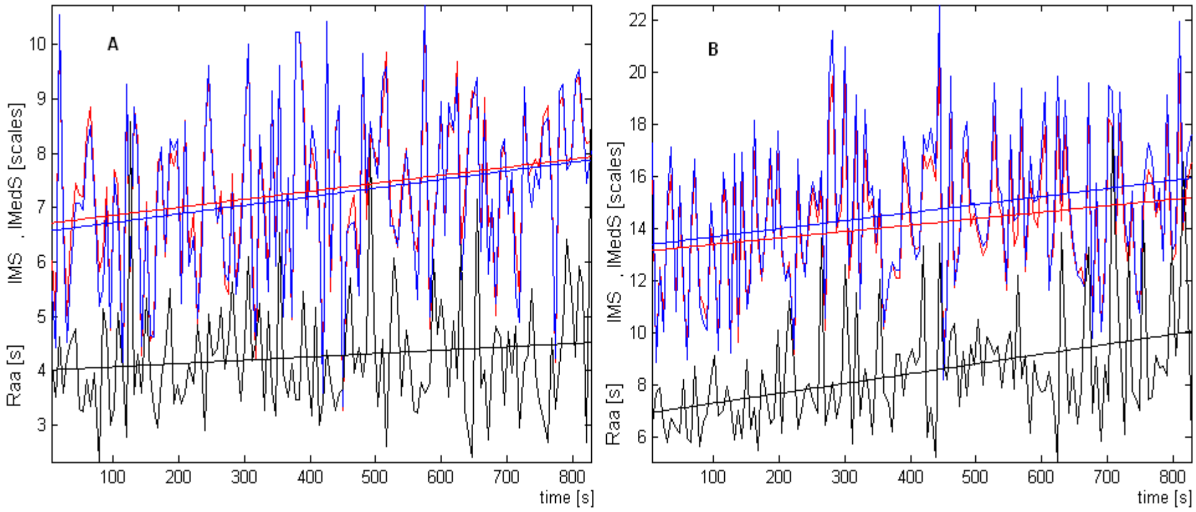

Figure1. The evolution of Area/Amplitude Ratio (Raa), Instantaneous Mean Scale (IMS - red), Instantaneous MedianScale (IMedS - blue) with advancing fatigue, for the SEMG (A) and MMG (B), computed on epochs of 100ms.

3. Results

Raa, IMS and IMedS showed positive slopes (Figure 1) in all subjects (SEMG and MMG), from the beginning of the contraction, for all the epochs. This proved the central component of the fatigue. The two-way analysis of variance (ANOVA) - performed separately on the SEMG and MMG - showed (i) no significant differences between the means either among the epochs or between sexes and (ii) no interaction between any epoch and any of the subject sexes - the probability values were greater than 0.05 -, for Raa, IMS, and IMedS as well. Computationally, the Raa was 5.52±.97 times quicker than the WT. For the given number of scales considered (30) IMS, IMedS – computed from WT – required 285±57 times larger memory than needed for Raa.

4. Discussion and conclusions

As hypothesized, the experiments showed an increase of Raa, IMS and IMedS during the development of neuromuscular fatigue from the beginning of the contraction both for the SEMG and MMG, due to a central intervention in modulating the muscle activation with increasing fatigue.

WT methods are redundant and inefficient in terms of computational time or storage space [9] - due to a complex mathematical instrument - associated with the use of appropriate criteria to choose a proper mother wavelet. The Raa parameter overcame such problems. The work demonstrated that Raa has a similar behavior as IMS and IMedS and requires less memory.

This work performed a functional comparison between scale-oriented parameters computed via the WT and author's original parameter Raa and demonstrated that they have a similar behavior.

Computationally, Raa is 5.52±.97 times quicker than the WT. For the given number of scales considered (30) the memory required for IMS, IMedS is 285±57 times larger than for Raa.

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