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Smoothing EMG signals:
Implications on delay calculation.

KEY WORDS:

Root mean square (RMS). Window length. Window type.

ABSTRACT

For the smoothing process it is necessary to select a window to be used during the signal processing (window length, and the window type). This selection can influence the results in a biological phenomenon like electromechanical delay (EMD)? This study aims to analyze the influence of the smoothing processing on the quantification of an EMD. EMG data from 480 cycles of pedaling were collected from three muscles distributed in four different cadences. Six cyclists and six triathletes, took part of the experiment. Kinematics and kinetics data were collected at the same time as EMG data. The results showed that difference concerned the highest cadences of 90 and 105 rpm, the largest window size of 450 ms, and the rectangular window type. Difference between sizes also occurred in the highest cadences, 90 and 105 rpm, only in rectangular type, when compared small sizes with larger sizes. When analyzing the influence of smoothing processing on the quantification of EMD, results indicate that signal processed with larger windows lengths and rectangular type differed from the others in the higher cadences. This result suggests that researchers should choose lengths of up to 350 ms and hamming or triangular types when smoothing EMG data.

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Suavizando os sinais EMG: Implicações sobre o cálculo da defasagem eletromecânica.

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RESUMO

Para o processo de suavização do sinal EMG é necessário selecionar uma janela a ser utilizada durante o processamento (tamanho da janela e o tipo de janela). Pode esta seleção influenciar os resultados de um fenómeno biológico como o atraso eletromecânico (EMD). Este estudo tem como objetivo analisar a influência do processamento de suavização no cálculo do EMD. Foram coletados dados de EMG de 480 ciclos de pedalada de três músculos distribuídos em quatro cadências diferentes. Seis ciclistas e seis triatletas participaram do experimento. Dados de cinemática e cinética foram coletados ao mesmo tempo, bem como dados EMG. Os resultados mostraram que a diferença ocorre nas cadências mais altas (90 e 105 rpm), no maior tamanho de janela de 450ms e no tipo de janela retangular. Diferenças entre os tamanhos também ocorreram nas cadências mais altas, 90 e 105 rpm, apenas no tipo retangular, quando comparado com os tamanhos. Ao analisar a influência do processamento na quantificação da EMD, os resultados indicam que o sinal processado com tamanhos de janelas grandes e no tipo retangular diferiu dos demais nas cadências mais elevadas. Este resultado sugere que os pesquisadores devem escolher comprimentos de até 350ms e Hamming ou tipos triangulares para suavização dos dados EMG.

PALAVRAS CHAVE:

Valor RMS. Tamanho de janela. Tipo de janela.

INTRODUCTION

Surface electromyography (EMG) signals represents the sum of action potentials generated by active motor units [2,16], being an interferential signal of random characteristics [10], the EMG can be evaluated, in the time domain, by two main methods: 1) finding a single value that will represent the amount of signal, classically an RMS value or an integral value; or 2) processing the signal using smoothing or enveloping procedures in order to obtain a new curve that will better represent the characteristics of the signal. Using a single value to represent an event is usually used in cases when the analysis is made considering the magnitude of the electric signal of an event and statistical comparisons are being performed. The use of smoothing procedures that will result in a signal in time is interesting when analysis such as the variation in a signal throughout an event is necessary.

For the smoothing process it is necessary to select a window to be used during the signal processing. This window is essentially characterized by two factors: 1) the number of points, known as the window length, corresponding to the length of the signal to be processed in each step, and 2) the weight value attributed to each point in the window, known as the window type. Once the window's length and type are defined, a representative value for each window can be calculated. The signal will then be represented by all the calculated values, forming a new smoothed curve.

However, the definition of the window type and length is usually guided by the subjective experience of the researcher [7]. There are a huge number of window types that are used in the literature, such as Hamming, Hanning, Rectangular or Triangular. According to the window type chosen, results will be different, for example, when considering the instant of onset/ offset, the peak position and even the signal's magnitude. At the same time, while D'Alessio and Conforto [7] used window lengths between 10 and 150 ms, there are studies that used window lengths of 200 ms [1, 9] 400 ms [6] or even 500 ms [8, 18]. Depending on the windows size and type chosen, the changes may be easily identified in the curves generated by the smoothing process, as may be observed in Figure 1.

The influence of window length on the calculus of maximum voluntary contraction (MVC) value has been considered in literature. McLean et. al [15], tested how different window lengths would affect several aspects of EMG, including the MVC values, and considered that window length is an important factor when calculating RMS values. Mathiassen et al. [14], wrote a review about normalization of EMG amplitude using the superior trapezium muscle. In the review they found window lengths used for MVC ranged from 10 to 150 ms and the smaller lengths resulted in values 10 to 15% higher than the larger lengths.

Though the variation in the results caused by smoothing is perceptible [12], the effects on the variables calculated using information obtained a resultant smoothed curve is unclear. In practice, the question may be whether the variables obtained from a smoothed curve will significantly alter the interpretation of a neuromuscular phenomenon, such as electromechanical delay (EMD). EMD is defined as the time that exists between the onset of the muscle electric activity (EMG) and the development of force [5]. This temporal variation between electric stimulus and force production may be attributed to the physiological mechanisms of muscle contraction, such as the propagation of the action potential or the elastic components of the [11]. Regardless of the mechanisms that define the EMD, in order to calculate the time difference between both events, it is necessary to find the specific onset moment or the moment of peak occurrence in each event's curve. Therefore, an important question to be considered is whether the mathematical procedure (smoothing) change EMD biological phenomena? In order to answer this question this study aims to analyze the influence of the smoothing processing on the quantification of electromechanical delay.

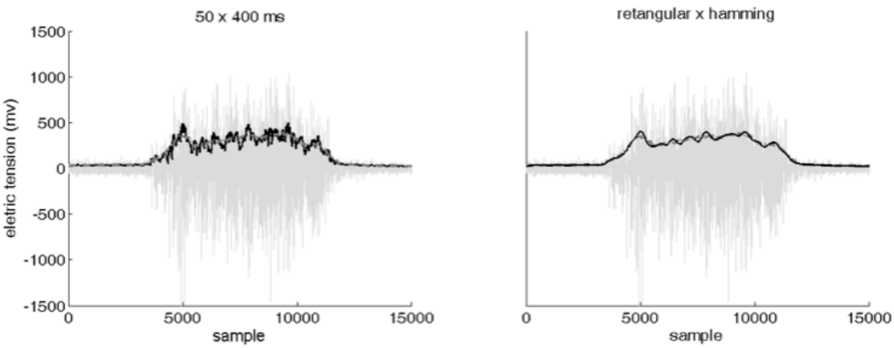

FIGURE 1 — Influence of smoothing on an EMG signal. 2000 samples equals 1 second. Left side: Rectangular windows with two different lengths (50 ms in black, 400 ms in gray). Right side: 350 ms windows using two different types (hamming in black, rectangular in gray).

MATERIALS AND METHODS

EMG data from 480 cycles of pedaling were collected from three muscles distributed in four different cadences (60, 75, 90 and 105 rpm) in randomized order. Twelve athletes, six cyclist (25.1 ± 7.6 years) and six triathletes (27.5 ± 9.2 years), took part of the experiment.

For data acquisition an ergometer (Cardio2 bicycle, Medical Graphics Corp., St. Louis, USA), which was adapted with competitive clip pedals, handlebars and saddle was used. EMG data was collected from the right lower limb with an EMG system (Bortec Electronics Inc., Calgary, Canada) and surface electrodes (Ag/ AgCl; 2.2 cm apart) in bipolar configuration with frequency of 1818Hz per channel (11 channels in 20 kHz), as suggested by the International Society of Electromyography and Kinesiology. After skin was shaved, abraded and cleaned, electrodes were positioned aligned to the muscle fibers, on the bellies of the muscles *Gluteus Maximus* (GM), *Rectus Femoris* (RF) and *Vastus Lateralis* (VL). Reference electrode was positioned over the medial anterior face of tibia.

Kinematics and kinetics data were collected at the same time as EMG data. The kinematic data were acquired using Peak 5.3 system. A Pulnix camera (Peak Performance Technologies Inc., Englewood, USA) 120Hz was positioned in the sagital plane in order to record a reflective point positioned in the pedal center. The crank angles were calculated from kinematics records and used to divide the pedaling cycles, where the beginning of each cycle was considered when the crank was in vertical position (top position) at zero degree.

Measurements of normal (Fy) and tangential (Fx) force direction components were possible by the use of a strain gauges instrumented platform-pedal [4] throughout pedaling in a frequency of 1818 Hz. Force signals were processed with Butterworth low-pass digital filter, with a cutoff frequency of 10 Hz, according to residual criteria [21]. A resulting curve force (FR) was calculated by equation 1.

$$F_R = \sqrt{F_X^2 + F_y^2} \tag{1}$$

EQUATION 1

The EMG data was filtered with a Butterworth digital band-pass filter (20-600Hz). The smoothed curve was calculated using a mobile window process, with three windows types (Rectangular, Hamming and Triangular) and five window lengths (50, 150, 250, 350 and 450).

EMD was quantified by cross correlations procedure, which searches the highest correlation between force and EMG curves [19], according to equation 2:

$$R_{xy}(\tau) = \frac{\int_{-T}^{T} x(t) \cdot y(t+\tau)\,d\tau}{R_{xx}R_{yy}} \tag{2}$$

EQUATION 2

where:

Rxy (τ) is the cross correlation function between EMG and force curves in a given period of temporal shifting (τ);

T is time duration of force and EMG curves;

x and y are EMG and force curves, respectively;

Rxx and Ryy represent maximum values of the respective auto-correlates of EMG and force curves defined at τ=0,000

STATISTICAL ANALYSIS

In order to test the influence of different EMG signals processing (windows type and lengths) and cadences on EMD multiples three factors ANOVA was used (one for each muscle), using Bonferroni and Dunnett's post hoc, depending on samples homogeneity. Significance level was $p<0.05$.

RESULTS

Data from muscles *Gluteus Maximus*, *Rectus Femoris* and *Vastus Lateralis* are presented on Table 1. The values from EMD's (Mean SD) values from different EMG signal processing, analyzing the influence of different window types and size in different cadences are presented. No interaction between variables was found.

Mainly differences were found in the highest cadences of 90 and 105 rpm, the largest window size of 450 ms, and the Rectangular window type. Difference between sizes also occurred in the highest cadences, 90 and 105 rpm, only in rectangular type, when compared small sizes with larger sizes.

TABLE 1 — Different letters represent difference between window length for a same cadence within the same muscle.

		GLUTEUS					
Size	Type	60	75	90		105	
		M SD	M SD	M SD		M SD	
50	R	56.6 16.9	72.0 13.4	91.4 16.6	a	107.8 20.2	a
	H	57.5 33.4	72.2 11.7	91.1 16.6		107.7 20.6	
	T	57.4 33.3	72.2 11.8	91.1 16.7		107.7 20.5	
150	R	52.9 24.7	71.4 21.6	91.5 15.7	a	110.0 20.3	a
	H	55.2 29.3	72.8 15.8	91.5 16.3		108.5 19.8	
	T	55.0 29.1	72.7 16.1	91.5 16.3		108.5 19.8	
250	R	48.8 18.1	64.7 26.1	86.5 16.4	a	111.1 24.9	a
	H	53.0 25.3	71.7 19.5	91.1 15.9		109.4 19.9	
	T	52.8 24.8	71.5 19.7	90.8 15.8		109.4 20.0	

VASTUS						RECTUS					
60	75	90		105		60	75	90		105	
M SD	M SD	M SD		M SD		M SD	M SD	M SD		M SD	
130.7 20.9	131.1 14.9	133.1 16.5	a	126.9 25.5	a	214.2 40.1	209.4 34.9	194.1 22.1	a	189.3 18.2	a
130.8 20.1	131.4 14.2	134.0 16.1		122.3 22.4		204.2 47.7	209.0 37.0	194.4 22.9		188.3 19.8	
130.9 20.0	131.4 14.2	133.9 16.1		127.0 26.0		211.2 41.1	209.1 36.9	194.4 22.9		188.4 19.7	
127.3 26.5	125.6 19.0	126.4 17.4	ab	124.6 26.9	a	214.0 36.3	207.0 24.9	191.0 19.0	a	185.9 180	a
130.4 22.9	130.0 16.3	131.3 16.8		126.1 25.3		214.5 39.2	210.4 31.1	193.3 20.9		188.4 18.5	
130.3 23.1	129.8 16.5	131.1 16.8		126.0 25.4		214.5 39.0	210.4 30.7	193.2 20.8		188.3 18.5	
118.9 27.7	115.4 22.7	115.9 18.9	ab	118.9 31.9	a	211.6 32.5	199.8 23.6	183.8 20.5	a	177.6 25.0	ab
128.2 25.2	126.7 18.2	127.4 17.3		124.6 26.2		213.9 36.9	207.8 25.2	191.5 19.4		187.2 17.8	
127.7 25.2	126.3 18.3	127.0 17.3		124.4 26.3		213.9 36.7	207.5 24.9	191.2 19.4		187.0 18.0	

		GLUTEUS					
Size	Type	60	75	90		105	
		M SD	M SD	M SD		M SD	
350	R	46.2 17.6	53.4 30.6	70.7 24.2	ab	98.2 34.5	a
	H	51.4 21.6	68.5 21.9	89.1 15.7		109.6 20.6	
	T	51.0 21.0	67.9 21.9	88.5 15.7		109.5 20.8	
450 *	R	41.1 17.9	43.4 30.9	46.7 25.8	b	64.5 33.0	b
	H	48.7 17.9	64.7 24.0	86.0 16.2		108.1 21.4	
	T	48.2 17.6	63.8 23.8	84.9 16.4		106.5 22.1	

* in 450 ms window length, rectangular window type was different from hamming and triangular on 90 and 105 rpm for all muscles.

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DISCUSSION

Based on the results from muscles vastus lateralis, gluteus maximum and rectus femoris in different cadences, electromyographic signal processing affected in a limited way the EMD calculus in cycling, when considering smoothing with different window types and window lengths.

The objective of electromyographic signal smoothing process is to highlight the signals main spectral characteristics, such as the moment of peak, peak-to-peak distance, and onset/ offset [(10)] which is, in some analysis, an essential step on EMG data processing.

In this study, *Rectus Femoris* EMD varied between 144.2 and 214.5ms. In the literature, EMD's of 67 ± 25ms were found when pedalling at a cadence of 60 rpm [(17)]. In another study, values between 93 and 125ms are reported during voluntary knee extension [(20)]. *Gluteus Maximus* EMD in this study varied between 41.1 and 111.1ms. In the same study by Prilutsky [(17)], EMD values for *Gluteus Maximus* found were 121 112ms. For *Vastus Lateralis* muscle, this study found EMD between 75.2 and 134ms, while in the literature, during isometric contractions, values between 41 and 118ms are reported [(20)].

In the review by Mathiassen et al. [(14)], windows lengths ranged from 10 to 150ms, and the MVC's highest values were found in the smaller windows lengths. Although the present study used larger windows lengths, the EMD values obtained in 50ms windows were significantly higher than those found in 450ms windows in the rectangular window type. Larger window lengths provide a better smoothing of the signal, although it makes it harder to detect small variations. Smaller window lengths better keep the raw signal characteristics, but imply in high oscillations [(7)].

In the present study, smoothing only influenced the higher cadences of 90 and 105 rpm for both window length and type. These are the cadences that cyclists usually indicate as their favourite cadences [(3, 4)]. However, when considered how cadence affected EMD, no significant effect was found. This may happen because variables such as fibre type, muscle length and type of contraction [(22)] alter EMD values or the activation patterns for the maintenance of a task. Hug e Dorel [(12)] showed that there is no consensus about the effect that increases in cadence have on the activation of several muscles during cycling, and that myoelectric activity of the main muscle groups may increase or decrease when cadence increases.

Usually, the time necessary for distending the elastic elements in series is considered the main reason for the generation of EMD [(13)], however Zhou et al. [(22)] suggest that this affirmation should be reconsidered. The smaller EMD of 70.1ms (450ms window length, rectangular type) and the highest EMD of 134.0ms (50ms window length, hamming type) found for *Vastus Lateralis* in this study may be partially explained by the signal processing. Besides, a factor that so far has not been considered, i.e. EMG signals processing, does influence the results, and consequently the analysis and interpretation of EMD.

CONCLUSION

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When analyzing the influence of smoothing processing on the quantification of EMD, results indicate that differences occur. Signal processed with larger window lengths and rectangular type differed from the others in the higher cadences. This result suggests that researchers should choose lengths of up to 350 ms and hamming or triangular types when smoothing EMG data. It may also be suggested that similar studies that used different window types and lengths may be compared when the lengths used were between 50 and 350 ms.

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