MECHANOMYOGRAPHIC ANALYSIS WITH 0.2 S AND 1.0 S TIME DELAY AFTER ONSET OF CONTRACTION

Eddy Krueger, Eduardo M. Scheeren, Gean Francesco D. Chu, Percy Nohama
CPGEI, Federal Technological University of Paraná, Ave Sete de Setembro 3165, Rebouças, Curitiba, PR, Brazil

Guilherme N. Nogueira-Neto, Vera Lúcia S. Nantes Button
School of Electrical and Computer Engineering, University of Campinas, Campinas, SP, Brazil

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Abstract: Muscle contractions generate lateral oscillations and motion artifacts that can be detected by MMG sensors placed in the inner and outer sides of the forearm. These artifacts can significantly affect signal processing and eventually it is necessary to eliminate their influence in order to detect movements reliably. One approach is to respect a time delay after the onset of contraction. This study aimed to evaluate the correlation of 0.2 s and 1.0 s time delays after the onset of contraction during wrist movements. This work respected two different time delays before initiating the signal analysis. Two analysis window lengths were evaluated (0.25 s and 0.50 s). The results showed that there are strong correlations between the acquired signals with both time delays, mainly the devised RZ feature (0.81–0.95). This study was a first approach to determine whether triaxial MMG features can be used for motor prosthesis control. The axial moduli presented strong correlations for all movements and can be productive in future applications.

1 INTRODUCTION

Mechanomyography (MMG) sensors can be built with triaxial accelerometers (Nogueira-Neto et al., 2008). These transducers measured the displacement accelerations during muscle contractions in three axes of movement and also their modulus. One of the differences between MMG and EMG temporal characteristics are the initial and final contraction movement artifacts (Silva and Chau, 2003) existing in MMG, that was denominated onset of contraction (Nolan and dePaor, 2004). These artifacts jeopardize processing because they contaminate signal temporal and spectral behaviors (Silva and Chau, 2003). Some studies use analysis windows with a time delay beginning on the onset of contraction to characterize signals, e. g. for prosthesis control (Prociow et al., 2008, Alves and Chau, 2008). In preliminary tests, a time delay of 1.0 s after the onset of contraction (1.0AOC) was considered too long for practical purposes because it was impossible to characterize the four different movements using this delay. In order to control a myoelectrical prosthesis, short delay and analysis window length (AWL) are necessary because human perception needs 300 ms or less to consider an event as having occurred in real time (Englehart and Hudgins, 2003).

The purpose of this study is to evaluate the behavior of MMG features obtained with 0.2 s after onset of contraction (0.2AOC) and 1.0AOC during four different wrist movements.

2 METHODS

2.1 Volunteers

Twelve male volunteers (24±5.5 years old) without neuromuscular or elbow and wrist joint problems performed the tests. The study was approved by the institute's ethics committee. All participants were instructed in detail about the test protocol and they agreed to participate in the study. Then, they were submitted to skin preparation (trichotomy and cleaning) and sensor placement.

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2.2 Sensors

The developed MMG sensors used Freescale MMA7260Q MEMS triaxial accelerometers with high sensitivity 800 mV/V at 1.5 G (G, gravitational acceleration). Electronic circuits allowed 10x amplification and 4-40 Hz Butterworth filtering, focusing MMG passband (Silva and Chau, 2003). Individual axes and their modulus were acquired.

A string was stretched from the epicondyle until the centre of carpal region to help in determining the right sensor placement, approximately 7 cm from the epicondyles over the muscle belly of the forearm (Wojtczak et al., 2009), with the Y axis parallel to the muscle fibers as shown in Figure 1.

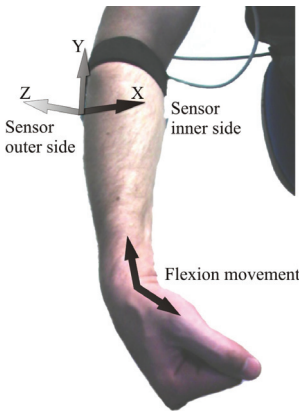

Figure 1: Volunteer and MMG sensor placement.

2.3 Protocol

The volunteers were seated on a chair where they performed five concentric contractions for each wrist movement of the dominant limb: flexion, extension, ulnar and radial deviations. The sequence of movements was randomly chosen. The limb stayed loose, closed fist, in neutral anatomical position without touching any body. Researchers indicated the start and end of contractions in order to determine the contraction timing (approx. 2.5 s).

2.4 Data Acquisition and Analysis

A LabVIEW™ program was coded to acquire MMG signals. All signals and volunteer data were saved into European Data Format (EDF) files. The data acquisition board was a Data Translation™ DT300 series with 1 kHz sample rate. Figure 2 shows the MMG Z axis signal for a wrist flexion detailing the onset of contraction artifact, 0.2AOC and 1.0AOC time delays, 0.25 s and 0.5 s AWLs.

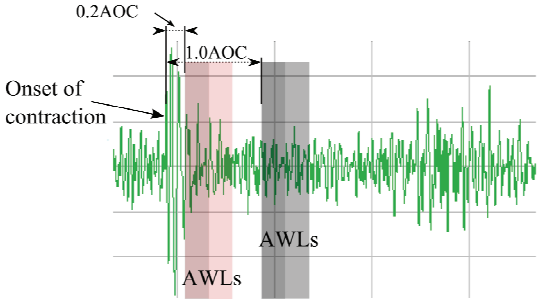

Figure 2: MMG Z axis. Details: onset of contraction, 0.2AOC, 1.0AOC and AWL intervals (darker shades 0.25 s AWLs and darker plus lighter shades 0.5 s AWLs).

From the five repeated contractions, the central one was chosen for analysis. Temporal features were calculated for all signals and each AWL. Root mean square (RMS) is the quadratic mean indicating the range of muscle displacement represented by its acceleration. Zero-crossing is the number of times that the signal crossed the baseline. Peak counting is the number of peaks (sub-window of 30 ms) in the AWL. Zero-crossing and peak counting are temporal features, however both have direct connection with frequency spectrum. Zero-crossing has close relation with the signal fundamental frequency and peak counting is related to spectral higher frequencies. In addition to the raw features, multiplications were performed in order to devise hybrid values. MMG captures muscle oscillations during contraction and stretching (unlike EMG for electrical activity). Eventually, RMS is bigger during stretching than contraction. The multiplication of RMS (energy related) and zero-crossing (frequency related) can enhance the discriminatory procedure, thus the RZ feature was created. After t-test analysis, Pearson's correlation coefficients (R) between 0.2AOC and 1.0AOC were calculated. In order to determine R between individual values of each sensor, data were splitted by: (a) movement, (b) side of the forearm (inner and outer), (c) axes/modulus, (d) AWL and (e) analysis.

3 RESULTS

The t-test revealed that the values of all features, signals and AWLs were different when comparing 0.2AOC and 1.0AOC. Table 1 shows only the R values that presented strong correlation between 0.2AOC and 1.0AOC, i. e. values greater than 0.75.

Table 1: Features that presented strong correlation coefficients (R) between 0.2AOC and 1.0AOC.

Side	Mov	AWL	Axis/Mod	Feature	R
Inner	Ext	.25s	Z	RZ	0.79
			Mod	RZ	0.81
				Zc	0.88
		.5s	X	RMS	0.79
				RZ	0.82
			Y	RZ	0.88
			Mod	RZ	0.93
				Zc	0.84
	Rad	.25s	X	RMS	0.80
				RZ	0.91
			Mod	Zc	0.82
		.5s	X	RMS	0.87
				Zc	0.84
				RZ	0.95
			Y	RZ	0.84
			Mod	Pc	0.78
				RMS	0.78
				RZ	0.93
				Zc	0.88
	Flex	.5s	X	RMS	0.84
Outer	Flex	.5s	Mod	Zc	-0.90

Wrist movement (Mov), extension (Ext), radial deviation (Rad), flexion (Flex), modulus (Mod), zero-crossing (Zc), peak counting (Pc), RMS*zero-crossing (RZ)

4 DISCUSSION

The purpose of this study was to evaluate the difference between 0.2AOC and 1.0AOC in forearm muscles by MMG analysis. Since this work was a first approach, we decided to take the extremities: a short (0.2 s) and a long time delay (1.0 s). We hypothesized that if 0.2 s did not have difference with 1.0 s delay then it would be unproductive to investigate intermediate delays.

The t-test showed that all feature values between 0.2AOC and 1.0AOC were different. This can have occurred because the onset of contraction (see Figure 1) had a high amplitude and since it is within any 0.2AOC AWL it was expected that the artifact influenced the analysis.

According to the results indicated in Table 1, the major number of strong correlations occurred on the inner side of the forearm. Anatomically, the inner side is responsible for wrist flexion and ulnar deviation movements. However, even though the extention and radial deviation belong to the outer side, they appeared several times in the inner side sensor. This was considered a correlation between 0.2AOC and 1.0AOC during antagonist movements. It was assumed that 0.2AOC incorporated the initial contraction interference that follows immediately the onset of contraction. In this perspective, the strong correlations between 0.2AOC and 1.0AOC, recorded by an MMG sensor positioned over antagonist muscles, mean that this muscle group do not introduce significant interference from the onset of contraction. From the control strategy point of view, this is an important finding because spurious contractions registered on this side could be rejected. The feature of flexion movement was singular because it was the only agonistic movement that appeared in the inner side and the only one with $R > 0.75$ in the outer side (in spite of being antagonist). The greater the R (the closest to 1.0) the more similar the features behaved comparing 0.2AOC and 1.0AOC. Therefore, despite using a short delay will probably involve a part of the onset of contraction, choosing 0.2AOC and 0.25 s delay is acceptable because the total time is almost completely within human perception range (Englehart and Hudgins, 2003).

Strong correlations were not observed for ulnar deviation in both sides. Apparently, the inner side was affected by the flexion and ulnar deviation movement artifacts, because of the inexistence of strong correlations. The observation of eleven correlations to radial deviation obtained for the inner side is attributed to the contractions having lower amplitude movement artifacts. Radial deviation range of movement (21°±4.0°) (Cipriano, 2003) is the smallest among the other wrist movements and, thus, can support the idea of onset of contraction amplitude interference.

(Petitjean et al., 1998) used electrical stimulation to obtain a single twitch. Their results showed that the increase in electrical stimulation amplitude lead to an increase in MMG peak-to-peak amplitude, but the duration of movement artifact was very similar, approximately 20 ms.

Some studies used a time delay after the onset of contraction to minimize the movement artifact. Such time delays range from 0.67 s up to 1.0 s (Beck et al., 2004, Alves and Chau, 2008, Nolan and dePaor, 2004, Smith et al., 1998).

Another strategy is to dismiss the initial 30% of signal, thus eliminating the movement artifact generated at the onset of contraction, and analysing the remaining signal (Prociow et al., 2008). However, this approach can lead to latency problems due to human perception and further works in prosthetic control can face practical problems in patient-prosthesis interaction.

One interesting observation has to do with the moduli features. The moduli presented many strong correlations, five against one, two and four occurrences for Z, Y, and X axes, respectively. They had strong correlation between 0.2AOC and 1.0AOC for both AWLs. The moduli values can be calculated with bi- and triaxial accelerometers and their use can be helpful because of results repeatability, specially the number of zero-crossings.

The RZ feature brought good perspectives to wrist movement analyses. Table 1 shows nine strong correlations whereas the RMS value and zero-crossing, from where it is derived, presented six and five correlations respectively. The use of peak counting to determine muscle contraction was not effective when performed concomitantly with movement artifact, since only one correlation was observed between 0.2AOC and 1.0AOC. Further studies with new indicators can improve MMG movement analysis, making unnecessary to eliminate unwanted artifact interferences in the onset of contraction, therefore, enhancing myoelectrical prosthesis control.

5 CONCLUSIONS

This paper investigated mechanomyographic analyses with 0.2 s and 1.0 s time delay after onset of contraction during four wrist movements. The main outcome was the great amount of correlation between antagonist sides. In such case, the strong correlations between 0.2AOC and 1.0AOC in antagonist sides mean that the onset of contraction do not interfere with the time delay. Radial deviation has a smaller range of movement and for this reason varying the time delays before the analyses did not affect their correlation. Modulus was the most frequent feature with strong correlation with varying time delay what showed its repeatability. The correlations were strong for antagonist movements mainly in the inner side of the forearm.

Of all analysed features for 0.2AOC and 1.0AOC, it was demonstrated that in antagonist movements RZ feature, zero-crossing and RMS are very similar and can be used, if necessary, to reduce the time delay for myoelectrical prosthesis activation.

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