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A template subtraction method for reducing electrocardiographic artifacts in EMG signals of low intensity

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ABSTRACT

The electromyogram (EMG) has been used in several studies for different areas. Whenever recorded on trunk muscles and close to heart, the EMG may be contaminated by electrocardiographic signal (ECG), which may hamper information based on EMG measures, by either decreasing the median frequency (MDF) or increasing the root mean square value (RMS). Therefore, ECG removal from this contaminated EMG is an issue, but the signal processing task is challenging due to the spectral overlapping of signals. The Butterworth high-pass filter with a 30 Hz cutoff frequency has been considered a suitable removal technique in the literature. However, the frequency band below 30 Hz is strongly attenuated, leading thus to information loss on the EMG. In order to mitigate this problem, a simple template subtraction method is proposed, in which the template is based on the contaminated signal itself. Real contamination and emulated mixtures based in real signals were used and the MDF, RMS, correlation coefficient and Kulback-Leibler divergence were analyzed as performance measures. The performance of the proposed method was compared to a Butterworth high-pass filter and it is shown that the template subtraction method has preserved better the EMG information.

1. Introduction

The electromyogram (EMG) is a recording of the electrical activity from skeletal muscular tissue and it has been used in researches on biomechanics [1], ergonomics [2], motor control [3], sensory-motor responses [4], myoelectrically controlled prostheses [5], respiratory muscles analysis [6] and others The EMG application areas are diverse, mainly on academic-scientific approaches. The EMG has also been useful to evaluate the performance and conditions of the muscles, as well as to provide information about the muscle rehabilitation and neurological dysfunctions [7,8].

When the EMG is recorded on trunk muscles and close to heart, the electrocardiographic signal (ECG), i.e., the signal concerning electrical activity from cardiac muscular tissue, is recorded together with the skeletal muscle signals. The ECG presence on the electromyographic signals represents an interference that may mistake information on EMG. For example, it can decrease the median frequency (MDF) or increase the root-mean square value (RMS) [9], which are measures normally used on electromyography and those distortions compromise the clinical interpretation accuracy and effectiveness.

There are different signal processing methods for reducing the ECG interference on EMG (e.g. gating, adaptive filter, high-pass filter, wavelet, independent component analysis (ICA), and template subtraction) [9–15]. However, their performance is hampered by factors such as information loss, difficulty or even impossibility to obtain an interference copy, multi-channel recording requirements; and the major problem concerns signal spectrum overlapping. Due to such issue, the ECG is one of the worst interference to be solved in EMG decontamination. The overlapping is mainly concentrated on the spectral band between 1 and 50 Hz [16].

The Butterworth high-pass filter (HPF) with a 30 Hz cutoff-frequency is the most used method for ECG removing and, according to some authors [17,18], this filter has better performance than the other methods. However, its use implies attenuation in EMG activities below 30 Hz, which may alter the evaluation of EMG signals mainly if there are low intensity muscular contractions.

Accessing motor units recruitment in low degree of muscular contraction is important for diagnosing disorders of nervous system and muscular tissue [19], besides obtaining physiological parameters from specific activities of the neuromuscular system. The knowledge of biomechanical patterns helps understanding the

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muscular performance, the mechanisms involved in trauma and protection, as well as provides valuable information for the rehabilitation process. As an example, low-intensity contractions are associated with motor control, which is an important mechanism in the postural maintenance and in the spine stability [20]. Furthermore, muscle stiffness reduction in a segment, associated to a poor neuromuscular control, can result in postural instability [21].

Muscle fatigue assessment may be an aim in the neuromuscular analysis. The muscle fatigue may result from a progressive decrease of muscular power during a sustained contraction [22], which may lead to changes on physiological mechanisms and load distribution, and hence to biomechanical changes [23].

Thus, considering the relevance and interest on EMG of low-intensity contractions and that the ECG interference removal is a necessary task, a simple template subtraction (TS) method is proposed to reduce the ECG interference in EMG of low-intensity contractions, trying to preserve as much as possible the muscular signal. This method supports applications where multi-channel recorded are not provided, and an ECG reference is not available. Additionally, the proposed method does not require muscular recording during rest. The technique was evaluated in both experimental (ECG-contaminated) and emulated (artifact-free EMG signals added to pure ECG data) EMG signals. The achieved performance is compared to the Butterworth HPF approach.

2. Methods

This work was submitted and approved by the Ethics Committee Research of the Institute of Collective Health Studies of the Federal University of Rio de Janeiro (Process Number 95/2010). Five male volunteers participated in this study (age: 27 ± 3 years, weight 73.5 ± 10 kg, height: 174 ± 8 cm) and criteria for inclusion were: no back pain; no disease or physical limitations that prohibited the proposed activities; do not have historic of orthopedic or neurological dysfunctions; having not undergone previous surgery; no cardiac disease historic; and have read and signed the consent form.

2.1. Signal acquisition and preprocessing

The EMG signals were recorded using 8-mm-diameter surface bipolar electrodes (Ag/AgCl) and were amplified (MP150WSW, Biopac Systems, Inc.©, Santa Barbara, CA, USA, gain set to 5000). Signal digitization was performed by a 12-bit A/D converter (1 kHz sampling and analogue bandpass from 1 to 500 Hz, which is suitable for surface EMG [19]). The electrodes were placed following the SENIAM recommendations [24]. Previously, trichotomy with disposable materials and skin cleaning with sterile gauze and alcohol were both performed to decrease the impedance. The volunteers stayed in standing position during electrode coupling.

The contaminated EMG was recorded on right erector spinae muscle at the T12 vertebral level (*i.e.* the electrodes were placed two-finger away from the spinous process). Three different trials were realized in isometric contraction and each record lasted 40 s, with 5-minute rest between contractions. The trials consisted in to maintain upright stance, bilateral plantar flexion and trunk flexion, which were performed in random order. For supporting these positions, it is required motor unit recruitment that may be slightly differentiated for each one, which represented three muscle contraction levels.

Simultaneously, both the EMG of right medial gastrocnemius muscle (where the ECG interference may be neglected) and the ECG were collected. These signals were recorded to construct emulated mixtures in order to evaluate the proposed method. The electrodes used for collecting the gastrocnemius signal were placed on the most prominent bulge of the muscle. The electrodes (Ag/AgCl) used for ECG recording were placed one on left fourth intercostal space,

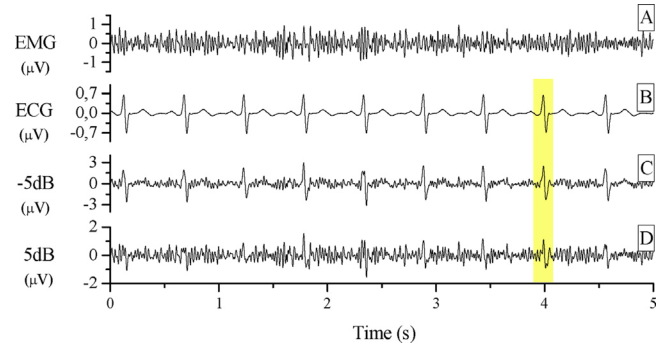

Fig. 1. Signals used on emulated mixtures: gastrocnemius EMG (A); ECG signal (B). Emulated mixtures with SIR of: -5 dB (C) and 5 dB (D). (Just 5 s of the signal are shown, in order to facilitate the visualization).

close to sternum, and the other one on medial line between the first electrode and right shoulder. The analogue bandpass filter of ECG module was adjusted for the 1–125 Hz range (sampling rate and gain as in EMG acquisition).

The emulated mixture was obtained by adding the gastrocnemius EMG to the ECG collected on the chest. Two signal-to-interference ratios (SIR) (-5 and 5 dB) were produced to simulate different contamination levels. Thus, two emulated mixtures were produced for each gastrocnemius contraction. Both EMG and ECG RMS-values were calculated and the ratio between these two values was used as a multiplying factor to automatically adjust the ECG-signal amplitude parcel, according to the desired SIR value, in the emulated EMG contaminated signal. In the -5 dB SIR, the QRS complexes could be easily observed (QRS complexes are characteristic waveforms that represent the ventricular contractions [19]; whereas in the 5 dB-SIR mixture they are harder to be observed (Fig. 1). All signals were preprocessed with band-pass filter with 10 and 100 Hz cut-off frequencies, since low intensity muscular contractions, which result in small amplitude signals, are of major interest in the present work. The signal amplitudes were normalized by their maximum values.

2.2. Subtraction method

In a subtraction method, it is typically required a template of the contaminant signal to be subtracted from the contaminated one [25]. This template can be obtained by an additional recording of the reference signal, from a pre-existing template or during EMG recording with relaxed muscle. In the present work, such template will be estimated just from the contaminated signal, as described next. The processing steps of the proposed method are shown in Fig. 2.

Firstly, the contaminated signal is bandpass filtered through a fourth-order Butterworth block with a frequency band of 4–50 Hz. This aims at emphasizing the ECG most energetic spectral band. Next, the filtered signal is rectified and duplicated. Each signal replica is filtered with a moving average filter, 0.1 s window-length for the first, and 1 s for the second one [26]. The intersection points between both moving average filtered signals are used for peak detection, i.e. the QRS complex peaks are detected on bandpass filtered signal only between intersection points. The positive peak represents the R wave, whereas the negative one represents the S wave. The maximum mean peak (absolute value) between S and R waves is selected. This procedure is to ensure that the algorithm uses the highest peaks of QRS complexes, minimizing, thus, the detection error.

After setting the peak positions, 0.16-second acquisition windows centered on each peak position were applied and grouped together to form the QRS segments. Such window length is based