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Processing the surface mechanomyographic signal

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Abstract

Signal processing is an important issue that should be considered prior to recording mechanomyographic (MMG) signals. The first studies in this area found that the fast Fourier transform and maximum entropy spectrum estimation techniques provided MMG frequency spectra that were very similar in shape. The shape of the spectrum from the maximum entropy spectrum estimation technique, however, was highly dependent on the model order that was chosen. Recent investigations have also used joint time-frequency signal processing techniques, such as wavelet- based methods and the short-time Fourier transform to analyze

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MMG signals. The results from these studies have shown that when the wavelet-based techniques were used, the patterns of responses for MMG center frequency were very similar to those from Fourier-based methods. An advantage of the wavelet-based methodology, however, is that it provides information in both the time and frequency domains, and, therefore, is ideal for processing nonstationary MMG signals, such as those recorded during dynamic muscle actions. Additional research still needs to be done to identify what type of information can be provided by joint time-frequency processing of MMG signals.

Introduction

There has been a great deal of work performed in the area of mechanomyographic (MMG) signal processing. One of the first studies was done by Diemont et al. (1988). The authors detected surface MMG signals from the biceps brachii during submaximal isometric muscle actions of the forearm flexors at 20% and 80% MVC. The signals were then processed with the fast Fourier transform (FFT) and maximum entropy spectrum estimation (MESE) algorithms, both of which provide power spectra. An important consideration, however, is that the MESE technique does not assume signal stationarity like the FFT method.Thus, the MESE technique could potentially be useful when processing nonstationary MMG signals. The results showed that the power spectra from the FFT and MESE algorithms were very similar in shape, as long as the correct model order was used with the MESE technique. Specifically, when the model order was too low, the power spectrum was excessively smooth, but when the model order was too high, the power spectrum was often noisy with a great deal of spurious information. Thus, it was suggested that the model order should be chosen carefully when using the MESE algorithm. In addition, the power spectra from both algorithms were usually positively skewed, and, therefore, the resulting MMG mean power frequency (MPF) values were generally greater than the MMG median frequency values. Therefore, it was recommended that the MPF or median frequency values could be used to characterize the shape of the MMG power spectrum (Diemont et al. 1988). This study was followed up by a second investigation (Figini and Diemont 1989) that used both the FFT and MESE methods to calculate the cross spectrum of MMG and EMG signals. Specifically, the cross spectrum provides information regarding the common frequency components in MMG and EMG signals, and the authors suggested that this information must be related to the activation pattern of the muscle. In addition, it was concluded that appropriate selection of the signal processing technique was just as important as the choice of a proper experimental design (Figini and Diemont 1989).

Goddard et al. (2005) performed an interesting study that used the discrete wavelet transform to examine the MMG signals from the soleus during quiet resting in either a supine (i.e., with the subject lying on their back) or sitting (i.e., with the feet motionless on the ground) position. The results showed that the resting muscle activity from the soleus was greater in the seated than the supine position. In addition, the amplitude of the MMG signal increased throughout the 20 minute period in the sitting position. The results from the discrete wavelet transform also showed that the increase in MMG amplitude over the 20 minute period occurred primarily in the 16-62 Hz frequency range. Thus, it was concluded that resting MMG activity could be due to skeletal muscle contraction for the purpose of returning blood back to the heart (i.e., the “skeletal muscle pump” phenomenon). In addition, it was hypothesized that MMG could potentially be used as a diagnostic device for identifying those with inadequate skeletal muscle pump activity, thereby putting them at risk for complications from hypotension and reduced blood flow during orthostasis (Goddard et al. 2005). Torres et al. (2005) recently used the wavelet transform to process MMG signals from the diaphragm of two mongrel dogs. Specifically, the MMG sensor was placed in the 8th intercostal space, and an MMG signal was recorded from the diaphragm during normal breathing. As acknowledged by the authors, this task is challenging because movement of the thoracic wall creates large motion artifacts in the MMG signal. Thus, the purpose of the wavelet analysis was to separate the MMG signals of the diaphragm from the motion artifacts caused by movement of the thoracic wall. The results showed that for the first dog tested, the cutoff frequency needed to eliminate motion artifact was between 6.6 and 13.52 Hz, but for the second dog, the best cutoff frequency was between 1.64 and 3.3 Hz. Thus, it was concluded that the wavelet technique was a useful method for separating the low- and high-frequency components of the MMG signal, although different cutoff frequencies may be needed for different signals. In addition, wavelet-based signal processing methods may be useful for analyzing the MMG signals detected from the diaphragm during normal breathing (Torres et al. 2005).

Our laboratory has performed several investigations to compare the patterns of responses for MMG center frequency obtained with wavelet- and Fourier-based methods. Specifically, Beck et al. (2005) reported that during 50 consecutive maximal concentric isokinetic muscle actions of the forearm flexors at a velocity of $180°\cdot s^{-1}$, there were quadratic decreases in MMG MPF, MMG median frequency (both obtained with the discrete Fourier transform),

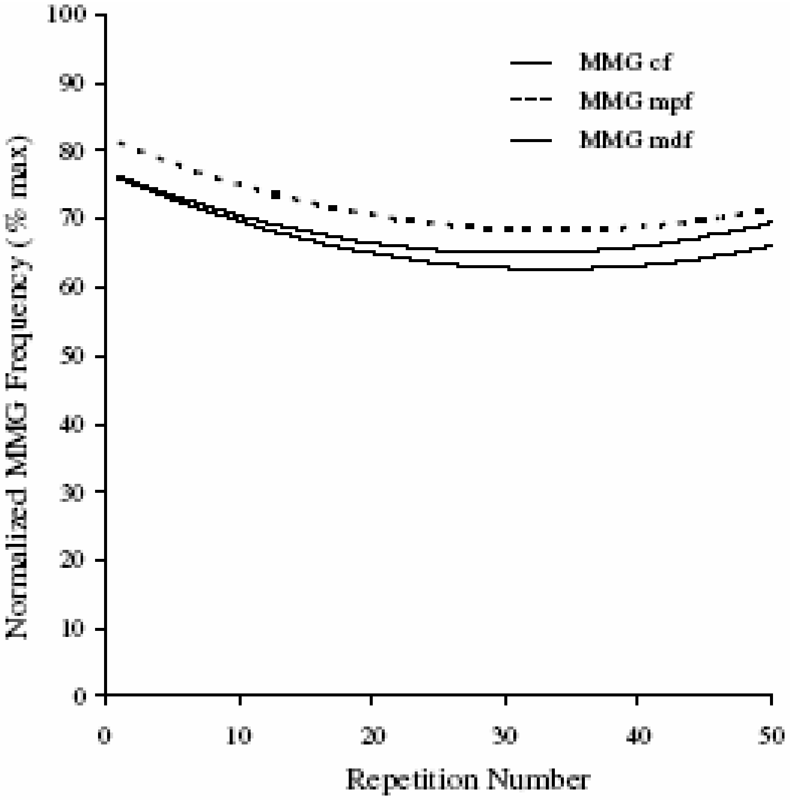

Figure 1. Patterns of responses for mechanomyographic (MMG) mean power frequency (mpf), median frequency (mdf), and wavelet center frequency (cf) for the biceps brachii muscle during 50 consecutive maximal concentric isokinetic muscle actions of the forearm flexors at a velocity of 180°·s^{-1}. Notice that the patterns of responses for MMG frequency were very similar among the three methods. *Reprinted with permission from Beck et al. (2005).

and MMG wavelet center frequency (obtained with the discrete wavelet transform) (Figure 1).

These findings were important from a practical standpoint because it has been suggested that Fourier-based methods should not be used to process nonstationary signals (e.g., MMG signals recorded during dynamic muscle actions). Wavelet-based methods, however, do not assume signal stationarity, which may make them more appropriate for processing MMG signals recorded during dynamic muscle actions. Despite the concerns over signal stationarity, the results from our study showed that the patterns of responses for MMG center frequency were very similar for the Fourier- and wavelet-based methods. Thus, it was concluded that the discrete Fourier transform is an acceptable method for determining the patterns of responses for MMG center frequency during fatiguing dynamic muscle actions (Beck et al. 2005). Similar results were also reported for the biceps brachii during submaximal to maximal concentric (Beck et al. 2005) and eccentric (Beck et al. 2006) isokinetic muscle actions of the forearm flexors. Ryan et al. (2008) performed an interesting study that compared the patterns of responses for MMG center frequency from the short-time Fourier and continuous wavelet transforms. Specifically, the subjects were required to perform a 6-second isometric ramp muscle action of the leg extensors from 5-100% MVC, and surface MMG signals were detected from the vastus lateralis and rectus femoris. The results showed that the short-time Fourier and continuous wavelet transforms provided similar patterns of responses for MMG center frequency (Figure 2).

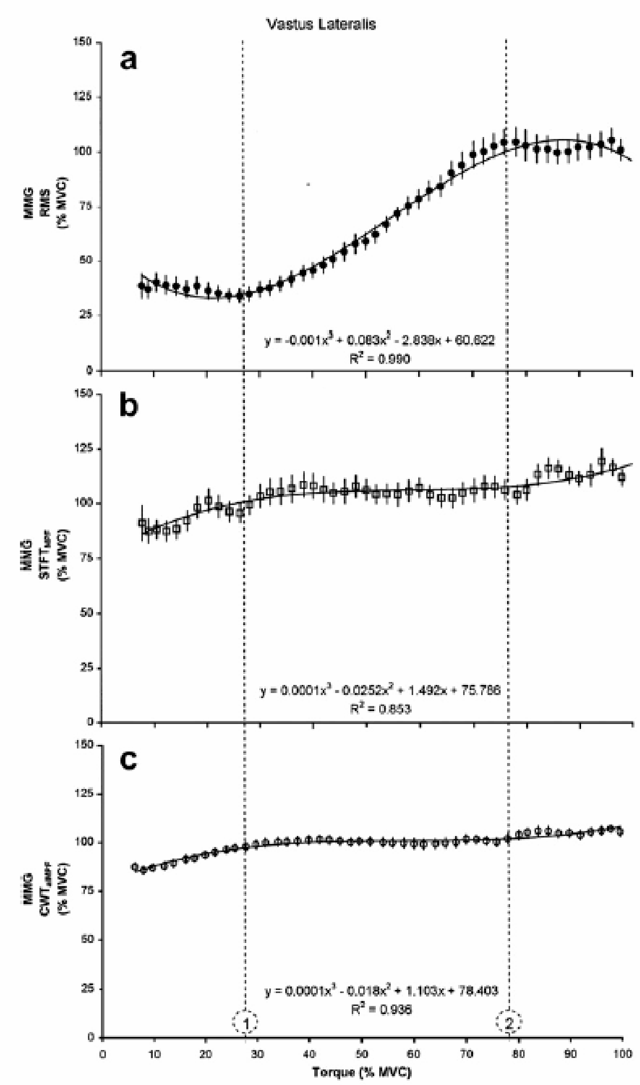

Figure 2. Mechanomyographic (MMG) amplitude (top graph), mean power frequency (MPF) from the short-time Fourier transform (STFT), and MPF from the continuous wavelet transform (CWT) for the vastus lateralis during a 6-second isometric ramp muscle action of the leg extensors. Notice that the patterns of responses for MMG MPF from the STFT were very similar to those from the CWT. *Reprinted with permission from Ryan et al. (2008).

Thus, these findings were similar to the results from our previous investigations, and suggested that Fourier- and wavelet-based methods provided similar information regarding the patterns of responses for MMG center frequency (Ryan et al. 2008).

The interest in wavelet-based methods for processing MMG signals was important because it provided the impetus for our laboratory to develop a filter bank of wavelets designed specifically for MMG signals (Beck et al. 2008). Specifically, these wavelets cover the entire frequency range for MMG and are designed to provide the best possible combination of time and frequency resolution. The unique aspect of the wavelets, however, is that they are nonlinearly scaled, which allows them to provide equal weight to high and low frequency components in MMG signals (Figure 3).

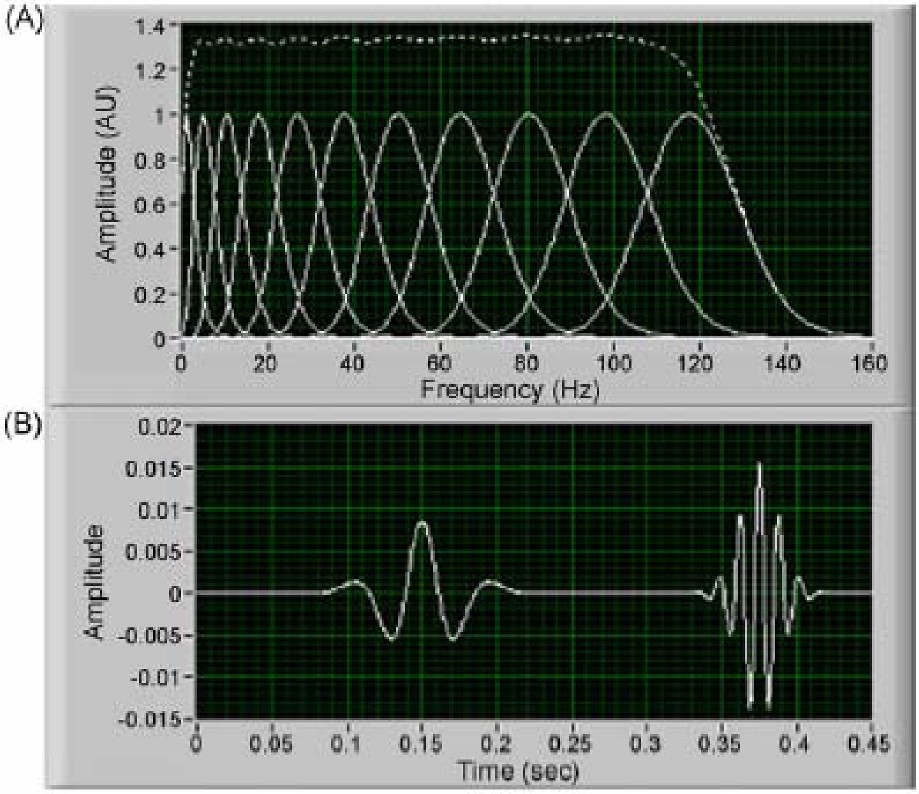

Figure 3. Filter bank of wavelets used for the nonlinear scaling wavelet analysis designed by Beck and von Tscharner (2008) for mechanomyographic (MMG) signals. (A) shows the frequency domain representation of the wavelets and their sum (dashed line). (B) shows two of the wavelets in the time domain. Notice that in (A), the sum of the wavelets is almost perfectly flat across the entire frequency range for MMG (i.e., 5-100 Hz). Also, notice that in (B), the two wavelets have a different number of oscillations, which is a property of their nonlinear scaling. *Reprinted with permission from Beck et al. (2008).

In addition, the results from the MMG wavelet analysis are in the form of a time-frequency distribution known as an intensity pattern. This pattern is similar in principle to the spectrogram from the short-time Fourier transform and scalogram from linearly scaled wavelets. An important distinction, however, is that the wavelet analysis is designed specifically for MMG signals, whereas the short-time Fourier and linearly scaled wavelet transform are intended for many different types of signals (Beck et al. 2008).

Overall, the results from these studies have shown that both Fourier- and wavelet-based techniques are adequate for examining changes in MMG center frequency. An advantage of the wavelet-based methodologies, however, is that they provide much more information, and they are more appropriate for nonstationary MMG signals than the Fourier-based techniques. More research still needs to be done to identify applications of the results from wavelet analysis of MMG signals.

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