Spectral Analysis of Bioelectric Signals by Adapted Wavelet Transforms

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ABSTRACT: *In this study we use the adapted wavelet transform methods (wavelet and cosine packets) for spectral analysis of bioelectric signals. These methods have recently been introduced for analysis of non-stationary signals. Using recordings of the heart rate variability in twenty healthy subjects, the estimated power in different frequency bands is compared to results based on the classical methods: fast Fourier transform and autoregressive modelling.*

Results: Cosine packets gave similar results as the classical methods, and may be preferred to characterise the rhythmic components in the recorded signals. On the other hand, the non-stationary fluctuations, i.e., the "trend", was efficiently decomposed using the wavelet transform method.

1. INTRODUCTION

Spectral analysis is frequently used to study beat-to-beat fluctuations in signals of bioelectric origin. In many bioelectric signals the power in different spectral regions can be linked to various physiological mechanisms. For example, the high-frequency region (HF, 0.15-0.40 Hz) in the heart rate variability (HRV) normally reflects the respiratory related activity in the autonomic control of blood circulation. The-low frequency region (LF, 0.05-0.15 Hz) is linked to the response of the baroreceptor reflex. The fluctuations below 0.05 Hz are related to many factors, such as vasomotion, thermoregulation and other non-stationary control systems [1].

In many clinical studies, power spectrum analysis of HRV data is based on the fast Fourier transform (FFT) or autoregressive (AR) algorithms. These methods relies on the assumption that the signal is stationary, at least during short-term segments. In a recent study, we proposed how the adapted wavelet transforms can be used to analyze and quantify the components in the HRV spectrum [2]. These methods include wavelet packets (WP) and cosine packets (CP) and were chosen because the signal can be analyzed and quantified at different scales, i.e., long time windows can be used to analyze the low frequency components and short windows for the high frequency components in the signal.

The purpose of this study is to apply the WP and CP methods to HRV signals obtained from healthy subjects during provocative maneuvers and compare the results with the classical methods (FFT and AR).

2. METHOD

HRV data was obtained from 20 healthy normal subjects (age 20-40 years, 10 male and 10 female). A single-lead ECG was recorded at 500 Hz and stored in a computer. The recordings started with the subject lying down and having normal spontaneous breathing for six min. This was followed by four sequences each lasting one min: controlled breathing at six breaths/min, rest, 12 breaths/min and rest. The recordings continued for approximately four min after passive tilt to a 70-degree upright position. The R-R intervals were transformed to a heart rate time series by cubic spline interpolation and resampling at a frequency of 2.5 Hz.

The decomposition of the signal with the discrete WP transform, is based on a partition in the frequency plane using a quadrature mirror filter bank. The filter bank consists of pairs of highpass and lowpass filters organized in a tree-structure, where the signal at each scale is decomposed into its detail (highpass component) and approximation (lowpass) signals and downsampled [3]. At each scale the frequency axis is recursively divided in halves. The transform coefficients are the outputs from the filters.

The basis functions for the CP transform, are cosines multiplied by smooth cutoff functions [3]. This is in contrast to the Fourier analysis, where the basis functions are of infinite duration. The CP algorithm is based on a segmentation in the time plane, where the segments of the signal are recursively divided into halves.

Both transform methods results in an orthogonal decomposition of the time series [3,4]. The power in the LF (0.02-0.15 Hz) and HF (0.15-0.40 Hz) bands, therefore was calculated as the log-transform of the sum of the magnitude square of the transform coefficients within each frequency band [2]. In this study we used an uniform partition of the frequency and time axes.

All HRV recordings were detrended to reduce the non-stationary component in the signal using an algorithm based on the discrete wavelet transform as described earlier [2]. This essentially resulted in high-pass filtering with a sharp cut-off frequency at f=0.0195 Hz.

Because many clinical studies of HRV are based on the estimated band power, with less focus on the location of spectral peaks within the frequency bands, we used the FFT with a rectangular window [5]. An AR-model of order 30 was used and the parameters were estimated according to Marple's modified covariance method [5]. The spectral components were quantified using residual integration.

The Matlab software (MathWorks, Naticks, Ma.) and the Wavbox toolbox [6] (WavBox ToolSmiths, Stanford, Ca) was used for data recording and analysis.

3. RESULTS

Fig.1 shows the recorded heart rate, estimated trend component and detrended signal in a 26-year old male subject. The estimated power in the LF and HF bands using the WP, CP, FFT and AR methods are shown in Fig. 2 and 3.

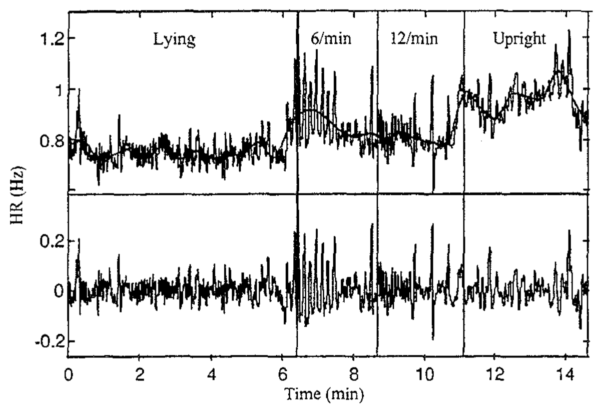

Figure 1.Recorded heart rate and estimated trend (top) and detrended signal (bottom). The vertical lines indicate the onset of the provocative manoeuvres.

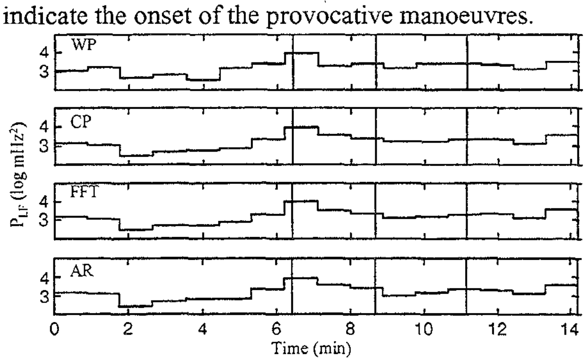

Figure 2. Estimated power in the LF band using the WP, CP, FFT and AR methods.

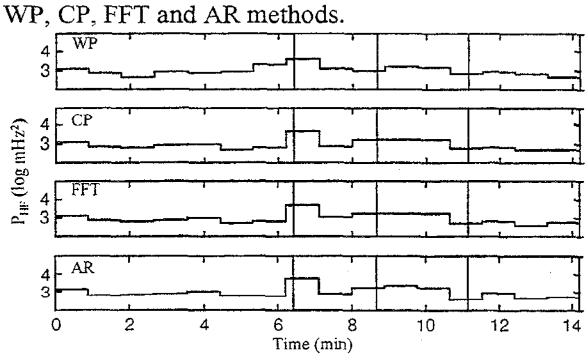

Figure 3. Estimated power in the HF band using the WP, CP, FFT and AR methods.

Table 1 shows the correlation between the estimated band powers using the four methods on 16 subsegments of approximate length 50 s from all 20 recordings.

	PLF			PHF		
	WP	FFT	AR	WP	FFT	AR
CP	0.74	0.99	0.92	0.82	0.98	0.87
WP		0.75	0.66		0.83	0.70
FFT			0.92			0.87

Table 1. Squared correlation coefficients for comparisons between the different methods

4. DISCUSSION

The findings in this study show that the adapted wavelet transforms can be alternatives to the AR and FFT methods to detect and quantify changes in heart rate and in the HRV spectrum during provocative maneuvers. The CP method gave similar results as AR and FFT for this special case when all subsegments were of equal length. However, the WP and CP methods also offers the possibility to analyze the signals with different resolution in time and frequency for the low-frequency and high-frequency components. We are preparing a study on this topic, where we also verify the performance of the methods using simulated signals.

We believe that the decomposition of the non-stationary fluctuations using the discrete wavelet transform might be preferred to, e.g., polynomial detrending. The methods used in this study may also be applied to other types of bioelectric signals.

5. REFERENCES

[1] A. Malliani, M. Paganini, F. Lombardi and S. Cerutti, "Cardiovascular neural regulation explored in the frequency domain," Circulation, vol. 84, pp 482-492, 1991.

[2] U. Wiklund, M. Akay and U. Niklasson , "Short-term analysis of heart-rate variability by adapted wavelet transforms," IEEE Eng. Med. Biol., vol. 16, pp. 113-118+138, 1997.

[3] M.V. Wickerhauser. *Adapted wavelet analysis from theory to software*. Wellesley MA: A K Peters, 1994.

[4] M.Vetterli and J. Kovacevic. *Wavelets and Subband Coding*. Englewood Cliffs NJ: Prentice Hall, 1995.

[5] S.M. Marple. *Digital spectral analysis with applications*. Englewood Cliffs NJ: Prentice Hall, 1988.

[6] C. Taswell, "Wavbox 4: A software toolbox for wavelet transforms and adaptive wavelet packet decompositions," in A. Antoniadis and G. Oppenheim, *Wavelets and statistics, Lecture notes in statistics, vol. 103*. Springer Verlag, 1995.