

DYNAMIC NON-DETERMINISTIC CHARACTERIZATION OF HRV THROUGH MULTIREOLUTION WAVELET DECOMPOSITION

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Abstract- The present study investigates the multiresolution wavelet decomposition approach to the analysis of the heart rate variability (HRV) and the autonomic function. Autocorrelation analysis of the informative low- to high-frequency LF/HF ratio in time indicates that study of this parameter's long-term dependencies may prove diagnostically important. Return maps of the LF and HF octave bands of the multiresolution wavelet transform exhibited chaotic control behavior in the LF energy and repetitive patterns in the HF region of the HRV.

INTRODUCTION

Heart rate variations are a rapidly reacting indicator to subtle status changes of various physiological factors [1]. The powerful influence of the sympathetic and parasympathetic nervous systems makes the heart rate variability (HRV) an important parameter for evaluation during postsurgical recovery or cardiac and diabetic mass screenings. Power spectra (and statistical measures) of the HRV are routine tools for assessment of the autonomic function today [2]. However they require at least quasi-stationarity of the HR signal and although these methods have an excellent frequency resolution, in many cases their time resolution is insufficient. Dynamic changes even during short-time physical and mental load tests could make the assumption for signal stationarity inappropriate and any non-deterministic patterns would be systematically distorted. Clearly, another decomposition method with inherent temporal features is necessary to assess successfully the physiologically informative low- (LF) and high-frequency (HF) components of the HRV.

METHODS

We analyzed long-term (30 min.) ECG recordings from the AHA database through

wave recognition techniques described elsewhere [3]. Subsequently the HRV time series was interpolated to an equidistant sampling rate of 5 Hz.

We made extensive tests with both the continuous (CWT) and discrete (DWT) wavelet transforms as HRV signal decomposition tools. We selected the orthogonal multiresolution pyramidal DWT algorithm [4] for characterization of dynamic changes in the HRV, because of its non-redundancy, computational efficiency and multiresolution properties [5].

The dyadic pyramid wavelet representation $(A_{2^{-j}}f, (D_{2^{-j}}f)_{-J \leq j \leq -1})$ of the DWT essentially decomposes a sequence of length $N = 2^J$ into J multiresolution levels of approximated $A_{2^{-j}}f$ and detail $D_{2^{-j}}f$ signals with dyadically decreasing temporal and increasing frequency resolutions. At each level j discrete quadrature mirror filters G (high-pass) and H (low-pass), corresponding to wavelet and scale functions, process the approximated and subsampled input signal from the previous pyramid level, producing coarse and detailed output signals at the currently analyzed octave band.

After testing a number of wavelets, we chose the short orthogonal Daubechies 4 wavelet in our current investigation for minimum redundancy between scales. We used the square moduli of the dyadic wavelet coefficients $D_{2^{-j}}f$, setting to zero the bottom 3 % of them.

RESULTS

We analyzed the time course of the LF (0.00488 - 0.156 Hz), HF (0.156 - 0.625 Hz), LF/HF and LF+HF band energies of the HRV wavelet coefficients and the autocorrelations of these time series. The LF and LF/HF bands robustly detected corresponding events in the HRV time series. The autocorrelation function of the LF/HF time series proved especially interesting, revealing in many cases additional

modulation patterns. To identify the presence of any non-deterministic patterns in the wavelet representation of the HRV, we used return maps with embedding dimension $m = 2$. The lags were determined through maxima of the autocorrelation function for the LF, HF, LF/HF and LF+HF octave band energies. In this case, typical LF return maps showed chaotic patterns, while HF maps were highly structured.

DISCUSSION

A major distinction of the DWT representation, which could change the evaluation of HRV, is that this method inherently accounts for frequency events in time. The degree of frequency-time spottiness and repetition patterns should also be considered through various methods. Although statistical measures give a fair common picture, we observed the presence of strange attractor-like patterns through the return map plots -- especially of the LF octave bands of the DWT. This could be possibly explained by non-deterministic control processes in the underlying thermal, vasomotor and hormonal regulation and in the specific interaction patterns of the sympathetic and parasympathetic nervous systems. On the other hand, the structured HF return maps would correspond to a more regular respiratory control modulation.

We studied as well some condensed characterization parameters like mean and median scale representations, skewness and variance, applied for the entire studied time range. They might be considered useful for fast screening purposes, although they are not directly comparable to conventional STFT and AR spectra.

These results suggest that the multiresolution orthogonal wavelet decomposition appears to be a useful technique for characterization of the dynamic changes and repetition patterns of the various HRV signal components and could be advantageous in extraction of fiducial markers for autonomic function events.

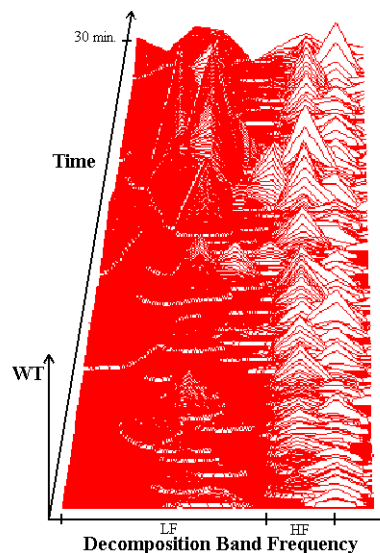


Fig.1. The square moduli of the WT coefficients for a long-term heart rate variability signal of a normal subject.

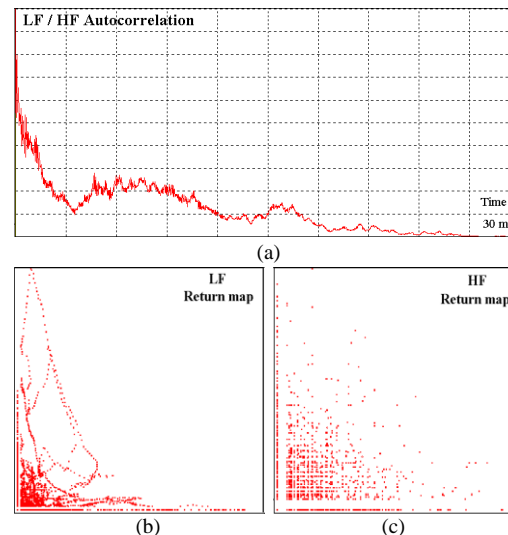


Fig.2. Identification of non-deterministic and repetitive patterns through (a) Autocorrelation function of the DWT energy time series of the LF / HF octave band ratio (b) Return map of the LF energy time series indicating possible underlying chaotic regulation in the autonomic innervation and functional control processes (c) Return map of the HF energy time series, reflecting a respiratory modulation pattern. Lags are derived from autocorrelation maxima.

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