Biomedical Signal Processing and Control 38 (2017) 143–147

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

Short communication

# Respiratory sigh associated transient autonomic changes detected with a continuous wavelet method of heart rate variability analysis

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ARTICLE INFO

*Article history:*
Received 22 January 2017
Received in revised form 19 April 2017
Accepted 15 May 2017

*Keywords:*
Wavelet
Rat
Autonomic

ABSTRACT

The measure of heart rate variability (HRV) from an EKG recording is a non-invasive way to evaluate autonomic nervous system (ANS) activity. Traditional methods use either nonparametric (Fourier techniques) or parametric (autoregressive) algorithms. These methods have poor temporal resolution of signal transients and require a stationary signal for accurate evaluation. The short time Fourier transform (STFT) has been used as an attempt to overcome this problem, but still a transient may be poorly localized to time and "blurred" within the signal.

We present a Morlet continuous wavelet transform (CWT) algorithm for HRV analysis. A rat model was used of normal respirations with intermittent sighs. Both EKG and respiratory recordings were made. RR interval files were detrended and resampled at 10 Hz using a cubic spline algorithm. Wavelet scales were generated and converted to frequency bands corresponding to sympathetic (SNS) and parasympathetic (PNS) activity. A transient burst in mostly SNS but also PNS activity was noted leading up to a respiratory sigh.

To our knowledge, this is the first time brief changes in ANS activity have been detected in association with a respiratory sigh. As demonstrated by this study, this method of HRV analysis may a useful method of investigating transient changes in ANS activity.



## 1. Introduction

Variation of heart rate (HR) and blood pressure (BP) occurs in a cyclical fashion. Heart rate variability (HRV) has been shown to be an index of autonomic nervous system (ANS) function, with its analysis providing insight into ANS activity [1]. HRV measurement is performed using either time or frequency domain measures. Time domain measures include statistical and geometric measures, whereas frequency domain analysis permits analysis of contributions of both sympathetic (SNS) and parasympathetic (PNS) nervous systems. High frequency (HF) components are mostly reflective of PNS activity (0.15–0.40 Hz human, 0.8–2.5 Hz rat) and low frequency (LF) are mostly SNS activity with a small contribution from the PNS (0.04–0.15 Hz human, 0.2–0.8 Hz rat) [1,2].

An overall reduction in heart rate variability (HRV) and also an increase in the LF/HF ratio is associated with excessive cardiovascular mortality in various disease states, such as systemic arterial hypertension, ischemic heart disease, and congestive heart failure [3,4]. Additionally, heart failure disease severity as quantified by the left ventricle (LV) ejection fraction (EF) and also progressive diastolic abnormalities consistent with high LV filling pressures (restrictive LV filling) are also associated with progressive reduction in HRV. These parameters are associated with cardiac death and also hospital readmissions [5,6].

Several methods are used for analysis of HRV. Traditional methods used are generally classified as either parametric or nonparametric [2]. Nonparametric methods use the Fast Fourier Transform (FFT) and parametric methods use autoregressive algo-

*Abbreviations:* ANS, Autonomic nervous system; BP, Blood pressure; CWT, Continuous wavelet transform; DC, Direct current; EF, Ejection fraction; EKG, Electrocardiogram; HF, High frequency; HR, Heart rate; HRV, Heart rate variability; LF, Low frequency; LV, Left ventricle; FFT, Fast Fourier transform; PNS, Parasympathetic nervous system; RR, R to R interval on EKG; STFT, Short time Fourier transform; SNS, Sympathetic nervous system.

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http://dx.doi.org/10.1016/j.bspc.2017.05.005
1746-8094/

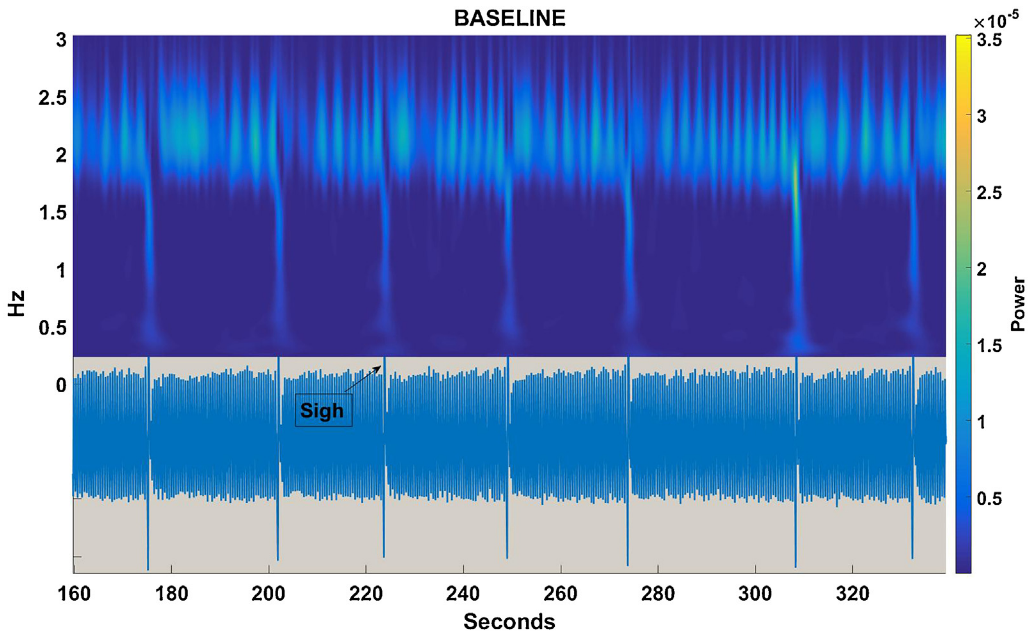


**Fig. 1.** Results of Morlet CWT analysis of RR interval file for HRV analysis. (Top plot) A representative time segment (160 s through 340 s segment) of the surface plot is illustrated. This demonstrates "power" calculated in frequency ranges of interest (0.2 Hz through 2.5 Hz). A colormap on the right represents power. (Lower plot) A simultaneous respiratory recording is plotted with the location of sighs noted. From this plot, it appears that HF power is generally higher than LF power, but around the time of each sigh there appears a surge in LF power with a relative drop in HF power. Colorbar power (right side) units are in $s^2$/Hertz.

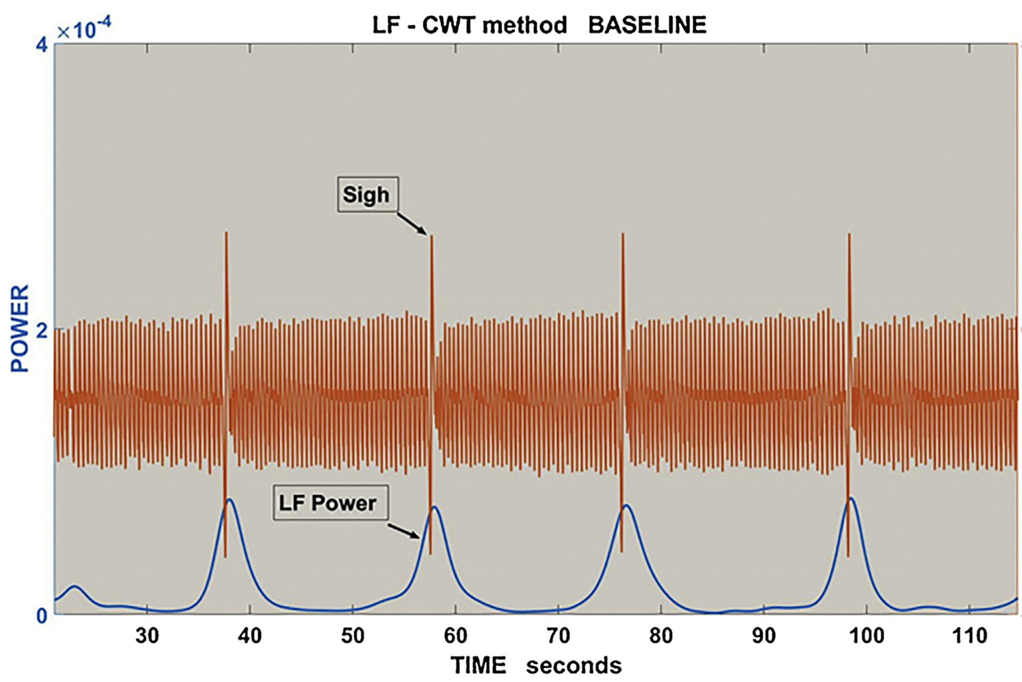


**Fig. 2.** A representative segment of time (20 s to 115 s) plot of LF power and respirations. This demonstrates the temporal relation of transient LF changes in relation to a sigh. Y-axis power units are in $seconds^2$/Hertz.

rithms. While the FFT is computationally fast, parametric methods yield a smoother power spectral plot. Choosing a correct model order, however, may not be intuitive and may be difficult as it is in general not known prior to analysis [7–9].

These traditional methods of HRV analysis do not have temporal resolution for detection of transients in a signal, and also require a statistically stationary time domain signal. As many disease states, such as hypertensive heart disease and chronic heart failure, have stationary signals, these traditional methods of analysis are satisfactory [7]. Several conditions, however, may be associated with transient changes in autonomic function. Accordingly, these signals containing transients will not be statistically stable (change in histogram statistics during a transient) [10]. Such an example of the occurrence of a transient in the RR interval may be when evaluating an acute intervention or for a clinical scenario, such as acute alterations related to obstructive sleep apnea, or in an animal model that we evaluated, that of a respiratory sigh [11–16].

For improved temporal resolution of transient changes in signal frequencies, a moving window termed the short time Fourier transform (STFT), may be used to analyze segments of a time series.